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# PRESSURE VESSEL HANDBOOK

*Twelfth Edition*

*with foreword by*  
***Paul Buttod***  
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*Tulsa, Oklahoma*

***Eugene F. Megyesy***



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NOTE: This new edition of the Pressure Vessel Handbook supersedes all previous editions, effective July 1, 2001.

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The changes over the previous Eleventh Edition have been made necessary by the revision of Codes, Standards, Specifications, etc.

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## FOREWORD

Engineers who design equipment for the chemical process industry are sooner or later confronted with the design of pressure vessels and mounting requirements for them. This is very often a frustrating experience for anyone who has not kept up with current literature in the field of code requirements and design equations.

First he must familiarize himself with the latest version of the applicable code. Then he must search the literature for techniques used in design to meet these codes. Finally he must select material properties and dimensional data from various handbooks and company catalogs for use in the design equations.

Mr. Megyesy has recognized this problem. For several years he has been accumulating data on code requirements and calculational methods. He has been presenting this information first in the form of his "Calculation Form Sheets" and now has put it all together in one place in the Pressure Vessel Handbook.

I believe that this fills a real need in the pressure vessel industry and that readers will find it extremely useful.

Paul Buttod



## PREFACE

This reference book is prepared for the purpose of making formulas, technical data, design and construction methods readily available for the designer, detailer, layoutmen and others dealing with pressure vessels. Practical men in this industry often have difficulty finding the required data and solutions, these being scattered throughout extensive literature or advanced studies. The author's aim was to bring together all of the above material under one cover and present it in a convenient form.

The design procedures and formulas of the ASME Code for Pressure Vessels, Section VIII Division I have been utilized as well as those generally accepted sources which are not covered by this Code. From among the alternative construction methods described by the Code the author has selected those which are most frequently used in practice.

In order to provide the greatest serviceability with this Handbook, rarely occurring loadings, special construction methods or materials have been excluded from its scope. Due to the same reason this Handbook deals only with vessels constructed from ferrous material by welding, since the vast majority of the pressure vessels are in this category.

A large part of this book was taken from the works of others, with some of the material placed in different arrangement, and some unchanged.

The author wishes to acknowledge his indebtedness to Professor Sándor Kalinszky, János Bodor, László Félégyházy and József Györfi for their material and valuable suggestions, to the American Society of Mechanical Engineers and to the publishers, who generously permitted the author to include material from their publications.

The author wishes also to thank all those who helped to improve this new edition by their suggestions and corrections.

Suggestions and criticism concerning some errors which may remain in spite of all precautions shall be greatly appreciated. They contribute to the further improvement of this Handbook.

Eugene F. Megyesy



## ASME CODE vs. THIS HANDBOOK

<p><b>The ASME BOILER AND PRESSURE VESSEL CODE - 2001, Sect VIII, Div. 1</b></p> <p>The American Society of Mechanical Engineers set up a Committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels that will perform in a safe and reliable manner.</p> <p>The Code comprises these rules.</p> <p>Its scope includes vessels:</p> <ol style="list-style-type: none"> <li>1. made of nonferrous materials, cast iron, high alloy and carbon steel,</li> <li>2. made by welding, forging, bracing, and</li> <li>3. applying a wide variety of construction methods and details.</li> </ol> <p>It includes all vessels where the question of safety is concerned.</p>	<p><b>PRESSURE VESSEL HANDBOOK - 2001, Twelfth Edition</b></p> <p>The Handbook covers design and construction methods of pressure vessels:</p> <ol style="list-style-type: none"> <li>1. made of carbon steel,</li> <li>2. made by welding</li> <li>3. applying construction methods and details which are the most economical and practical, which are in accordance with the Code rules, and thus generally followed by the industry.</li> </ol> <p>The vast majority of the pressure vessels today fall into this category.</p> <p>For construction rules and details which are excluded from the scope of the Handbook, references are made to the applicable Code paragraphs to avoid neglecting them.</p>
<p>The Code - as it is stated in paragraph UG-2 — "does not contain rules to cover all details of design and construction. . . ."</p> <p>"where details are not given, it is intended that the Manufacturer . . . shall provide details of design and construction."</p>	<p>Details of design and construction not covered by the Code are offered by the Handbook including: Design of tall towers, wind load, earthquake, vibration, eccentric load, elastic stability, deflection, combination of stresses, nozzle loads, reaction of supports, lugs, saddles, and rectangular tanks.</p>
<p>"The Code is not a handbook." "It is not intended that this Section be used as a design handbook" as it is stated in the Foreword of the Code.</p>	<p>The aim of this Handbook is to be easily handled and consulted. Tables, charts eliminate the necessity of calculations, Geometry, layout of vessels, piping codes, API storage tanks, standard appurtenances, painting of steel surfaces, weights, measurements, conversion tables, literature, definitions, specification for vessels, design of steel structures, center of gravity, design of welded joints, bolted connections, boiler and pressure vessel laws, chemical resistance of metals, volumes, and surfaces of vessels, provide good serviceability.</p>
<p>The updated and revised Code is published in three years intervals. Addenda, which also include revisions to the Code, are published annually. Revisions and additions become mandatory six (6) months after the date of issuance, except for boilers and pressure vessels contracted for prior to the end of the 6 month period. (Code Foreword)</p>	<p>The Handbook is updated and revised in three years intervals, reflecting the changes of Code rules, new developments in the design and construction method, and includes the revisions of its sources.</p>



## THE ASME CODE

ASME Boiler and Pressure Vessel Code, Section VIII, Division 1  
An internationally recognized Code published by  
The American Society of Mechanical Engineers.

**PRESSURE VESSEL** - is a containment of solid, liquid or gaseous material under internal or external pressure, capable of withstanding also various other loadings.

**BOILER** - is a part of a steam generator in which water is converted into steam under pressure.

**RULES OF DESIGN AND CONSTRUCTION** - Boiler explosions around the turn of the century made apparent the need for rules governing the design and construction of vessels. The first ASME Code was published in 1914.

**ISSUE TIME** - The updated and revised Code is published in three years intervals (2001 and so on). Addenda, which also include revisions to the Code, are published annually. Revisions and additions become mandatory 6 months after the date of issuance, except for boilers and pressure vessels contracted for prior to the end of the 6 month period. (Code Foreword)

**SCOPE OF THE CODE** - The rules of this Division have been formulated on the basis of design principles and construction practices applicable to vessels designed for pressures not exceeding 3000 psi. Code U-1(d)

Vessels, which are not included in the scope of this Division, may be stamped with the Code U Symbol if they meet all the applicable requirements of this Division. Code U-2(g)

**THE DESIGN METHOD** - The Code rules concerning design of pressure parts are based on the maximum stress theory, i.e., elastic failure in a ductile metal vessel occurs when the maximum tensile stress becomes equal to the yield strength of the material.

**OTHER COUNTRIES' Codes** deviate from each other considerably, mainly because of differences in the basic allowable design stresses. The ASME Code's regulations may be considered to be at midway between conservative and unconservative design.

**COMPUTER PROGRAMS** - Designers and engineers using computer programs for design or analysis are cautioned that they are responsible for all technical assumptions inherent in the programs they use and they are solely responsible for the application of these programs to their design. (Code, Foreword)

**DESIGN AND CONSTRUCTION NOT COVERED** - This Division of the Code does not contain rules to cover all details of design and construction. Where complete details are not given, it is intended that the Manufacturer shall provide details which will be as safe as those provided by the rules of this Division. Code U-2(g)

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## PART I.

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IN REFERENCES THROUGHOUT THIS BOOK "CODE" STANDS FOR ASME BOILER AND PRESSURE VESSEL CODE SECTION VIII, DIVISION 1 — AN AMERICAN STANDARD.

2001 EDITION

## STRESSES IN PRESSURE VESSELS

Pressure vessels are subject to various loadings, which exert stresses of different intensities in the vessel components. The category and intensity of stresses are the function of the nature of loadings, the geometry and construction of the vessel components.

### LOADINGS (Code UG-22)

- Internal or external pressure
- Weight of the vessel and contents
- Static reactions from attached equipment, piping, lining, insulation,
- The attachment of internals, vessel supports, lugs, saddles, skirts, legs
- Cyclic and dynamic reactions due to pressure or thermal variations
- Wind pressure and seismic forces
- Impact reactions due to fluid shock
- Temperature gradients and differential thermal expansion
- Abnormal pressures caused by deflagration.

STRESSES (Code UG-23)	MAXIMUM ALLOWABLE STRESS
a. Tensile stress	$S_a$ = Maximum allowable stress in tension for carbon and low alloy steel Code Table UCS-23; for high alloy steel Code Table UHA-23, psi. (See properties of materials page 186–190.)
b. Longitudinal compressive stress	The smaller of $S_a$ or the value of factor B determined by the procedure described in Code UG 23 (b) (2)
c. General primary membrane stress induced by any combination of loadings. Primary membrane stress plus primary bending stress induced by combination of loadings, except as provided in d. below.	$1.5 S_a$ $S_a$ = (see above)
d. General primary membrane stress .1.2 times the stress permitted in a., b., induced by combination of earth- or c. This rule applicable to stresses quake or wind pressure with other exerted by internal or external pressure loadings. Seismic force and wind or axial compressive load on a cylinder. pressure need not be considered to act simultaneously.	



## STRESSES IN CYLINDRICAL SHELL

Uniform internal or external pressure induces in the longitudinal seam two times larger unit stress than in the circumferential seam because of the geometry of the cylinder.

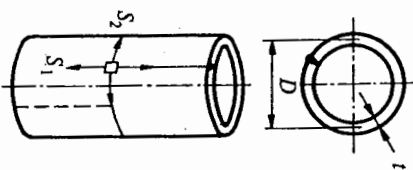
A vessel under external pressure, when other forces (wind, earthquake, etc.) are not factors, must be designed to resist the circumferential buckling only. The Code provides the method of design to meet this requirement. When other loadings are present, these combined loadings may govern and heavier plate will be required than the plate which was satisfactory to resist the circumferential buckling only.

The compressive stress due to external pressure and tensile stress due to internal pressure shall be determined by the formulas:

FORMULAS	
CIRCUMFERENTIAL JOINT	LONGITUDINAL JOINT
$S_1 = \frac{PD}{4t}$	$S_2 = \frac{PD}{2t}$

<p><b>NOTATION</b></p> <p><math>D</math> = Mean diameter of vessel, inches</p> <p><math>P</math> = Internal or external pressure, psi</p> <p><math>S_1</math> = Longitudinal stress, psi</p> <p><math>S_2</math> = Circumferential (hoop) stress, psi</p> <p><math>t</math> = Thickness of shell, corrosion allowance excluded, inches</p>	
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## EXAMPLE

Given  $D = 96$  inches  
 $P = 15$  psi  
 $t = 0.25$  inches

$$S_1 = \frac{PD}{4t} = \frac{15 \times 96}{4 \times 0.25} = 1440 \text{ psi}$$

$$S_2 = \frac{PD}{2t} = \frac{15 \times 96}{2 \times 0.25} = 2880 \text{ psi}$$

For towers under internal pressure and wind load the critical height above which compressive stress governs can be approximated by the formula:

$$H = \frac{PD}{32t}$$

where  $H$  = Critical height of tower, ft.

## INTERNAL PRESSURE

## 1. OPERATING PRESSURE

The pressure which is required for the process, served by the vessel, at which the vessel is normally operated.

## 2. DESIGN PRESSURE

The pressure used in the design of a vessel. It is recommended to design a vessel and its parts for a higher pressure than the operating pressure. A design pressure higher than the operating pressure with 30 psi or 10 percent, whichever is the greater, will satisfy this requirement. The pressure of the fluid and other contents of the vessel should also be taken into consideration. See tables on page 29 for pressure of fluid.

## 3. MAXIMUM ALLOWABLE WORKING PRESSURE

The internal pressure at which the weakest element of the vessel is loaded to the ultimate permissible point, when the vessel is assumed to be:

- in corroded condition
- under the effect of a designated temperature
- in normal operating position at the top
- under the effect of other loadings (wind load, external pressure, hydrostatic pressure, etc.) which are additive to the internal pressure.

When calculations are not made, the design pressure may be used as the maximum allowable working pressure (MAWP) code 3-2.

A common practice followed by many users and manufacturers of pressure vessels is to limit the maximum allowable working pressure by the head or shell, not by small elements as flanges, openings, etc.

See tables on page 28 for maximum allowable pressure for flanges.

See tables on page 142 for maximum allowable pressure for pipes.

The term, maximum allowable pressure, new and cold, is used very often. It means the pressure at which the weakest element of the vessel is loaded to the ultimate permissible point, when the vessel:

- is not corroded (new)
- the temperature does not affect its strength (room temperature) (cold) and the other conditions (c and d above) also need not to be taken into consideration.

## 4. HYDROSTATIC TEST PRESSURE

At least 1.3 times the maximum allowable working pressure or the design pressure to be marked on the vessel when calculations are not made to determine the maximum allowable working pressure.

If the stress value of the vessel material at the design temperature is less than at the test temperature, the hydrostatic test pressure should be increased proportionally.

Hydrostatic test shall



In this case, the test pressure shall be:

$$1.5 \times \text{Max. Allow. W. Press.} \times \frac{\text{Stress Value S At Test Temperature}}{\text{Stress Value S At Design Temperature}} \\ (\text{Or Design Press.})$$

Vessels where the maximum allowable working pressure limited by the flanges, shall be tested at a pressure shown in the table:

Primary Service Pressure Rating	150 lb	300 lb	400 lb	600 lb	900 lb	1500 lb	2500 lb
Hydrostatic Shell Test Pressure	425	1100	1450	2175	3250	5400	9000

Hydrostatic test of multi-chamber vessels: Code UG-99 (e)

A Pneumatic test may be used in lieu of a hydrostatic test per Code UG-100

Proof tests to establish maximum allowable working pressure when the strength of any part of the vessel cannot be computed with satisfactory assurance of safety, prescribed in Code UG-101.

#### 5. MAXIMUM ALLOWABLE STRESS VALUES

The maximum allowable tensile stress values permitted for different materials are given in table on page 189. The maximum allowable compressive stress to be used in the design of cylindrical shells subjected to loading that produce longitudinal compressive stress in the shell shall be determined according to Code par. UG-23 b, c, & d.

#### 6. JOINT EFFICIENCY

The efficiency of different types of welded joints are given in table on page 172. The efficiency of seamless heads is tabulated on page 176.

The following pages contain formulas used to compute the required wall thickness and the maximum allowable working pressure for the most frequently used types of shell and head. The formulas of cylindrical shell are given for the longitudinal seam, since usually this governs.

The stress in the girth seam will govern only when the circumferential joint efficiency is less than one-half the longitudinal joint efficiency, or when besides the internal pressure additional loadings (wind load, reaction of saddles) are causing longitudinal bending or tension. The reason for it is that the stress arising in the girth seam pound per square inch is one-half of the stress in the longitudinal seam.

The formulas for the girth seam accordingly:

$$t = \frac{PR}{2SE + 0.4P} \quad P = \frac{2SEt}{R - 0.4t}$$

See notation on page 22.

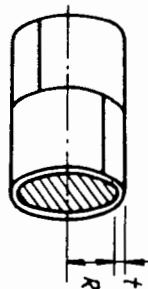


# INTERNAL PRESSURE

## FORMULAS IN TERMS OF INSIDE DIMENSIONS

### NOTATION

$P$  = Design pressure or max. allowable working pressure, psi  
 $S$  = Stress value of material, psi, page 189  
 $E$  = Joint efficiency, page 172  
 $R$  = Inside radius, inches  
 $D$  = Inside diameter, inches  
 $t$  = Wall thickness, inches  
 $C.A.$  = Corrosion allowance, inches

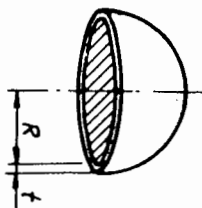


### CYLINDRICAL SHELL (LONG SEAM)<sup>1</sup>

$$t = \frac{PR}{SE - 0.6P}$$

$$P = \frac{SEt}{R + 0.6t}$$

1. Usually the stress in the long seam is governing. See preceding page.
2. When the wall thickness exceeds one half of the inside radius or  $P$  exceeds 0.385  $SE$ , the formulas given in the Code Appendix 1-2 shall be applied.



### SPHERE and HEMISPHERICAL HEAD

$$t = \frac{PR}{2SE - 0.2P}$$

$$P = \frac{2SEt}{R + 0.2t}$$

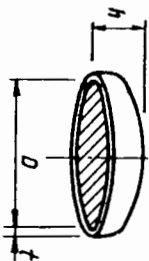
1. For heads without a straight flange, use the efficiency of the head to shell joint if it less than the efficiency of the seams in the head.
2. When the wall thickness exceeds 0.356  $R$  or  $P$  exceeds 0.665  $SE$ , the formulas given in the Code Appendix 1-3, shall be applied.

### 2:1 ELLIPSOIDAL HEAD

$$t = \frac{PD}{2SE - 0.2P}$$

$$P = \frac{2SEt}{D + 0.2t}$$

1. For ellipsoidal heads, where the ratio of the major and minor axis is other than 2:1, see Code Appendix 1-4(c).



$$h = D/4$$

## EXAMPLES

### DESIGN DATA:

$P$  = 100 psi design pressure  
 $S$  = 20,000 psi stress value of SA 515-70 plate @ 500°F  
 $E$  = 0.85, efficiency of spot-examined joints of shell and hemis. head to shell

$E$  = 1.00, joint efficiency of seamless heads  
 $R$  = 48 inches inside radius\*  
 $D$  = 96 inches inside diameter\*  
 $t$  = required wall thickness, inches  
 $C.A.$  = 0.125 inches corrosion allowance\*  
 \* in corroded condition greater with the corrosion allowance.

### SEE DESIGN DATA ABOVE

Determine the required thickness,  $t$  of a shell

$$t = \frac{100 \times 48.125}{20,000 \times 0.85 - 0.6 \times 100} = 0.284 \text{ in.}$$

$$+ C.A. \quad \frac{0.125 \text{ in.}}{0.409 \text{ in.}}$$

Use 0.500 in. plate

### SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure  $P$  for 0.500 in. thick shell when the vessel is in new condition.

$$P = \frac{20,000 \times 0.85 \times 0.500}{48 + 0.6 \times 0.500} = 176 \text{ psi}$$

### SEE DESIGN DATA ABOVE

The head furnished without straight flange.

Determine the required thickness,  $t$  of a hemispherical head.

$$t = \frac{100 \times 48.125}{2 \times 20,000 \times 0.85 - 0.2 \times 100} = 0.142 \text{ in.}$$

$$+ C.A. \quad \frac{0.125 \text{ in.}}{0.267 \text{ in.}}$$

Use 0.3125 in. plate

### SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure,  $P$  for 0.3125 in. thick head, when it is in new condition.

$$P = \frac{2 \times 20,000 \times 0.85 \times 0.3125}{48 + 0.2 \times 0.3125} = 221 \text{ psi}$$

### SEE DESIGN DATA ABOVE

Determine the required thickness of a seamless ellipsoidal head.

$$t = \frac{100 \times 96.25}{2 \times 20,000 \times 1.0 - 0.2 \times 100} = 0.241 \text{ in.}$$

$$+ C.A. \quad \frac{0.125 \text{ in.}}{0.366 \text{ in.}}$$

Use 0.375 in. min. thk. head

### SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure,  $P$  for 0.250 in. thick seamless head, when it is in corroded condition.

$$P = \frac{2 \times 20,000 \times 1.0 \times 0.250}{96.25 + 0.2 \times 0.250} = 103 \text{ psi}$$



# INTERNAL PRESSURE

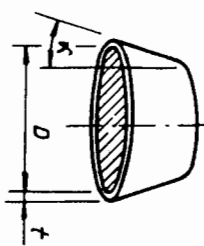
## FORMULAS IN TERMS OF INSIDE DIMENSIONS

### NOTATION

$P$  = Design pressure or max. allowable working pressure psi  
 $S$  = Stress value of material psi, page 189  
 $E$  = Joint efficiency, page 172  
 $R$  = Inside radius, inches

$D$  = Inside diameter, inches  
 $\alpha$  = One half of the included (apex) angle, degrees  
 $L$  = Inside radius of dish, inches  
 $r$  = Inside knuckle radius, inches  
 $t$  = Wall thickness, inches  
 $C.A.$  = Corrosion allowance, inches

### CONE AND CONICAL SECTION



$$t = \frac{PD}{2 \cos \alpha (SE - 0.6P)}$$

$$P = \frac{2SEt \cos \alpha}{D + 1.2t \cos \alpha}$$

1. The half apex angle,  $\alpha$  not greater than  $30^\circ$
2. When  $\alpha$  is greater than  $30^\circ$  special analysis is required. (Code Appendix 1-5(g))

E

### ASME FLANGED AND DISHED HEAD (TORISPHERICAL HEAD)

When  $L/r = 16^{2/3}$

$$t = \frac{0.885PL}{SE - 0.1P}$$

$$P = \frac{SEt}{0.885L + 0.1t}$$

When  $L/r$  less than  $16^{2/3}$

$$t = \frac{PLM}{2SE - 0.2P}$$

$$P = \frac{2SEt}{LM + 0.2t}$$

When the min. tensile strength of material exceeds 70,000 psi. see Code UG-32(e)

### VALUES OF FACTOR "M"

$L/r$	1.00	1.25	1.50	2.00	2.50	2.75	3.00	3.25	3.50	4.00	4.50	5.00	5.50	6.00	6.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22	1.25	1.28	1.34	1.39
$L/r$	7.00	7.50	8.00	8.50	9.00	9.50	10.0	10.5	11.0	11.5	12.0	13.0	14.0	15.0	16.0
M	1.41	1.44	1.46	1.48	1.50	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72	1.75

THE MAXIMUM ALLOWED RATIO :  $L = D + 2t$

(see note 2 on facing page)

## EXAMPLES

### DESIGN DATA:

$P$  = 100 psi design pressure  
 $S$  = 20,000 psi stress value of SA 515-70 plate @ 500°F  
 $E$  = 0.85, efficiency of spot-examined joints  
 $E$  = 1.00, joint efficiency of seamless heads

$L$  = 96 inches inside radius of dish\*  
 $D$  = 96 inches inside diameter\*  
 $t$  = required wall thickness, inches  
 $\alpha$  =  $30^\circ$  one half of the apex angle  
 $C.A.$  = 0.125 inches corrosion allowance  
 \* in corroded condition greater with the corrosion allowance

### SEE DESIGN DATA ABOVE

$\cos 30^\circ = 0.866$

Determine the required thickness,  $t$  of a cone

$$t = \frac{2 \times 0.866 (20,000 \times 0.85 - 0.6 \times 100)}{100 \times 96.25} = 0.328 \text{ in.}$$

+ C.A.

$$0.125 \text{ in.} + 0.453 \text{ in.}$$

Use 0.500 in. plate

### SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure,  $P$  for 0.500 in. thick cone, when the vessel is in new condition.

$$P = \frac{2 \times 20,000 \times 0.85 \times 0.500 \times 0.866}{96 + 1.2 \times 0.500 \times 0.866} = 152 \text{ psi}$$

### SEE DESIGN DATA ABOVE

$L/r = 16^{2/3}$

Determine the required thickness,  $t$  of a seamless ASME flanged and dishd head.

$$t = \frac{0.885 \times 100 \times 96.125}{20,000 \times 1.0 - 0.1 \times 100} = 0.426 \text{ in.}$$

+ C.A.

$$0.125 \text{ in.} + 0.551 \text{ in.}$$

Use 0.5625 in. plate

### SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure,  $P$  for 0.5625 in. thick seamless head, when the vessel is in new condition.

$$P = \frac{20,000 \times 1.0 \times 0.5625}{0.885 \times 96 + 0.1 \times 0.5625} = 132 \text{ psi}$$

### SEE DESIGN DATA ABOVE

Knuckle radius  $r = 6$  in.  $L/r = \frac{96}{6} = 16$   
 $M = 1.75$  from table.

Determine the required thickness  $t$  of a seamless ASME flanged and dishd head.

$$t = \frac{100 \times 96.125 \times 1.75}{2 \times 20,000 - 0.2 \times 100} = 0.421 \text{ in.}$$

+ C.A.

$$0.125 \text{ in.} + 0.546 \text{ in.}$$

Use 0.5625 in. min. thick head

### SEE DESIGN DATA ABOVE

Knuckle radius  $r = 6$  in.  $L/r = \frac{96}{6} = 16$   
 $M = 1.75$  from table

Determine the maximum allowable working pressure,  $P$  for a 0.5625 in. thick seamless head when the vessel is in corroded condition.

$$P = \frac{2 \times 20,000 \times 1.0 \times 0.5625}{96.125 \times 1.75 + 0.2 \times 0.4375} = 104 \text{ psi}$$

NOTE: When the ratio of  $L/r$  is greater than  $16^{2/3}$ , (non-Code construction) the values of



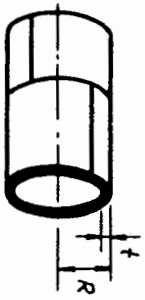
## INTERNAL PRESSURE

### FORMULAS IN TERMS OF OUTSIDE DIMENSIONS

#### NOTATION

$P$  = Design pressure or max. allowable working pressure, psi  
 $S$  = Stress value of material psi, page 189  
 $E$  = Joint efficiency, page 172  
 $R$  = Outside radius, inches  
 $D$  = Outside diameter, inches  
 $t$  = Wall thickness, inches  
 $C.A.$  = Corrosion allowance, inches

A



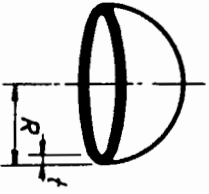
#### CYLINDRICAL SHELL (LONG SEAM),<sup>1</sup>

$$t = \frac{PR}{SE + 0.4P}$$

$$P = \frac{SEt}{R - 0.4t}$$

1. Usually the stress in the long seam is governing. See page 14
2. When the wall thickness exceeds one half of the inside radius or  $P$  exceeds 0.385  $SE$ , the formulas given in the Code Appendix 1-2 shall be applied.

B



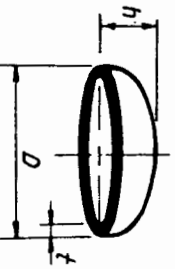
#### SPHERE and HEMISPHERICAL HEAD

$$t = \frac{PR}{2SE + 0.8P}$$

$$P = \frac{2SEt}{R - 0.8t}$$

1. For heads without a straight flange, use the efficiency of the head to shell joint if it is less than the efficiency of the seams in the head.
2. When the wall thickness exceeds 0.356  $R$  or  $P$  exceeds 0.665  $SE$ , the formulas given in the Code Appendix 1-3, shall be applied.

C



#### 2:1 ELLIPSOIDAL HEAD

$$t = \frac{PD}{2SE + 1.8P}$$

$$P = \frac{2SEt}{D - 1.8t}$$

1. For ellipsoidal heads, where the ratio of the major and minor axis is other than 2:1, see Code Appendix 1-4(c).

$$h = D/4$$

## EXAMPLES

#### DESIGN DATA:

$P$  = 100 psi design pressure  
 $S$  = 20,000 psi stress value of SA 515-70 plate @ 500°F  
 $E$  = 0.85, efficiency of spot-examined joints of shell and hemis. head to shell

$E$  = 1.00, joint efficiency of seamless heads

$R$  = 48 inches outside radius  
 $D$  = 96 inches outside diameter  
 $t$  = Required wall thickness, inches  
 $C.A.$  = 0.125 inches corrosion allowance

#### SEE DESIGN DATA ABOVE

Determine the required thickness,  $t$  of a shell

$$t = \frac{100 \times 48}{20,000 \times 0.85 - 0.4 \times 100} = 0.283 \text{ in}$$

$$+C.A. \quad 0.125 \text{ in.} \\ 0.408 \text{ in.}$$

Use: 0.4375 in. thick plate

#### SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure,  $P$  for 0.4375 in. thick shell when the vessel is in new condition.

$$P = \frac{20,000 \times 0.85 \times 0.4375}{48 - 0.4 \times 0.4375} = 155 \text{ psi}$$

#### SEE DESIGN DATA ABOVE

Head furnished without straight flange.

Determine the required thickness,  $t$  of a hemispherical head.

$$t = \frac{100 \times 48}{2 \times 20,000 \times 0.85 + 0.8 \times 100} = 0.141 \text{ in.}$$

$$+C.A. \quad 0.125 \text{ in.} \\ 0.266 \text{ in.}$$

Use: 0.3125 in. min. thick head

#### SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure,  $P$  for 0.3125 in. thick head, when the vessel is in new condition.

$$P = \frac{2 \times 20,000 \times 0.85 \times 0.3125}{48 - 0.8 \times 0.3125} = 222 \text{ psi}$$

#### SEE DESIGN DATA ABOVE

Determine the required thickness  $t$  of a seamless ellipsoidal head.

$$t = \frac{100 \times 96}{2 \times 20,000 \times 1.0 + 1.8 \times 100} = 0.239 \text{ in.}$$

$$+C.A. \quad 0.125 \text{ in.} \\ 0.364 \text{ in.}$$

Use 0.375 in. min. thick head

#### SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure,  $P$  for 0.375 in. thick head, when it is in new condition.

$$P = \frac{2 \times 20,000 \times 1.0 \times 0.375}{96 - 1.8 \times 0.375} = 157 \text{ psi}$$



# INTERNAL PRESSURE

## FORMULAS IN TERMS OF OUTSIDE DIMENSIONS

### NOTATION

$P$  = Design pressure or max. allowable working pressure psi  
 $S$  = Stress value of material psi, page 189  
 $E$  = Joint efficiency, page 172  
 $R$  = Outside radius, inches

$D$  = Outside diameter, inches  
 $\alpha$  = One half of the included (apex) angle, degrees  
 $L$  = Outside radius of dish, inches  
 $r$  = Inside knuckle radius, inches  
 $t$  = Wall thickness, inches  
 $C.A.$  = Corrosion allowance, inches

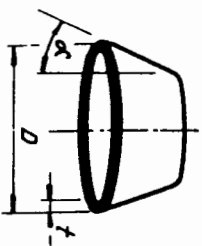
D

### CONE AND CONICAL SECTION

$$t = \frac{PD}{2 \cos \alpha (SE + 0.4P)}$$

$$P = \frac{2SEt \cos \alpha}{D - 0.8t \cos \alpha}$$

1. The half apex angle,  $\alpha$  not greater than  $30^\circ$
2. When  $\alpha$  is greater than  $30^\circ$ , special analysis is required. (Code Appendix 1-5(g))



E

### ASME FLANGED AND DISHD HEAD (TORISPHERICAL HEAD)

When  $L/r = 16^{2/3}$

$$t = \frac{0.885PL}{SE + 0.8P}$$

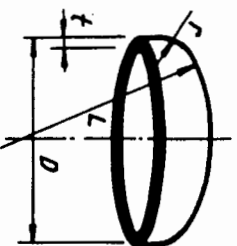
$$P = \frac{SEt}{0.885L - 0.8t}$$

When  $L/r$  Less Than  $16^{2/3}$

$$t = \frac{PLM}{2SE + P(M - 0.2)}$$

$$P = \frac{2SEt}{ML - t(M - 0.2)}$$

When the min. tensile strength of material exceeds 70,000 psi. see Code UG-32(e)



### VALUES OF FACTOR M

$L/r$	1.00	1.25	1.50	2.00	2.50	3.00	3.25	3.50	4.00	4.50	5.00	5.50	6.00	6.50
M	1.00	1.03	1.06	1.08	1.10	1.13	1.15	1.17	1.18	1.20	1.22	1.25	1.28	1.31
$L/r$	7.00	8.00	9.00	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
M	1.41	1.44	1.46	1.48	1.50	1.52	1.54	1.56	1.58	1.60	1.62	1.65	1.69	1.72

THE MAXIMUM ALLOWED RATIO :  $L \cdot t = D$

(see note on facing page)

# EXAMPLES

### DESIGN DATA:

$P$  = 100 psi design pressure  
 $S$  = 20,000 psi stress value of SA 515-70 plate @ 500°F  
 $E$  = 0.85, efficiency of spot-examined joints  
 $E$  = 1.00, joint efficiency of seamless

### heads

$R$  = 48 inches outside radius  
 $D$  = 96 inches outside diameter  
 $\alpha$  =  $30^\circ$  one half of the apex angle  
 $L$  = 96 inches outside radius of dish  
 $t$  = Required wall thickness, inches  
 $C.A.$  = 0.125 inches corrosion allowance

### SEE DESIGN DATA ABOVE

$\cos 30^\circ = 0.866$   
 Determine the required thickness,  $t$  of a cone

$$t = \frac{2 \times 0.866 \times (20,000 \times 0.85 + 0.4 \times 100)}{100 \times 96} = 0.326 \text{ in.}$$

$$+C.A. \quad 0.125 \text{ in.}$$

Use: 0.500 in. thick plate

### SEE DESIGN DATA ABOVE

$L/r = 16^{2/3}$   
 Determine the required thickness,  $t$  of a seamless ASME flanged and dished head.

$$t = \frac{0.885 \times 100 \times 96}{20,000 \times 1.0 + 0.8 \times 100} = 0.423 \text{ in.}$$

$$+C.A. \quad 0.125 \text{ in.}$$

Use: 0.5625 in. min. thick head

### SEE DESIGN DATA ABOVE

Determine the maximum allowable working pressure,  $P$  for 0.5625 in. thick seamless head, when the vessel is in corroded condition.

$$t = 0.5625 - 0.125 = 0.4375$$

$$P = \frac{20,000 \times 1.0 \times 0.4375}{0.885 \times 96 - 0.8 \times 0.4375} = 103 \text{ psi}$$

### SEE DESIGN DATA ABOVE

Knuckle radius  $r = 6$  in.  $L/r = \frac{96}{6} = 16$   
 $M = 1.75$  from table.  
 Determine the required thickness  $t$  of a seamless ASME flanged and dished head.

$$t = \frac{100 \times 96 \times 1.75}{2 \times 20,000 \times 1.0 + 100(1.75 - 0.2)} = 0.419 \text{ in.}$$

$$+C.A. \quad 0.125 \text{ in.}$$

Use: 0.5625 in. min. thick head

### SEE DESIGN DATA ABOVE

Knuckle radius  $r = 6$  in.  $L/r = \frac{96}{6} = 16$   
 $M = 1.75$  from table.  
 Determine the maximum allowable working pressure,  $P$  for a 0.5625 in. thick seamless head when the vessel is in corroded condition.

$$P = \frac{2 \times 20,000 \times 1.0 \times 0.4375}{1.75 \times 96 - 0.4375(1.75 - 0.2)} = 104 \text{ psi}$$

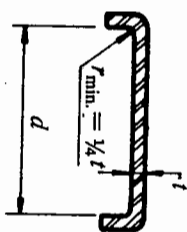
NOTE: When the ratio of  $L/r$  is greater than  $16^{2/3}$ , (non-Code construction) the values of  $M$  may be calculated by the formula:  $M = \frac{1}{4}(3 + \sqrt{L/r})$



## INTERNAL OR EXTERNAL PRESSURE FORMULAS

### NOTATION

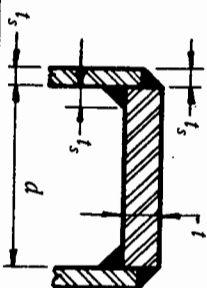
$P$  = Internal or external design pressure psi     $E$  = joint efficiency  
 $d$  = Inside diameter of shell, in.  
 $S$  = Maximum allowable stress value of material, psi  
 $t$  = Minimum required thickness of head, exclusive of corrosion allowance, in.  
 $t_h$  = Actual thickness of head exclusive of corrosion allowance, in.  
 $t_r$  = Minimum required thickness of seamless shell for pressure, in.  
 $t_s$  = Actual thickness of shell, exclusive of corrosion allowance, in.



### CIRCULAR FLAT HEADS

$$t = d \sqrt{0.13 P / SE}$$

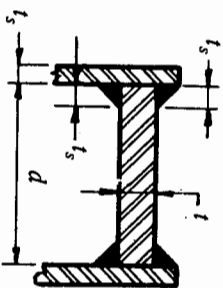
This formula shall be applied:  
 1. When  $d$  does not exceed 24 in.  
 2.  $t_h/d$  is not less than 0.05 nor greater than 0.25  
 3. The head thickness,  $t_h$  is not less than the shell thickness,  $t_s$



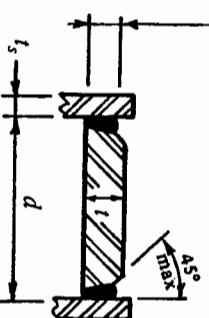
$$t = d \sqrt{CP / SE}$$

$$C = 0.33 t_r / t_s$$

$$C \text{ min.} = 0.20$$



D 2  $t$ , min. nor less than 1.25  $t_s$ , need not be greater than  $t$



Non-circular, bolted flat heads, covers, blind flanges Code UG-34; other types of closures Code UG-35

If a value of  $t_h/t_s$  less than 1 is used in calculating  $t$ , the shell thickness  $t_s$  shall be maintained along a distance inwardly from the inside face of the head equal to at least

$$2 \sqrt{dt_s}$$

## INTERNAL OR EXTERNAL PRESSURE EXAMPLES

### DESIGN DATA

$P$  = 300 psi design pressure     $E$  = joint efficiency  
 $d$  = 24 in. inside diameter of shell  
 $S$  = 17,100 psi maximum allowable stress value of SA-515-60 plate  
 $t_r$  = 0.243 in. required thickness of seamless shell for pressure.  
 $t_s$  = 0.3125 in. actual thickness of shell.

DETERMINE THE MINIMUM REQUIRED THICKNESS,  $t$

$$t = d \sqrt{0.13 P / SE} = 24 \sqrt{0.13 \times 300 / 17,100 \times 1} = 1.146 \text{ in.}$$

Use 1.25 in. head

$$\text{Checking the limitation of } \frac{t_h}{d} = \frac{1.25}{24} = 0.052$$

The ratio of head thickness to the diameter of the shell is satisfactory

### SEE DESIGN DATA ABOVE

$$C = 0.33 \frac{t_r}{t_s} = 0.33 \frac{0.243}{0.3125} = 0.26$$

$$t = d \sqrt{CP / SE} = 24 \sqrt{0.26 \times 300 / 17,100 \times 1} = 1.620 \text{ in.}$$

Use 1.625 in. plate

Using thicker plate for shell, lesser thickness will be satisfactory for the head.

$$t_s = 0.375 \text{ in.}$$

$$C = 0.33 \frac{t_r}{t_s} = 0.33 \frac{0.243}{0.375} = 0.214$$

$$t = d \sqrt{CP / SE} = 24 \sqrt{0.214 \times 300 / 17,100 \times 1} = 1.471 \text{ in.}$$

Use 1.625 in. plate

The shell thickness shall be maintained along a distance  $2 \sqrt{dt_s}$  from the inside face of the head

$$2 \sqrt{24 \times 0.375} = 6 \text{ in.}$$



**PRESSURE - TEMPERATURE RATINGS**  
FOR STEEL PIPE FLANGES AND FLANGED FITTINGS  
American National Standard ANSI B16.5-1996/1998 ADDENDA

Class	150 lb.	300 lb.	400 lb.	600 lb.	900 lb.	1,500 lb.	2,500 lb.
Hydrostatic test pressure, psig	450	1,125	1,500	2,225	3,350	5,575	9,275
Temperature, F	MAXIMUM ALLOWABLE NON-SHOCK PRESSURE PSIG.						
-20 to 100	285	740	990	1,480	2,220	3,705	6,170
200	260	675	900	1,350	2,025	3,375	5,625
300	230	655	875	1,315	1,970	3,280	5,470
400	200	635	845	1,270	1,900	3,170	5,280
500	170	600	800	1,200	1,795	2,995	4,990
600	140	550	730	1,095	1,640	2,735	4,560
650	125	535	715	1,075	1,610	2,685	4,475
700	110	535	710	1,065	1,600	2,665	4,440
750	95	505	670	1,010	1,510	2,520	4,200
800	80	410	550	825	1,235	2,060	3,430
850	65	270	355	535	805	1,340	2,230
900	50	170	230	345	515	860	1,430
950	35	105	140	205	310	515	860
1,000	20	50	70	105	155	260	430

Ratings apply to NPS ½ through NPS 24 and to materials:

A 105 (1) A 350 Gr. LF2 (1) A 350 Gr. LF6 Cl. 1 (4) A 216 Gr. WCB (1)  
A 515 Gr. 70 (1) A 516 Gr. 70 (1) (2) A 537 Cl. 1 (3)

**NOTES:**

(1) Permissible, but not recommended for prolonged use above 800 °F.

(2) Not to be used over 850 °F.

(3) Not to be used over 700 °F.

(4) Not to be used over 500 °F.

Flanges of ANSI B16.5 shall not be used for higher ratings except where it is justified by the design methods of the Code.

Ratings are maximum allowable non-shock working pressures expressed as gage pressure, at the tabulated temperatures and may be interpolated between temperatures shown.

Temperatures are those on the inside of the pressure-containing shell of the flange. In general, it is the same as that of the contained material.

Flanged fittings shall be hydrostatically tested.

**PRESSURE OF FLUID  
STATIC HEAD**

The fluid in the vessel exerts pressure on the vessel wall. The intensity of the pressure when the fluid is at rest is equal in all directions on the sides or at bottom of the vessel and is due to the height of the fluid above the point at which the pressure is considered.

The static head when applicable shall be added to the design pressure of the vessel.

The tables below when applicable shall be added to the design pressure of the water.

To find the pressure for any other fluids than water, the given in the tables shall be multiplied with the specific gravity of the fluid in consideration.

**Pressure in Pounds per Square Inch for Different Heads of Water**

Head Feet	0	1	2	3	4	5	6	7	8	9
0	0.43	0.87	1.30	1.73	2.16	2.60	3.03	3.46	3.90	
10	4.33	4.76	5.20	5.63	6.06	6.49	6.93	7.36	7.79	8.23
20	8.66	9.09	9.53	9.96	10.39	10.82	11.26	11.69	12.12	12.56
30	12.99	13.42	13.86	14.29	14.72	15.15	15.59	16.02	16.45	16.89
40	17.32	17.75	18.19	18.62	19.05	19.48	19.92	20.35	20.78	21.22
50	21.65	22.08	22.52	22.95	23.38	23.81	24.25	24.68	25.11	25.55
60	25.98	26.41	26.85	27.28	27.71	28.14	28.58	29.01	29.44	29.88
70	30.31	30.74	31.18	31.61	32.04	32.47	32.91	33.34	33.77	34.21
80	34.64	35.07	35.51	35.94	36.37	36.80	37.24	37.67	38.10	38.54
90	38.97	39.40	39.84	40.27	40.70	41.13	41.57	42.00	42.43	42.87

NOTE: One foot of water at 62° Fahrenheit equals .433 pound pressure per square inch. To find the pressure per square inch for any feet head not given in the table above, multiply the feet times .433.

**Heads of Water in Feet Corresponding to  
Certain Pressure in Pounds per Square Inch**

Pressure, lbs.	0	1	2	3	4	5	6	7	8	9
0	2.3	4.6	6.9	9.2	11.5	13.9	16.2	18.5	20.8	
10	23.1	25.4	27.7	30.0	32.3	34.6	36.9	39.3	41.6	43.9
20	46.2	48.5	50.8	53.1	55.4	57.7	60.0	62.4	64.7	67.0
30	69.3	71.6	73.9	76.2	78.5	80.8	83.1	85.4	87.8	90.1
40	92.4	94.7	97.0	99.3	101.6	103.9	106.2	108.5	110.8	113.2
50	115.5	117.8	120.1	122.4	124.7	127.0	129.3	131.6	133.9	136.3
60	138.6	140.9	143.2	145.5	147.8	150.1	152.4	154.7	157.0	159.3
70	161.7	164.0	166.3	168.6	170.9	173.2	175.5	177.8	180.1	182.4
80	184.8	187.1	189.4	191.7	194.0	196.3	198.6	200.9	203.2	205.5
90	207.9	210.2	212.5	214.8	217.1	219.4	221.7	224.0	226.3	228.6

NOTE: One pound of pressure per square inch of water equals 2.309 feet of water at 62° Fahrenheit. Therefore, to find the feet head of water for any pressure not given in the table above, multiply the pressure pounds per square inch by 2.309.



## TABLES

For quick comparison of required plate thickness and weight for various materials and at a different degree of radiographic examination.

**A** Stress values at temperature  $-20^{\circ}$  to  $500^{\circ}$  F.

	SA 285 C	SA 53 B SA 515-60 SA 516-60	SA 515-70 SA 516-70
85% J. E.	13,345	14,535	17,000
100% J. E.	15,700	17,100	20,000

**B** Ratios of Stress Values

	13,345	14,535	15,700	17,000	17,100	20,000
13,345	—	1.09	1.18	1.27	1.28	1.49
14,535	0.92	—	1.08	1.17	1.18	1.37
15,700	0.85	0.92	—	1.08	1.09	1.27
17,000	0.79	0.86	0.93	—	1.01	1.18
17,100	0.78	0.85	0.92	0.99	—	1.17
20,000	0.67	0.73	0.79	0.85	0.86	—

Table A shows the stress value of the most frequently used shell and head materials.

Table B shows the ratios of these stress values.

### EXAMPLE:

1. For a vessel using SA 515-70 plate, when spot radiographed, the required thickness 0.4426 inches and the weight of the vessel 12600 lbs.
2. What plate thickness will be required, and what will the weight of the vessel be using SA 285-C plate and full radiographic examination:

In case 1. The stress value of the material 17,000  
In case 2. The stress value of the material 15,700

The ratio of the two stress values from Table B=1.08 In this proportion the required plate thickness and the weight of the vessel will be increased.

$$0.4426 \times 1.08 = 0.4780 \text{ in.}$$

$$12600 \times 1.08 = 13608 \text{ lb.}$$

## EXTERNAL PRESSURE

### DESIGN PRESSURE

When Code Symbol is to be applied, the vessel shall be designed and stamped with the maximum allowable external working pressure. It is recommended that a suitable margin is provided when establishing the maximum allowable external pressure to allow for pressure variation in service. Code UG-28(f).

Vessels intended for service under external working pressure of 15 psi and less may be stamped with the Code Symbol denoting compliance with the rules for external pressure provided all the applicable rules of this Division are also satisfied. Code UG-28(f).

This shall not be applied if the vessel is operated at a temperature below minus  $20^{\circ}$  F, and the design pressure is determined by the Code UCS-66(c)(2) or Code UHA-51(b) to avoid the necessity of impact test.

Vessels with lap joints: Code UG-28(g) Non-cylindrical vessel, jacket: Code UG-28(i).

### TEST PRESSURE

Single-wall vessels designed for vacuum or partial vacuum only, shall be subjected to an internal hydrostatic test or when a hydrostatic test is not practicable, to a pneumatic test. Code UG-99(f).

Either type of test shall be made at a pressure not less than  $1\frac{1}{2}$  times the difference between normal atmospheric pressure and the minimum design internal absolute pressure. Code UG-99(f).

Pneumatic test: Code UG-100.

The design method on the following pages conform to ASME Code for Pressure Vessels Section VIII, Div. 1. The charts on pages 42-47 are excerpted from this Code.



# EXTERNAL PRESSURE

## FORMULAS

### NOTATION

- $P$  = External design pressure, psig.  
 $P_a$  = Maximum allowable working pressure, psig.  
 $D_o$  = Outside diameter, in.  
 $L$  = the length, in. of vessel section between:  
 1. circumferential line on a head at one-third the depth of the head-tangent line,  
 2. stiffening rings  
 3. jacket closure  
 4. cone-to-cylinder junction or knuckle-to-cylinder junction of a toriconical head or section,  
 5. tube sheets (see page 39)  
 $t$  = Minimum required wall thickness, in.

### CYLINDRICAL SHELL

#### Seamless or with Longitudinal Butt Joints

When  $D_o/t$  equal to or greater than 10 the maximum allowable pressure:

$$P_a = \frac{4B}{3(D_o/t)}$$

The value of B shall be determined by the following procedure:

1. Assume a value for  $t$ ; (See pages 49-51)
2. Determine  $L/D_o$  and  $D_o/t$
3. Enter Fig. G (Page 42) at the value of  $L/D_o$ . Enter at 50 when  $L/D_o$  is greater than 50, and at 0.05 when  $L/D_o$  is less than 0.05.

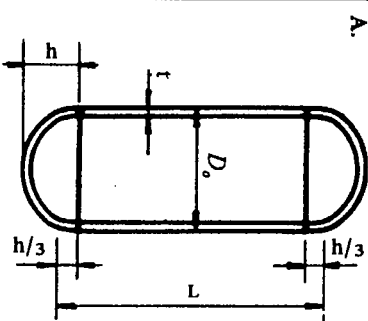
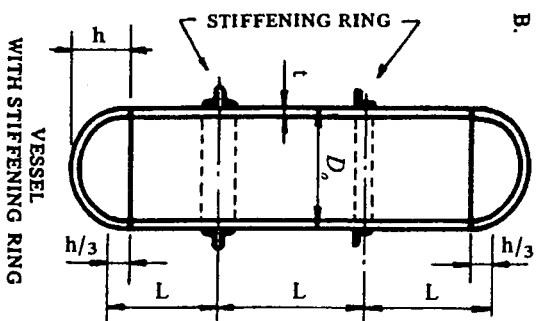
4. Move horizontally to the line representing  $D_o/t$ . From the point of intersection move vertically to determine the value of factor A.
5. Enter the applicable material chart (pages 43-47) at the value of A. Move vertically to the applicable temperature line\*.
6. From the intersection move horizontally and read the value of B.
7. Compute the maximum allowable working pressure,  $P_a$ .

If the maximum allowable working pressure is smaller than the design pressure, the design procedure must be repeated increasing the vessel thickness or decreasing L by stiffening ring.

\*For values of A falling to the left of the applicable temperature line, the value of  $P_a$  can be calculated by the formula:

$$P_a = \frac{2AE}{3(D_o/t)}$$

When the value of  $D_o/t$  is less than 10, the formulas given in the Code UG-28(c)(2) shall be applied.



# EXAMPLES

### DESIGN DATA

- $P$  = 15 psig. external design pressure  
 $D_o$  = 96 in. outside diameter of the shell  
 Length of the vessel from tangent line to tangent line: 48 ft. 0 in. = 576 in.  
 Heads 2:1 ellipsoidal  
 Material of shell SA - 285 C plate  
 Temperature 500° F  
 $E$  = Modulus of elasticity of material, 27,000,000 psi. @ 500 °F (see chart on page 43)

Determine the required shell thickness.

Assume a shell thickness:  $t = 0.50$  in. (see page 49)

Length  $L = 592$  in. (length of shell 576 in. and one third of the depth of heads 16 in.)

$$L/D_o = 592/96 = 6.17 \quad D_o/t = 96/0.5 = 192$$

$A = 0.00007$  from chart (page 42) determined by the procedure described on the facing page.

Since the value of A is falling to the left of the applicable temperature-line in Fig. CS-2 (pg. 43),

$$P_a = 2AE/3(D_o/t) = 2 \times 0.00007 \times 27,000,000/3 \times 192 = 6.56 \text{ psi.}$$

Since the maximum allowable pressure  $P_a$  is smaller than the design pressure  $P$  stiffening rings shall be provided.

Using 2 stiffening rings equally spaced between the tangent lines of the heads, Length of one vessel section,  $L = 200$  in. (length of shell 192 in. plus one third of depth of head 8 in.)

$$L/D_o = 200/96 = 2.08 \quad D_o/t = 96/0.5 = 192$$

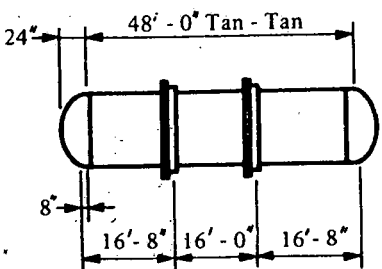
$$A = 0.00022 \text{ from chart (page 42)}$$

$$B = 3000 \text{ from chart (page 43)}$$

determined by the procedure described on facing page.

$$P_a = 4B/3(D_o/t) = 4 \times 3000/3 \times 192 = 20.8 \text{ psi.}$$

Since the maximum allowable pressure  $P_a$  is greater than the design pressure  $P$ , the assumed thickness of shell using two stiffening rings, is satisfactory.



See page 40 for design of stiffening rings.



# EXTERNAL PRESSURE

## FORMULAS

### NOTATION

- $P$  = External design pressure psig.  
 $P_a$  = Maximum allowable working pressure psig.  
 $D_o$  = Outside diameter of the head, in.  
 $R_o$  = Outside radius of sphere or hemispherical head,  $0.9D_o$  for ellipsoidal heads, inside crown radius of flanged and dished heads, in.  
 $t$  = Minimum required wall thickness, inches.  
 $E$  = Modulus of elasticity of material, psi. (page 43)

### SPHERE and HEMISPHERICAL HEAD

$$\text{The maximum allowable pressure: } P_a = \frac{B}{(R_o/t)}$$

The value of  $B$  shall be determined by the following procedure:

1. Assume the value for  $t$  and calculate the value of  $A$  using the formula:  $A = 0.125/(R_o/t)$  (see page 49)
2. Enter the applicable material chart (pages 43-47) at the value of  $A$ . Move vertically to the applicable temperature line.\*
3. From the intersection move horizontally and read the value of  $B$ .

\*For values of  $A$  falling to the left of the applicable temperature line, the value of  $P_a$  can be calculated by the formula:  $P_a = 0.0625 E / (R_o/t)^2$

If the maximum allowable working pressure  $P_a$  computed by the formula above, is smaller than the design pressure, a greater value for  $t$  must be selected and the design procedure repeated.

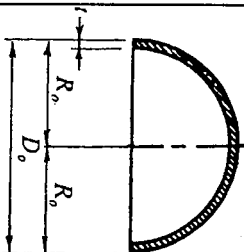
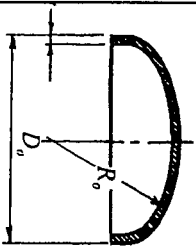
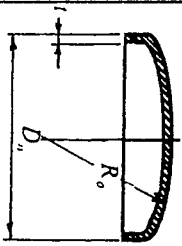
### 2:1 ELLIPSOIDAL HEAD

The required thickness shall be the greater of the following thicknesses.

- (1) The thickness as computed by the formulas given for internal pressure using a design pressure 1.67 times the external pressure and joint efficiency  $E = 1.00$ .
- (2) The thickness proofed by formula  $P_a = B/R_o/t$  where  $R_o = 0.9D_o$ , and  $B$  to be determined as for sphere.

### ASME FLANGED AND DISHED HEAD (TORISPHERICAL HEAD)

The required thickness and maximum allowable pressure shall be computed by the procedures given for ellipsoidal heads. (See above)  $R_o$  maximum =  $D_o$



## EXAMPLES

### DESIGN DATA:

- $P = 15$  psig external design pressure  
 $D_o = 96$  inches outside diameter of head  
 Material of the head SA-285C plate  
 500°F design temperature

Determine the required head thickness.

### SEE DESIGN DATA ABOVE

Assume a head thickness:  $t = 0.25$  in.  $R_o = 48.00$  in.

$$A = 0.125/(48.00/0.25) = 0.00065$$

From Fig. CS-2 (page 43)  $B = 8500$  determined by the procedure described on the facing page.

$$P_a = 8500/(48.00/0.25) = 44.27 \text{ psi.}$$

Since the maximum allowable working pressure  $P_a$  is exceedingly greater than the design pressure  $P$ , a lesser thickness would be satisfactory.

For a second trial, assume a head thickness:  $t = 0.1875$  in.

$$R_o = 48.00 \text{ in.}$$

$$A = 0.125/(48.00/0.1875) = 0.0005$$

$$B = 6700, \text{ from chart (page 43), } P_a = B/(R_o/t) = 6700/256 = 26.2 \text{ psi.}$$

The assumed thickness:  $t = 0.1875$  in. is satisfactory.

### SEE DESIGN DATA ABOVE. Procedure (2.)

Assume a head thickness:  $t = 0.3125$  in.  $R_o = 0.9 \times 96 = 86.4$  in.

$$A = 0.125/(86.4/0.3125) = 0.00045$$

$$B = 6100 \text{ from chart (page 43), } P_a = B/(R_o/t) = 6100/276 = 22.1 \text{ psi.}$$

Since the maximum allowable pressure  $P_a$  is greater than the design pressure  $P$  the assumed thickness is satisfactory.

### SEE DESIGN DATA ABOVE. Procedure (2.)

Assume a head thickness:  $t = 0.3125$  in.  $R_o = D_o = 96$  in.

$$A = 0.125/(96/0.3125) = 0.0004$$

$$B = 5200 \text{ from chart (page 43), } P_a = B/(R_o/t) = 5200/307 = 16.93 \text{ psi.}$$

Since the maximum allowable pressure  $P_a$  is greater than the design pressure  $P$  the assumed thickness is satisfactory.



# EXTERNAL PRESSURE

## FORMULAS

### CONE AND CONICAL SECTION

Seamless or with Built Joints

WHEN  $\alpha$  IS EQUAL TO OR LESS THAN  $60^\circ$  and  $D_1/t_e \geq 10$   
The maximum allowable pressure:

$$P_a = \frac{4B}{3(D_1/t_e)}$$

1. Assume a value for thickness,  $t_e$ .  
The values of  $B$  shall be determined by the following procedure:

2. Determine  $t_e$ ,  $L_e$ , and the ratios  $L_e/D_1$  and  $D_1/t_e$ .  
3. Enter chart G (page 42) at the value of  $L_e/D_1$  (Enter at 50 when  $L_e/D_1$  is greater than 50) Move horizontally to the line representing  $D_1/t_e$ . From the point of intersection move vertically and read the value of  $A$ .

4. Enter the applicable material chart at the value of  $A^*$  and move vertically to the line of applicable temperature. From the intersection move horizontally and read the value of  $B$ .

5. Compute the maximum allowable working pressure,  $P_a$ .

If  $P_a$  is smaller than the design pressure, the design, the design procedure must be repeated increasing the thickness or decreasing  $L$  by using of stiffening rings.

\*For values of  $A$  falling to the left of the applicable line, the value of  $P$  can be calculated by the formula:

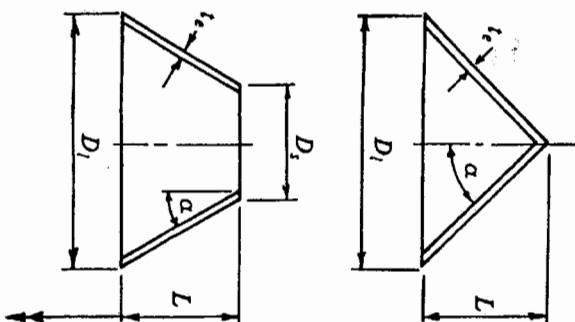
$$P_a = 2.4E/3(D_1/t_e)$$

For cones having  $D/t_e$  ratio smaller than 10, see Code UG-33 (f)(b)

### WHEN $\alpha$ IS GREATER THAN $60^\circ$

The thickness of the cones shall be the same as the required thickness for a flat head, the diameter of which equals the largest outside diameter of the cone.

Provide adequate reinforcing of the cone-to-cylinder juncture. See page 159



## NOTATION

- $A$  = factor determined from fig. UG-28.0 (page 42)  
 $B$  = factor determined from charts (pages 43-47)  
 $\alpha$  = one half of the included (apex) angle, degrees  
 $D_1$  = outside diameter at the large end, in.  
 $D_2$  = outside diameter at the small end, in.  
 $E$  = modulus of elasticity of material (page 43)  
 $L$  = length of cone, in. (see page 39)  
 $L_e$  = equivalent length of conical section, in.  $(L/2)(1 + D_2/D_1)$   
 $P$  = external design pressure, psi.  
 $P_a$  = Maximum allowable working pressure, psi  
 $t_e$  = minimum required thickness, in.  
 $t_e$  = effective thickness, in.  $= t \cos \alpha$

## EXAMPLES

### DESIGN DATA

$P = 15$  psi external design pressure  
 Material of the cone SA 285-C plate  
 500 F design temperature

### CONICAL HEAD

$D_1 = 96$  in.  $\alpha = 22.5$  degrees  $D_2 = 0$

Determine the required thickness,  $t$

Length,  $L = (D_1/2)/\tan \alpha = 48/0.4142 = 115.8$ , say 116 in

1. Assume a head thickness,  $t$ , 0.3125 in.

2.  $t_e = t \cos \alpha = 0.3125 \times 0.9239 = 0.288$ ;

$L_e = L/2(1 + D_1/D_2) = 116/2 \times (1 + 0/96) = 58$

$L_e/D_1 = 58/96 = 0.6$   $D_1/t_e = 96/0.288 = 333$

3.  $A = 0.00037$  (from chart, page 42)

4.  $B = 5,200$  (from chart, page 43)

5.  $P_a = \frac{4B}{3(D_1/t_e)} = \frac{4 \times 5,200}{3(333)} = 20.8$  psi.

Since the maximum allowable pressure is greater than the design pressure, the assumed plate thickness is satisfactory.

### CONICAL SECTION (See design data above)

$D_1 = 144$  in.  $D_2 = 96$  in.  $\alpha = 30$  deg.  
 Determine the required thickness,

Length,  $L = [(D_1 - D_2)/2]/\tan \alpha = 24/0.5774 = 41.6$  in.

1. Assume a head thickness,  $t$ , 0.375 in.

2.  $t_e = t \cos \alpha = 0.375 \times 0.866 = 0.324$

$L_e = (L/2)(1 + D_1/D_2) = 41.6/2 \times$

$(1 + 96/144) = 34.67$

$L_e/D_1 = 34.67/144 = 0.241$

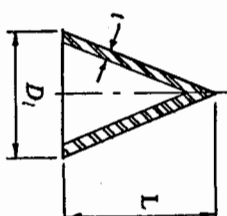
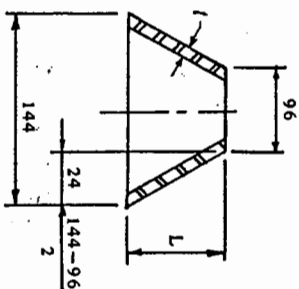
$D_1/t_e = 144/0.324 = 444$

3.  $A = 0.00065$  (from chart, page 42)

4.  $B = 8,600$  (from chart, page 43)

5.  $P_a = \frac{4B}{3(D_1/t_e)} = \frac{4 \times 8,600}{3 \times (144/0.324)} = 25.8$  psi.

Since the maximum allowable pressure  $P_a$  is greater than the design pressure  $P$ , the assumed thickness is satisfactory.





## NOTES

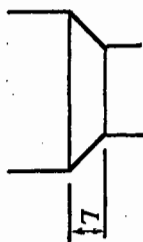
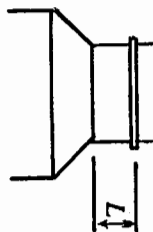
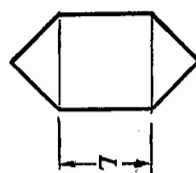
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INT. PRESS.

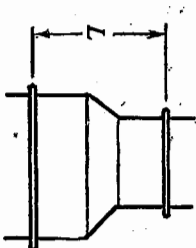
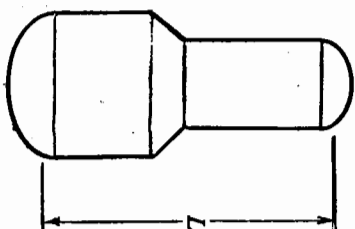
DESIGN

## EXTERNAL PRESSURE

## FORMULAS



Use  $L$  in calculation as shown when the strength of joints of cone to cylinder does not meet the requirements described on pages 163 - 169. It will result the thickness for the cone not less than the minimum required thickness for the joining cylindrical shell.



Use  $L$  in calculation as shown when the strength of joints of cone to cylinder meets the requirements described on pages 163 - 169.



## EXTERNAL PRESSURE DESIGN OF STIFFENING RINGS

### NOTATION

- $A$  = Factor determined from the chart (page 42) for the material used in the stiffening ring.
- $A_s$  = Cross sectional area of the stiffening ring, sq. in.
- $D_o$  = Outside Diameter of shell, in.
- $E$  = Modulus of elasticity of material (see chart on page 43)
- $I_s$  = Required moment of inertia of the stiffening ring about its neutral axis parallel to the axis of the shell, in.<sup>4</sup>.
- $I'_s$  = Required moment of inertia of the stiffening ring combined with the shell section which is taken as contributing to the moment of inertia. The width of the shell section  $1.10 \sqrt{D_o f}$  in.<sup>4</sup>.
- $L_s$  = The sum of one-half of the distances on both sides of the stiffening ring from the center line of the ring to the (1) next stiffening ring, (2) to the head line at  $\frac{1}{2}$  depth, (3) to a jacket connection, or (4) to cone-to-cylinder junction, in.
- $P$  = External design pressure, psi.
- $t$  = Minimum required wall thickness of shell, in.

- I. Select the type of stiffening ring and determine its cross sectional area  $A$ .
- II. Assume the required number of rings and distribute them equally between jacketed section, cone-to-shell junction, or head line at  $\frac{1}{2}$  of its depth and determine dimension,  $L_s$ .
- III. Calculate the moment of inertia of the selected ring or the moment of inertia of the ring combined with the shell section (see page 95).
- IV. The available moment of inertia of a circumferential stiffening ring shall not be less than determined by one of the following formulas:

$$I'_s = \frac{D_o^2 L_s (t + A_s/L_s) A}{10.9} \quad I_s = \frac{D_o^2 L_s (t + A_s/L_s) A}{14}$$

The value of  $A$  shall be determined by the following procedure:

1. Calculate factor  $B$  using the formula:  

$$B = \frac{3}{4} \left[ \frac{P D_o}{L_s + A_s \sqrt{L_s}} \right]$$
2. Enter the applicable material chart (pages 43 -47) at the value of  $B$  and move horizontally to the curve of design temperature. When the value of  $B$  is less than 2500,  $A$  can be calculated by the formula:  $A = 2B/E$ .
3. From the intersection point move vertically to the bottom of the chart and read the value of  $A$ .
4. Calculate the required moment of inertia using the formulas above.

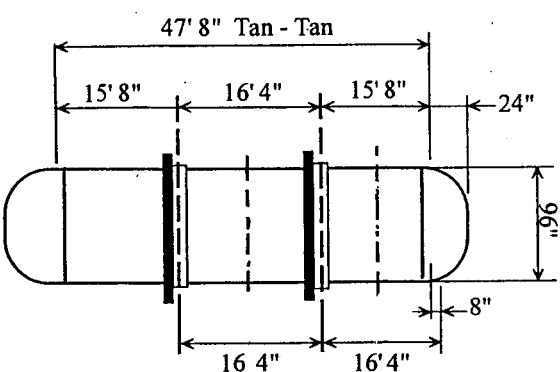
If the moment of inertia of the ring or the ring combined with the shell section is greater than the required moment of inertia, the stiffening of the shell is satisfactory. Otherwise stiffening ring with larger moment of inertia must be selected, or the number of rings shall be increased.

Stiffening ring for jacketed vessel: Code UG-29 (f)

## EXAMPLES

### DESIGN DATA:

- $P$  = 15 psi, external design pressure.
- $D_o$  = 96 in., outside diameter of the shell.
- Length of the vessel from tangent line to tangent line: 47 ft. 8 in. = 572 in.
- Heads 2:1 ellipsoidal
- Material of the stiffening ring SA-36
- Temperature 500°F
- $E$  = Modulus of elasticity of material, 27,000,000 psi, @ 500°F (see chart on page 43)
- $t$  = 0.500 in. thickness of shell



- I. An angle of  $6 \times 4 \frac{1}{16}$  selected.  
 $A_s = 3.03$  sq. in.
- II. Using 2 stiffening rings equally spaced between one-third the depths of heads (see figure),  
 $L_s = 196$  in.
- III. The moment of inertia of the selected angle: 11.4 in.
1. The value of Factor  $B$ :  
 $B = \frac{3}{4} [P D_o / (t + A_s/L_s)] = \frac{3}{4} [15 \times 96 / (0.5 + 3.03/196)] = 2095$
2. Since the value of  $B$  is less than 2500,  
 $A = 2B/E = 2 \times 2095 / 27,000,000 = 0.00015$
- IV. The required moment of inertia:

$$I_s = \frac{[D_o^2 L_s (t + A_s/L_s) A]}{14} = \frac{96^2 \times 196 \times (0.5 + 3.03/196) \times 0.00015}{14} = 9.97 \text{ in.}^4$$

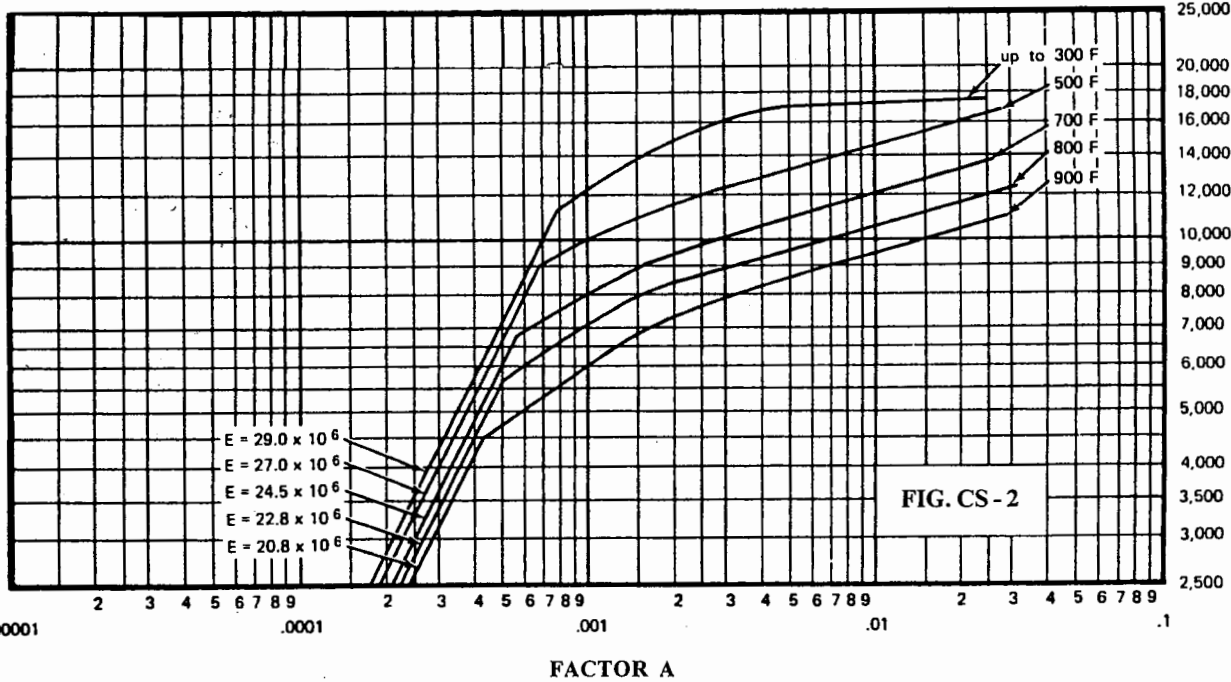
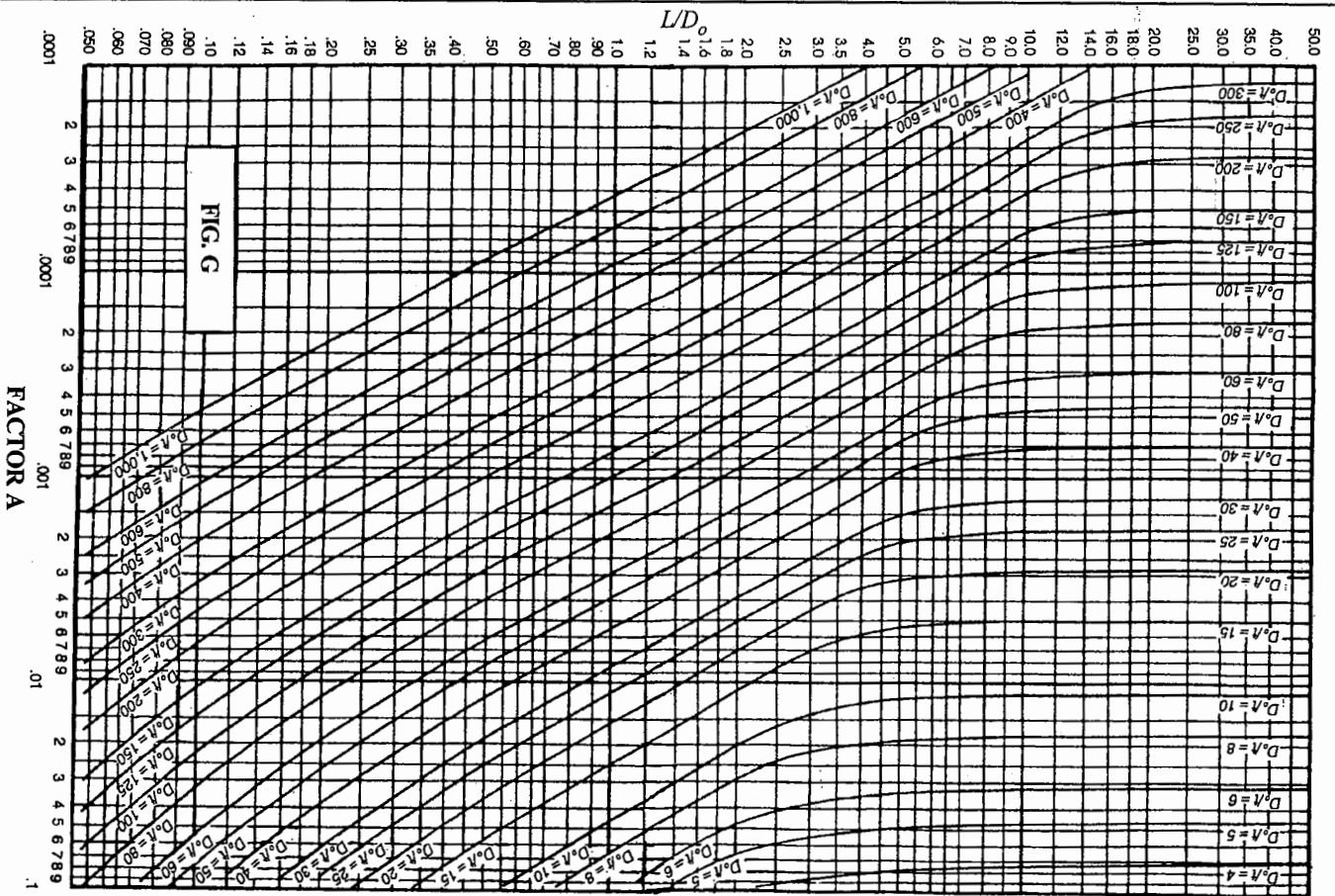
Since the required moment of inertia (9.97 in.<sup>4</sup>) is smaller than the moment of inertia of the selected angle (11.4 in.<sup>4</sup>) the vessel is adequately stiffened.

Stiffening rings may be subject to lateral buckling. This should be considered in addition to the required moment of inertia.

See pages 95-97 for stiffening ring calculations.



# THE VALUES OF FACTOR A USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE



**FIG. CS-2**

**NOTE:** In cases where the value of A falls to the right of the end of the temperature line, assume an intersection with the horizontal protection of the upper end of the temperature line.

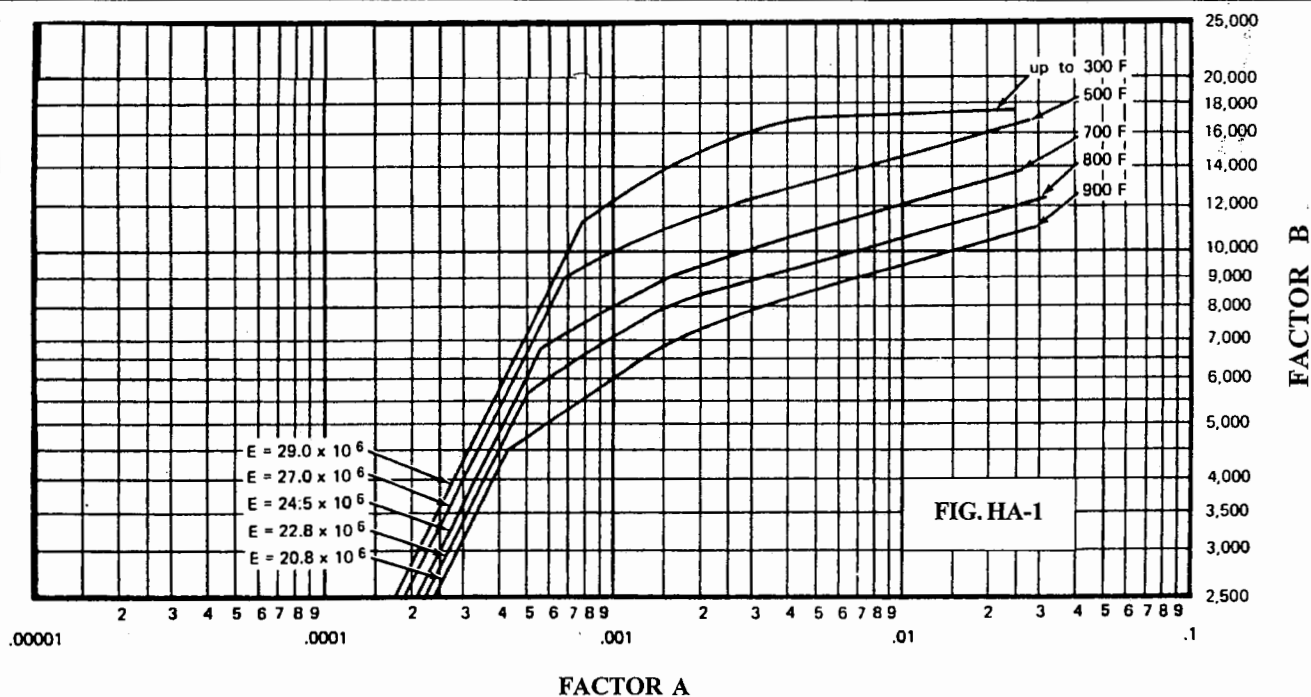
## THE VALUES OF FACTOR B

### USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

The values of the chart are applicable when the vessel is constructed of carbon steel and the specified yield strength 30,000 psi. and over. To this category belong the following most frequently used materials:

SA - 283 C	SA - 515	} All Grades	SA - 53 - B	Type 405	} Stainless Steel
SA - 285 C	SA - 516		SA - 106 - B	Type 410	



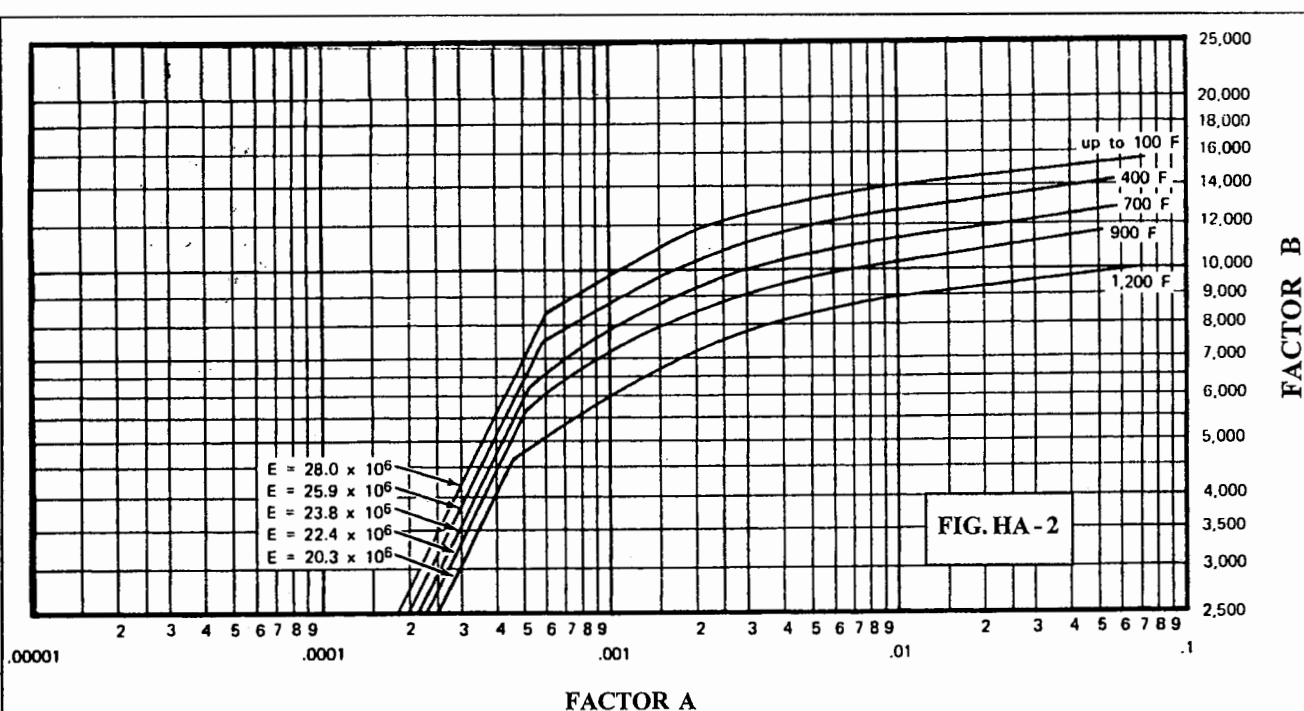


**NOTE:** In cases where the value of A falls to the right of the end of the temperature line, assume an intersection with the horizontal protection of the upper end of the temperature line.

### THE VALUES OF FACTOR B

#### USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

\*The values of the chart are applicable when the vessel is constructed of austenitic steel (18Cr-8Ni, Type 304) (Table 1 on page 190)



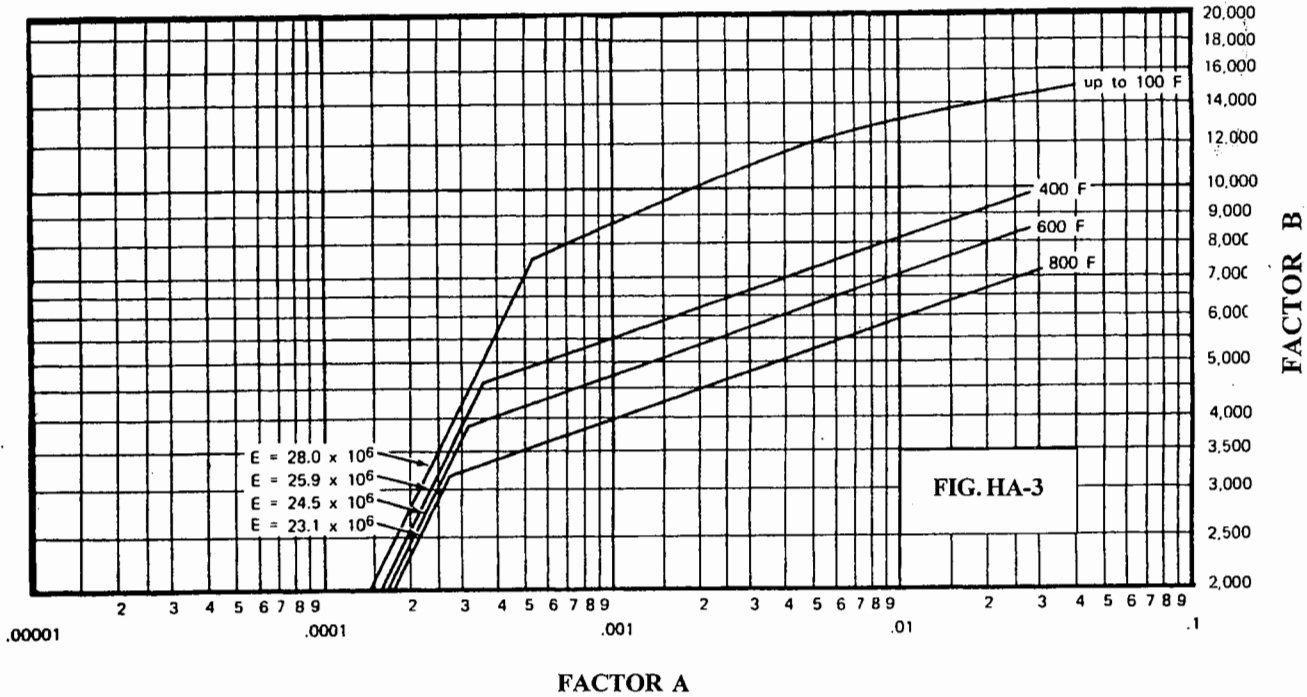
**NOTE:** In cases where the value of A falls to the right of the end of the temperature line, assume an intersection with the horizontal protection of the upper end of the temperature line.

### THE VALUES OF FACTOR B

#### USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

\*The values of the chart are applicable when the vessel is constructed of austenitic steel (18Cr-8Ni-Mo, Type 316) (Table 3 on page 190)



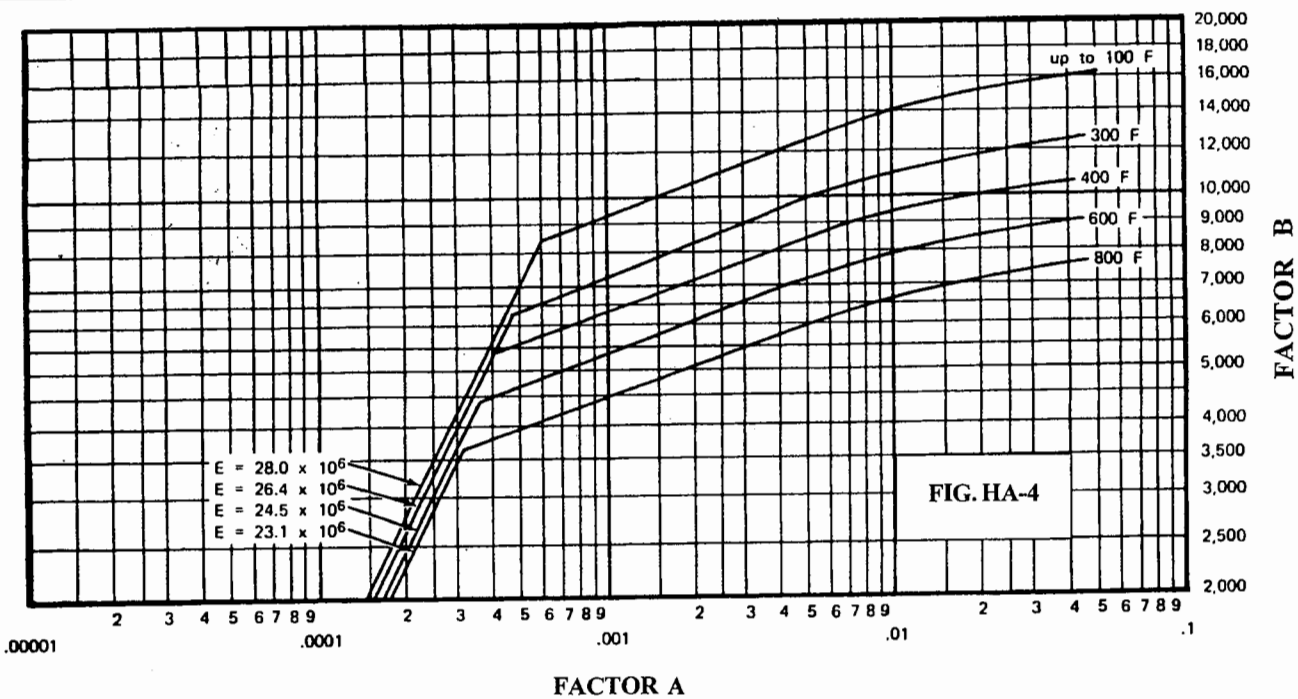


**NOTE:** In cases where the value of A falls to the right of the end of the temperature line, assume an intersection with the horizontal protection of the upper end of the temperature line.

### THE VALUES OF FACTOR B

#### USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

\*The values of the chart are applicable when the vessel is constructed of austenitic steel (18CR-8NI-0, 03 max. carbon, Type 304L) (Table 2 on page 190)



**NOTE:** In cases where the value of A falls to the right of the end of the temperature line, assume an intersection with the horizontal protection of the upper end of the temperature line.

### THE VALUES OF FACTOR B

#### USED IN FORMULAS FOR VESSELS UNDER EXTERNAL PRESSURE

\*The values of the chart are applicable when the vessel is constructed of austenitic steel (18CR-8Ni-Mo-0.03 max. carbon, Types 316L and 317L) (Table 4 on page 190)



# EXTERNAL PRESSURE CONSTRUCTION OF STIFFENING RINGS

## LOCATION

Stiffening rings may be placed on the inside or outside of a vessel.

## SHAPE OF RINGS

The rings may be of rectangular or any other sections.

## CONSTRUCTION

It is preferable to use plates in constructing a composite-section stiffener ring, rather than using standard structural shapes. The reason for this lies not only in the difficulties of rolling heavy structural shapes, but also because of the necessity to adjust the ring to the curvature of the shell. For large diameter vessels the maximum permissible out of roundness can result in a 1 - 2 inch gap between the shell and the ring. This can be eliminated if the vertical member of the ring is cut out of the plate in sections. The sections can be flame cut, instead of rolled and then butt-welded together in place.

## DRAIN AND VENT

Stiffener rings placed in the inside of horizontal shells have a hole or gap at the bottom for drainage and at the top for vent. Practically one half of a 3 inch diameter hole at the bottom and 1½ inch diameter hole at the top is satisfactory and does not affect the stress conditions. Figure A.

For the maximum arc of shell left unsupported because of gap in stiffening ring, see Code Figure UG.29.2.

## WELDING

According to the ASME Code (UG 30): Stiffener rings may be attached to the shell by continuous or intermittent welding. The total length of intermittent welding on each side of the stiffener ring shall be:

1. for rings on the outside, not less than one half the outside circumference of the vessel;
2. for rings on the inside of the vessel, not less than one third of the circumference of the vessel.

Where corrosion allowance is to be provided, the stiffening ring shall be attached to the shell with continuous fillet or seal weld. ASME Code (UG.30.)

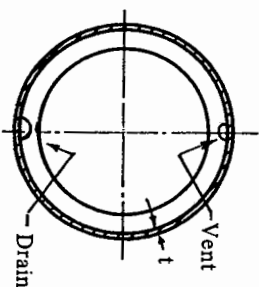


Figure A

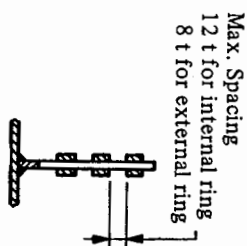


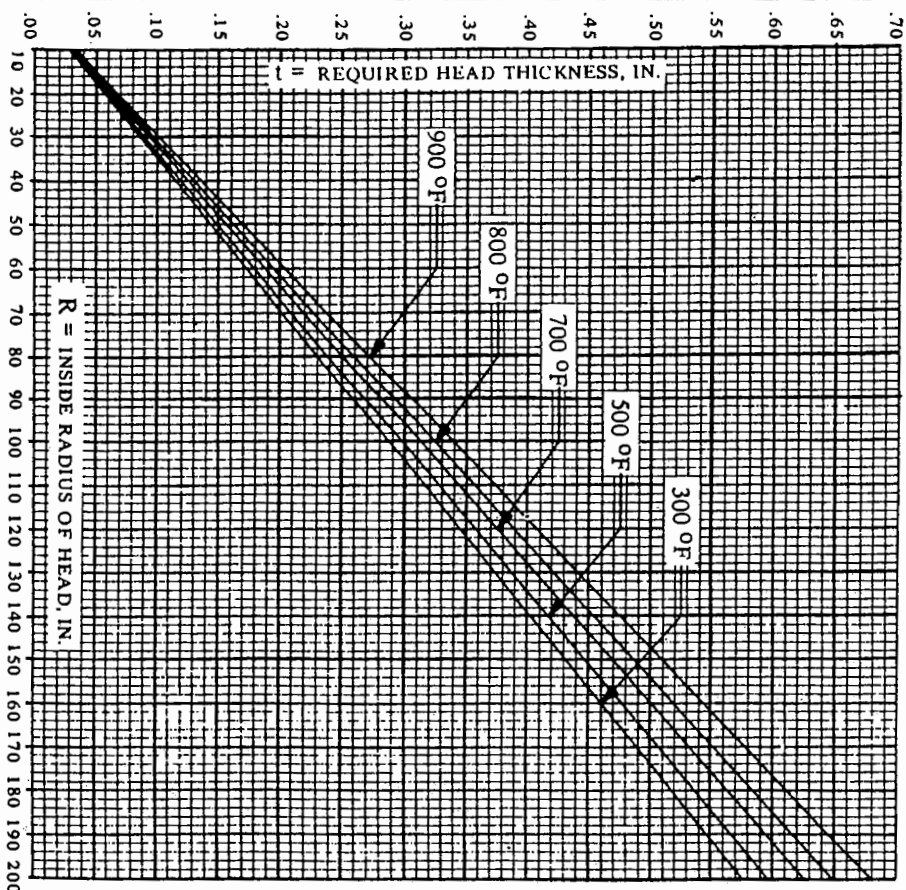
Figure B

**EXAMPLE:** RINGS OUTSIDE ¼" x 3" lg. fillet weld on 6" ctrs.  
RINGS INSIDE ¼" x 2" lg. fillet weld on 6" ctrs.

The fillet weld leg-size shall be not less than the smallest of the following: ¼ in,

## CHARTS FOR DETERMINING THE WALL THICKNESS FOR FORMED HEADS SUBJECTED TO FULL VACUUM

Using the charts, trials with different assumed thicknesses can be avoided. The charts has been developed in accordance with the design method of ASME Code, Section VIII, Division 1.



SPHERICAL, ELLIPSOIDAL, FLANGED AND DISHED HEADS  
(Specified yield strength 30,000 to 38,000 psi, inclusive)

To find the required head thickness: 1. Determine R, 2. Enter the chart at the value of R, 3. Move vertically to temperature line, 4. Move horizontally and read t.

t = Required head thickness, in.

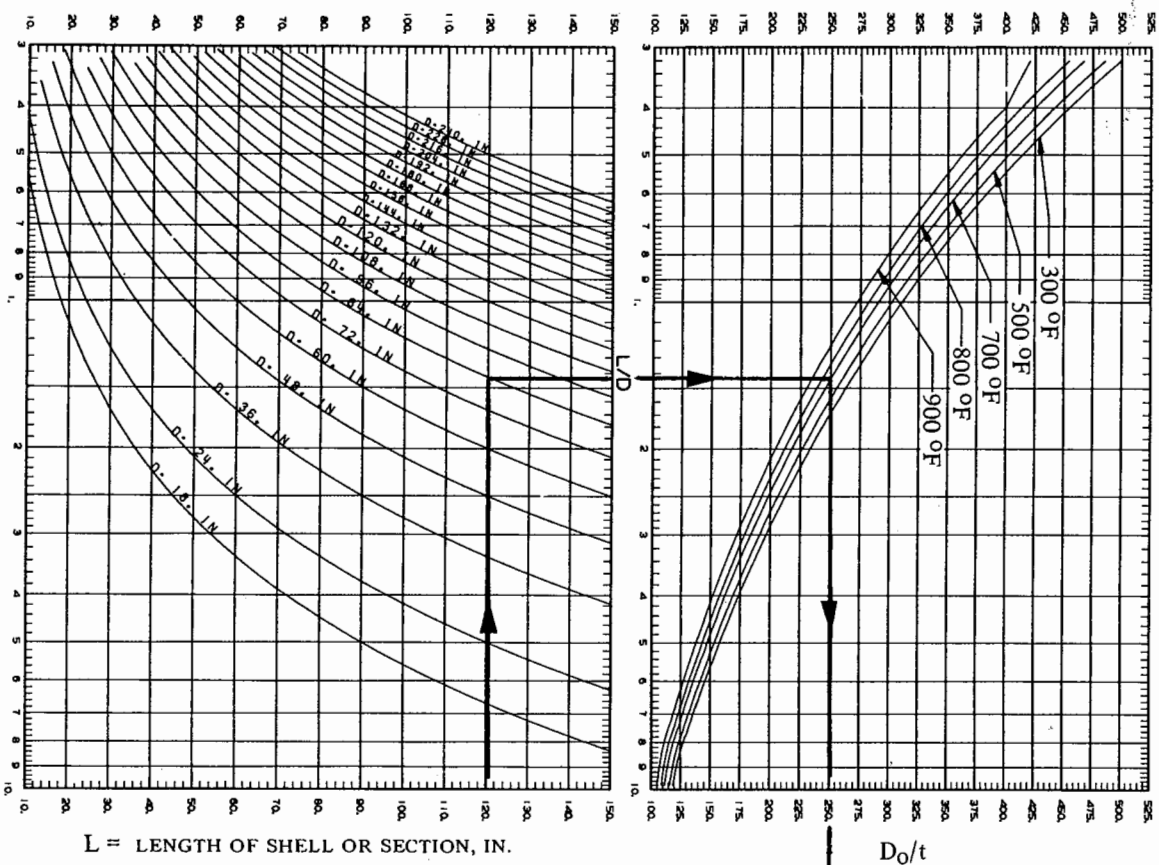
R = For hemispherical heads, the inside radius, in.

For 2:1 ellipsoidal heads  $0.9 \times D_o$

For flanged and dished heads, the inside crown radius, in.  $R_{max} = D_o$   
 $D_o$  = Outside diameter of the head, in.



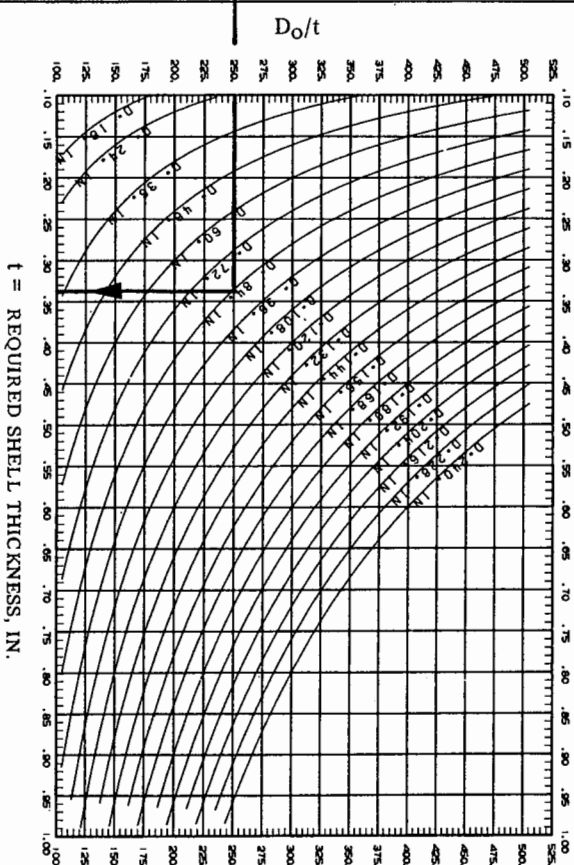
# CHARTS FOR DETERMINING THE WALL THICKNESS FOR VESSELS SUBJECTED TO FULL VACUUM



## CYLINDRICAL SHELL

(See facing page for explanation)

# CHARTS FOR DETERMINING THE WALL THICKNESS FOR VESSELS SUBJECTED TO FULL VACUUM



## CYLINDRICAL SHELL

(Specified yield strength 30,000 to 38,000 psi, inclusive)

To find the required shell thickness:

1. Enter lower chart (facing page) at the value of  $L$
2. Move horizontally to curves representing  $D_o$
3. Move vertically to temperature line
4. Move horizontally and read  $D_o/t$
5. Enter chart above at the value of  $D_o/t$
6. Move horizontally to curve  $D$
7. Move vertically down and read the value of  $t$

## NOTATION

- $t$  = Required shell thickness, in.  
 $D_o$  = Outside diameter of shell, in.  
 $L$  = Length of the vessel or vessel section, taken as the largest of the following:
1. Distance between the tangent lines of the heads plus one third of the depth of the heads if stiffening rings are not used, in.
  2. The greatest distance between any two adjacent stiffening rings, in.
  3. The distance from the center of the first stiffening ring to the head tangent line plus one third of the head depth, in.

The charts are from:

Logan, P. J., "Based on New ASME Code Addenda . . . Chart Finds Vessel Thickness," HYDROCARBON PROCESSING, 55 No. 5, May 1976 p. 217.

Logan, P. J., "A Simplified Approach to . . . Pressure Vessel Head Design," HYDROCARBON PROCESSING, 55 No. 11, November 1976 p. 265.

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## DESIGN OF TALL TOWERS

### WIND LOAD

The computation of wind load is based on Standard ANSI/ASCE 7-95, approved 1996.

The basic wind speed shall be taken from the map on the following pages.

The basic wind speed is 105 mph. in Hawaii and 125 mph. in Puerto Rico.

The minimum design wind pressure shall not be less than 10 lb./sq. ft.

When records and experience indicates that the wind speeds are higher than those reflected in the map, the higher values of wind speed shall be applied.

The wind pressure on the projected area of a cylindrical tower shall be calculated by the following formula.

$$F = q_z G C_f A_f$$

Table 6-1 ANSI/ASCE 7-95 STANDARD  
(Numbers of tables and paragraphs are references to this Standard.)

$(D \times H)$  Projected area of tower, sq. ft.

height of tower considered, ft.

outside diameter of tower, ft.

Shape factor = 0.8 for cylindrical tower (Table 6-7)

Gust response factor =  $(G_h \& G_d)^*$  (Para. 6.6)

When the tower is located:

in urban, suburban areas, Exposure B 0.8;

in open terrain with scattered obstruction, Exposure C 0.85;

in flat, unobstructed areas, Exposure D 0.85.

Velocity pressure at height  $z$  above ground, lb./sq. in.  
0.00256  $K_z K_{zt} V^2$  I, lb./sq. ft. (Table 6-1)

Design Wind Force, lb. on projected area of tower. (Para. 6.2)

Importance factor = 1.0 for structures that present low hazard to human life in event of failure (Para. 6.2).

Wind speed, mph. (Map 6-1)

Topographic factor = 1.0 when wind speed-up over hills and escarpment is not present. (Para. 6.5.5)

Velocity Pressure Exposure Coefficient\* Exposures B, C & D (Table 6-3)

\* See tables below for values of  $q$  and for combined values of  $G_h$ ,  $G_d$ , and  $K_z$  in Exposures B, C, and D.

#### VELOCITY PRESSURE, $q$

Basic wind speed, mph, $V$	70	80	90	100	110	120	130
Velocity Pressure psf 0.00256 $V^2$ , $q$	13	17	21	26	31	37	44

## DESIGN OF TALL TOWERS

### WIND LOAD

(Continued)

COEFFICIENT  $G$  (Gust response factor combined with Exposure Coefficient)

HEIGHT Above Ground, ft.	EXPOSURE B	EXPOSURE C	EXPOSED
0-15	0.6	1.1	1.4
20	0.7	1.2	1.5
40	0.8	1.3	1.6
60	0.9	1.4	1.7
80	1.0	1.5	1.8
100	1.1	1.6	1.9
140	1.2	1.7	2.0
200	1.4	1.9	2.1
300	1.6	2.0	2.2
500	1.9	2.3	2.4

The area of caged ladder may be approximated as 1 sq. ft. per lineal ft. Projected area of platform 8 sq. ft.

Users of vessels usually specify wind pressure for manufacturers without reference to the height zones or map areas. For example: 30 lb. per sq. ft. This specified pressure shall be considered to be uniform on the whole vessel.

The total pressure on a tower is the product of the unit pressure and the projected area of the tower. With good arrangement of the equipment, the exposed area of the wind can be reduced considerably. For example, by locating the ladder 90 degrees from the vapor line.

#### EXAMPLE:

Determine the wind load,  $F$   
DESIGN DATA:

the wind speed,  $V$  = 100 m.p.h

diameter of tower,  $D$  = 6 ft.

height of tower,  $H$  = 80 ft.

the tower located in flat, unobstructed area, exposure: D

The wind load,  $F = q_z \times G \times C_f \times A_f$

$q$  from table = 26 psf

$G$  from table = 1.8

Shape factor = 0.8

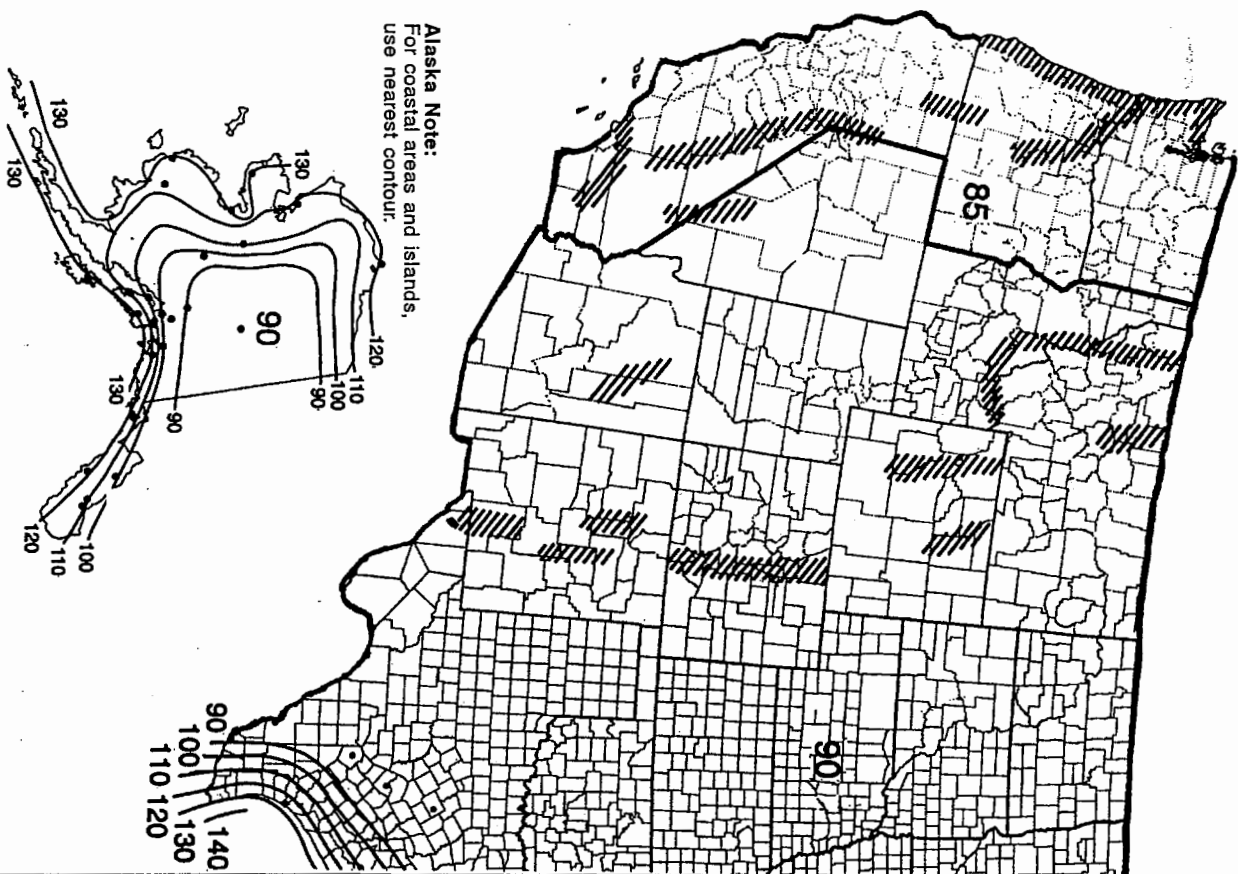
Area,  $A_f = DH = 6 \times 80 = 480$  sq. ft.

$F = 26 \times 1.8 \times 0.8 \times 480 = 17,971$  lbs.



## MAP OF WIND SPEED, V

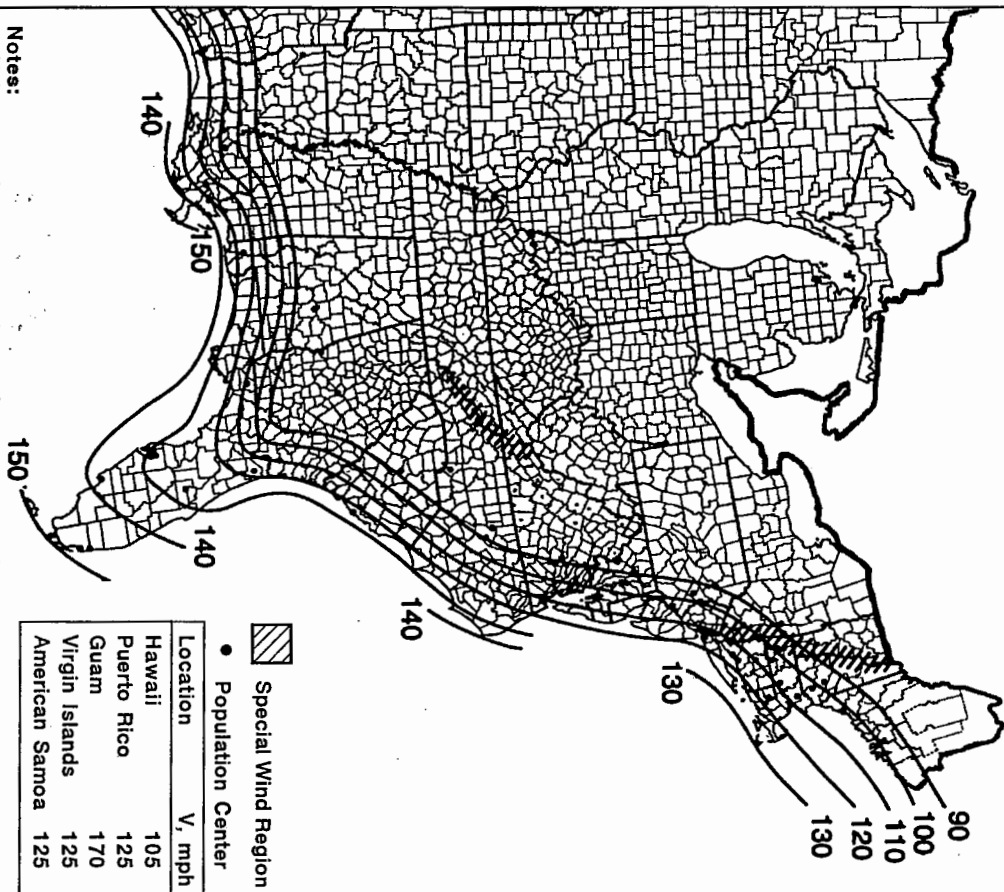
(miles per hour)



ANSI/AASCE STANDARD 7-95  
Courtesy of American Society of Civil Engineers

## MAP OF WIND SPEED, V

(miles per hour)



DESIGN



## DESIGN OF TALL TOWERS WIND LOAD

Computation of wind load as alternate method based on standard ASA A58.1-1955. This standard is obsolete but still used in some codes and foreign countries.

The wind pressure at 30 ft. level above ground for the United States is shown on the map on the facing page.

The table below gives the wind pressures for various heights above ground for the areas indicated by the map.

WIND PRESSURE $P_w$ WHEN THE HORIZONTAL CROSS SECTION SQUARE OR RECTANGULAR*												
HEIGHT ZONE ft.	MAP AREAS											
	20	25	30	35	40	45	50	55	60	65	70	75
less than 30	15	20	25	25	30	35	40					
30 to 49	20	25	30	35	40	45	50					
50 to 99	25	30	40	45	50	55	60					
100 to 499	30	40	45	55	60	70	75					

\*Multiply values of  $P_w$  with 0.80 when the horizontal cross section is hexagonal or octagonal and with 0.60 when the horizontal cross section is circular or elliptical.

### EXAMPLE:

Find the wind pressure  $P_w$  from map.

The vessel is intended to operate in Oklahoma, which is in the wind pressure map area marked 30. In this map area the wind pressures for various height zones are:

In the height zone less than 30 ft. 25 lb. per sq. ft.

In the height zone from 30-49 ft. 30 lb. per sq. ft.

For a cylindrical tower these values shall be multiplied by shape factor 0.6, then the wind pressure in different zones will be 15 and 18 lb. per sq. ft. respectively.

If many pieces of equipment are attached to the tower it is advisable to increase the shape factor (according to Brownell) up to 0.85 for a cylindrical vessel.

Users of vessels usually specify the wind pressure for manufacturers without reference to height zones or map areas. For example: 30 lb. per sq. ft. This specified pressure shall be considered to be uniform on the whole vessel.

Relation between wind pressure and wind velocity, when the horizontal cross section is circular, is given by the formula:

$$P_w = 0.0025 \times V_w^2 \quad \text{where} \quad P_w = \text{wind pressure lb. per sq. ft.}$$

$$V_w = \text{wind velocity mph}$$

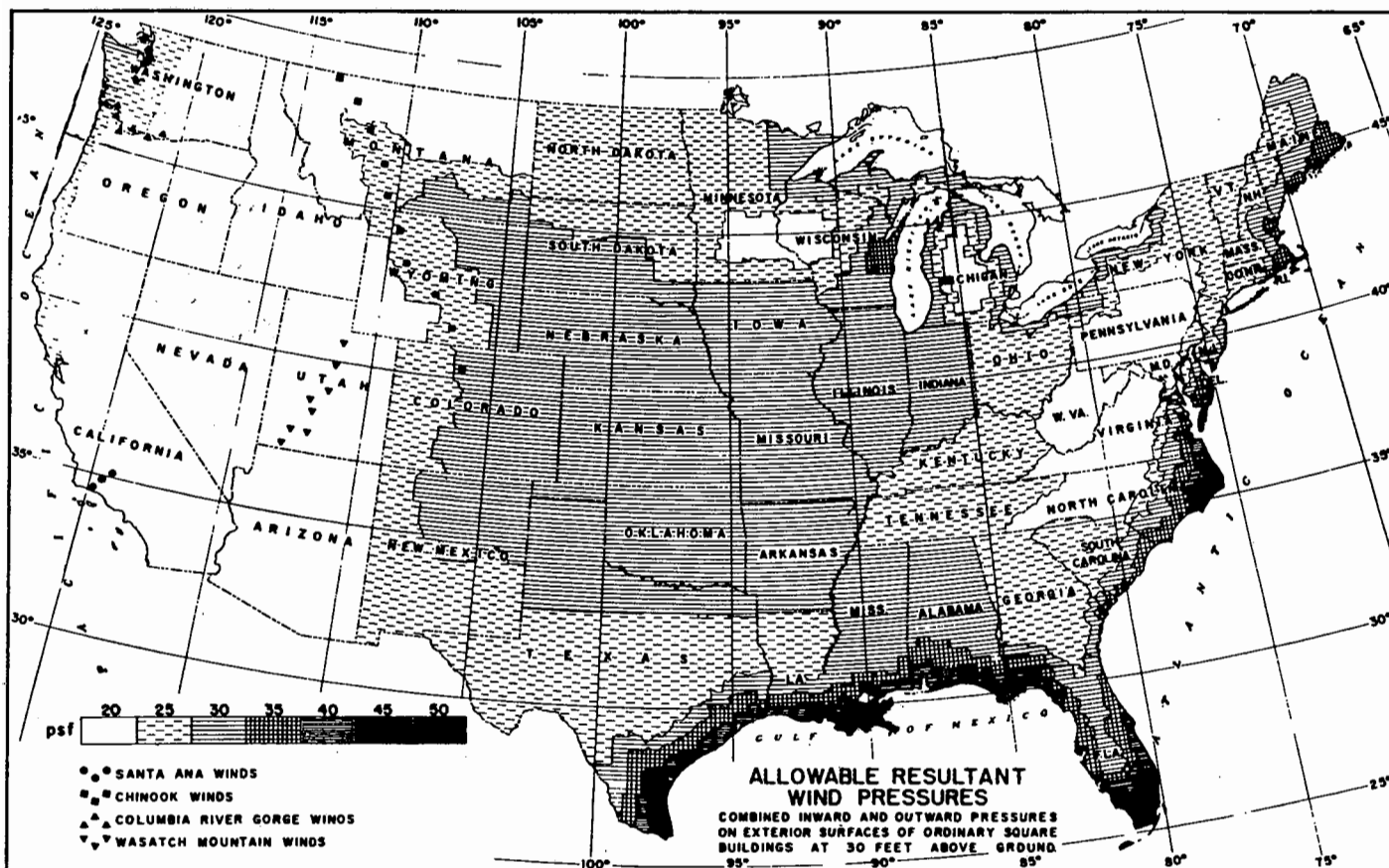
### EXAMPLE:

Wind of 100 mph velocity exerts a pressure:

$$P_w = 0.0025 \times V_w^2 = 25 \text{ lbs. per sq. ft. pressure on the projected area of a cylindrical vessel at a height of 30 feet above ground.}$$

The total wind pressure on a tower is the product of the unit pressure and the projected area of the tower. With a good arrangement of equipment the exposed area of the wind can be reduced considerably. For example, by locating the ladder 90 degrees from the vapor line.

## MAP OF WIND PRESSURE



The map based on the records of the United States Weather Bureau and developed by the National Bureau of Standards.

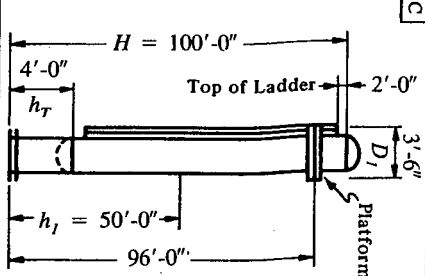
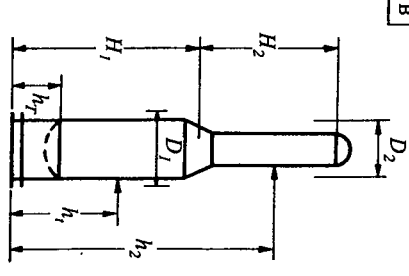
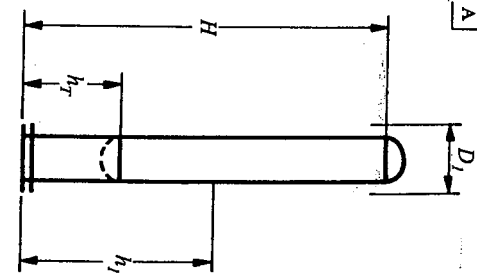


## DESIGN OF TALL TOWERS

## WIND LOAD

(Continuation)

FORMULAS			
SHEAR	MOMENT	STRESS	REQUIRED THICKNESS
$V = P_w D_{1,2} H_{1,2}$	$M = P_w D_{1,2} H_{1,2} h_{1,2}$	$S = \frac{12M}{R^2 \pi t}$	$t = \frac{12M}{R^2 \pi S E}$
NOTATION $D_{1,2}$ = Width of the vessel with insulation etc., ft. $E$ = Efficiency of the welded joints. $h_1/h_2$ = Lever arm, ft. $h_{1,2}$ = Distance from base to section under consideration, ft. $H_1/H_2$ = Length of vessel or vessel section, ft. $M$ = Maximum moment (at the base) ft. lb. $M_T$ = Moment at height $h_T$ , ft. lb. $P_w$ = Wind pressure, lb. per sq. ft. $R$ = Mean radius of vessel, in. $S$ = Stress value of material or actual stress psi. $V$ = Total shear, lb. $t$ = Required thickness, corrosion excluded, in.			



## EXAMPLE:

Given:  $D_1 = 4'-0"$   $D_2 = 3'-0"$   $H_1 = 56'-0"$   $H_2 = 44'-0"$   
 $h_T = 4'-0"$   $P_w = 30$  psf

Determine the wind moment

$$h_1 = H_1/2 = 28'-0" \quad h_2 = H_1 + (H_2/2) = 78'-0"$$

$$P_w \times D \times H = V \times h = M$$

Lower Section  $30 \times 4 \times 56 = 6720 \times 28 = 188,160$

Upper Section  $30 \times 3 \times 44 = 3,960 \times 78 = 308,880$

Total  $V = 10,680$   $M = 497,040$  ft. lb.

Moment at the bottom tangent line

$$M_T = M - h_T (V - 0.5 P_w D_1 h_T) =$$

$$497,040 - 4 (10,680 - 0.5 \times 30 \times 4 \times 4) = 455,280 \text{ ft. lb.}$$

## EXAMPLE:

Given:  $D_1 = 3$  ft. 6 in.  $H = 100$  ft. 0 in.  $h_T = 4$  ft. 0 in.  
 $P_w = 30$  psf

Determine the wind moment

$$h_1 = H/2 = 50 \text{ ft. 0 in.}$$

$$P_w \times D_1 \times H = V \times h_1 = M$$

Vessel  $30 \times 3.5 \times 100 = 10,500 \times 50 = 525,000$

Ladder  $30 \times 98 \text{ lin. ft.} = 2,940 = 49 = 144,060$

Platform  $30 \times 8 \text{ lin. ft.} = 240 \times 96 = 23,040$

Total  $V = 13,680$   $M = 692,100$  ft. lb.

Moment at the bottom tangent line

$$M_T = M - h_T (V - 0.5 P_w D_1 h_T) =$$

$$692,100 - 4 (13,680 - 0.5 \times 30 \times 3.5 \times 4) = 638,220 \text{ ft. lb.}$$

SEE EXAMPLES FOR COMBINED LOADS ON PAGE: 69

## DESIGN OF TALL TOWERS

## WEIGHT OF THE VESSEL

The weight of the vessel results compressive stress only when eccentricity does not exist and the resultant force coincides with the axis of the vessel. Usually the compression due to the weight is insignificant and is not controlling.

The weight shall be calculated for the various conditions of the tower as follows:

## A. Erection weight, which includes the weight of the:

## Equipments:

1. shell
2. heads
3. internal plate work
4. tray supports
5. insulation rings
6. openings
7. skirt
8. base ring
9. anchor ring
10. anchor lugs
11. miscellaneous
12. + 6% of the weight of items 1 through 11 for overweight of the plates and weight added by the weldings

Erection weight: the sum of items 1 through 18.

## B. Operating weight, which includes the weight of the:

1. vessel in erection condition
2. trays
3. operating liquid

## C. Test weight, which includes the weight of the:

1. vessel in erection condition
2. test water

The compressive stress due to the weight given by:

$$S = \frac{W}{c t} \quad \text{where}$$

$S$  = unit stress, psi  
 $W$  = weight of vessel above the section under consideration, lb.  
 $c$  = circumference of shell or skirt on the mean diameter, in.  
 $t$  = thickness of the shell or skirt, in.

The weight of different vessel elements are given in tables beginning on page 374



## DESIGN OF TALL TOWERS VIBRATION

As a result of wind, tall towers develop vibration. The period of the vibration should be limited, since large natural periods of vibration can lead to fatigue failure. The allowable period has been computed from the maximum permissible deflection.

The so called harmonic vibration is not discussed in this Handbook since the trays as usually applied and their supports prevent the arising of this problem.

### FORMULAS

Period of Vibration:  $T \text{ sec.} \quad T = 0.0000265 \left(\frac{H}{D}\right)^2 \sqrt{\frac{WD}{t}}$

Maximum Allowable Period of Vibration,  $T_a \text{ sec.} \quad T_a = 0.80 \sqrt{\frac{WH}{Vg}}$

### NOTATION

- $D$  = Outside diameter of vessel, ft.
- $H$  = Length of vessel including skirt, ft.
- $g$  = 32.2 ft. per sec. squared, acceleration
- $t$  = Thickness of skirt at the base, in.
- $V$  = Total shear, lb.,  $CW$ , see page 61
- $W$  = Weight of tower, lb.
- $w$  = Weight of tower per foot of height, lb.

### EXAMPLE

Given: Determine the actual and maximum allowable period of vibration

$$\begin{aligned} D &= 3.125 \text{ ft. } 0 \text{ in.} \\ H &= 100 \text{ ft. } 0 \text{ in.} \\ g &= 32.2 \text{ ft/sec}^2 \\ t &= 0.75 \text{ in.} \\ W &= 1440 \text{ lb.} \\ w &= 36,000 \text{ lb.} \\ &\text{in operating condition} \\ T &= 0.0000265 \left(\frac{100}{3.125}\right)^2 \sqrt{\frac{360 \times 3.125}{0.75}} = 1.05 \text{ sec.} \\ T_a &= 0.80 \sqrt{\frac{36000 \times 100}{1440 \times 32.2}} = 7.05 \text{ sec.} \end{aligned}$$

The actual vibration does not exceed the allowable vibration.

Reference: Freese, C. E.: Vibration of Vertical Pressure Vessel ASME Paper 1959.

## DESIGN OF TALL TOWERS SEISMIC LOAD (EARTHQUAKE)

The loading condition of a tower under seismic forces is similar to that of a cantilever beam when the load increases uniformly toward the free end. The design method below is based on Uniform Building Code, 1997 (UBC).

### FORMULAS

#### SHEAR

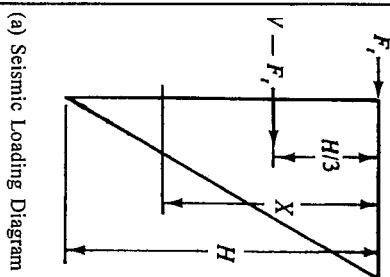
$$V = \frac{ZIC}{R_w} W$$

#### MOMENT

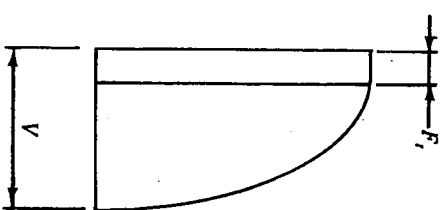
$$\begin{aligned} M &= [F_t \times H + (V - F_t) \times (2H/3)] \\ M_x &= [F_t \times X] \text{ for } X \leq H/3 \\ M_x &= [F_t \times H + (V - F_t) \times (X - H/3)] \\ &\text{for } X > H/3 \end{aligned}$$

#### Base Shear

The base shear is the total horizontal seismic shear at the base of a tower. The triangular loading pattern and the shape of the tower shear diagram due to that loading are shown in Fig. (a) and (b). A portion of  $F_t$  of total horizontal seismic force  $V$  is assumed to be applied at the top of the tower. The remainder of the base shear is distributed throughout the length of the tower, including the top.



(a) Seismic Loading Diagram



(b) Seismic Shear Diagram

Base Shear

### NOTATION

- $C$  = Numerical coefficient =  $\frac{2.35S}{T^{2/3}}$  (need not exceed 2.75)
- $C$  = Numerical coefficient = 0.035
- $D$  = Outside diameter of vessel, ft.
- $E$  = Efficiency of welded joints
- $F_t$  = Total horizontal seismic force at top of the vessel, lb., determined from the following formula:  
 $F_t = 0.07 TV$  ( $F_t$  need not exceed 0.25V)  
= 0, for  $T \leq 0.7$
- $H$  = Length of vessel including skirt, ft.



## DESIGN OF TALL TOWERS

### SEISMIC LOAD (EARTHQUAKE)

(Continuation)

#### NOTATION

- $I$  = Occupancy importance coefficient (use 1.0 for vessels)
- $M$  = Maximum moment (at the base), ft-lb.
- $M_x$  = Moment at distance  $X$ , ft-lb.
- $R$  = Mean radius of vessel, in.
- $R_w$  = Numerical coefficient (use 2.9 for vessels)
- $S$  = Site coefficient for soil characteristics

A soil profile with either:

- a) A rock-like material characterized by a shear-wave velocity greater than 2,500 feet per second or by other suitable means of classification.  $S = 1.0$
- b) Stiff or dense soil condition where the depth is less than 200 ft.  $S = 1$ . A soil profile with dense or stiff soil conditions, where the soil depth exceeds 200 feet.  $S = 1.2$ .

A soil profile of 40 feet or more in depth and containing more than 20 feet of soft to medium stiff clay, but not more than 40 feet of soft clay.  $S = 1.5$ .

A soil profile containing more than 40 feet of soft clay.  $S = 2.0$ .

$S_t$  = Allowable tensile stress of vessel plate material, psi.

$T$  = Fundamental period of vibration, seconds  
 $= C_t \times H^{1/4}$

$t$  = Required corroded vessel thickness, in.

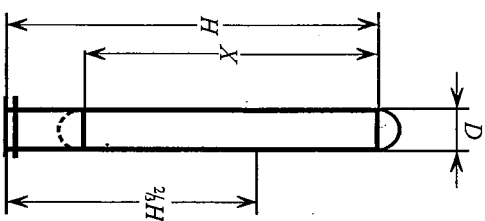
$$\frac{12M}{\pi R^2 S_t E} \quad \text{or} \quad \frac{12M_x}{\pi R^2 S_t E}$$

$V$  = Total seismic shear at base, lb.

$W$  = Total weight of tower, lb.

$X$  = Distance from top tangent line to the level under consideration, ft.

$Z$  = Seismic zone factor,  
 0.075 for zone 1  
 0.15 for zone 2A  
 0.2 for zone 2B  
 0.3 for zone 3  
 0.4 for zone 4



(see map on the following pages for zoning).

## DESIGN OF TALL TOWERS

### SEISMIC LOAD (EARTHQUAKE)

EXAMPLE

Given:

Seismic zone: 2B

$Z = 0.2$

$D = 37.5 \text{ in.} = 3.125 \text{ ft.}$

$X = 96 \text{ ft., } 0 \text{ in.}$

$H = 100 \text{ ft., } 0 \text{ in.}$

$W = 35,400 \text{ lb.}$

Determine: The overturning moment due to earthquake at the base and at a distance  $X$  from top tangent line.

First, fundamental period of vibration shall be calculated.

$$T = C_t \times H^{3/4} = 0.035 \times 100^{3/4} = 1.1 \text{ sec.}$$

and

$$I = 1, \quad S = 1.5, \quad R_w = 2.9,$$

$$C = \frac{1.25S}{T^{2/3}} = \frac{1.25 \times 1.5}{1.1^{2/3}} = 1.76 < 2.75$$

$$V = \frac{ZIC}{R_w} \times W = \frac{0.2 \times 1 \times 1.76}{2.9} \times 35,400 = 4,296 \text{ lb.}$$

$$F_t = 0.07 TV = 0.07 \times 1.1 \times 4,296 = 330 \text{ lb.}$$

$$M = [F_t H + (V - F_t) (2H/3)] =$$

$$[330 \times 100 + (4,296 - 330) (2 \times 100/3)] = 294,756 \text{ ft. - lb.}$$

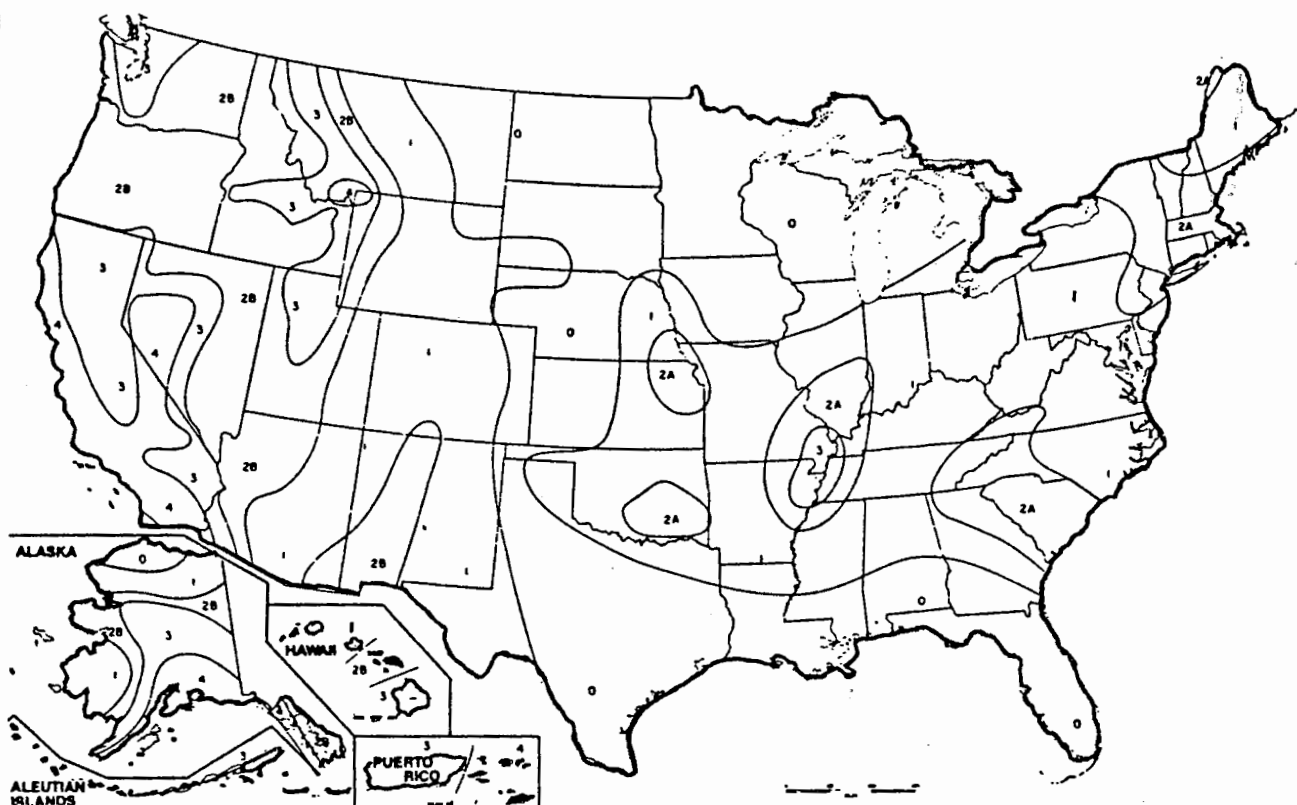
$X > \frac{H}{3}$  thus

$$M_x = [F_t X + (V - F_t) (X - H/3)] =$$

$$[330 \times 96 + (4,296 - 330) (100 - 33)] = 281,138 \text{ ft. - lb.}$$



## SEISMIC ZONE MAP OF THE UNITED STATES



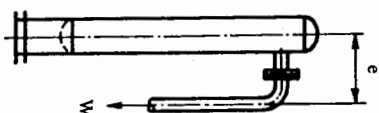
For areas outside of the United States, see Appendix Chapter 23 of UBC :1991

NOTES



## DESIGN OF TALL TOWERS ECCENTRIC LOAD

Towers and their internal equipment are usually symmetrical around the vertical axis and thus the weight of the vessel sets up compressive stress only. Equipment attached to the vessel on the outside can cause unsymmetrical distribution of the loading due to the weight and result in bending stress. This unsymmetrical arrangement of small equipment, pipes and openings may be neglected, but the bending stresses exerted by heavy equipment are additional to the bending stresses resulting from wind or seismic load.



FORMULAS		
MOMENT	STRESS	REQUIRED THICKNESS
$M = We$	$S = \frac{12We}{\pi R^2 t}$	$t = \frac{12We}{R^2 \pi S E}$

NOTATION

$e$  = Eccentricity, the distance from the tower axis to center of eccentric load, ft.  
 $E$  = Efficiency of welded joints.  
 $M$  = Moment of eccentric load, ft. lb.  
 $R$  = Mean radius of vessel, in.  
 $S$  = Stress value of material, or actual bending stress, psi  
 $t$  = Thickness of vessel, excluding corrosion allowance, in.  
 $W$  = Eccentric load, lb.

### EXAMPLE

Given:  $e = 4$  ft. 0 in.  
 $R = 15$  in.  
 $t = 0.25$  in.  
 $W = 1000$  lb.

Determine moment,  $M$ , and stress,  $S$ .  
 Moment,  $M = We = 1000 \times 4 = 4000$  ft. lb.

$$S = \frac{12We}{\pi R^2 t} = \frac{12 \times 1000 \times 4}{\pi \times 15^2 \times 0.25} = 272 \text{ psi}$$

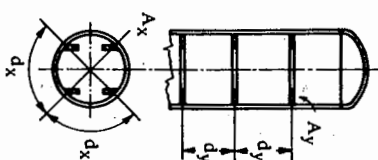
When there is more than one eccentric load, the moments shall be summarized, taking the resultant of all eccentric loads.

## Design of Tall Towers ELASTIC STABILITY

A tower under axial compression may fail in two ways because of instability:

1. By buckling of the whole vessel (Euler buckling)
2. By local buckling

In thin-walled vessels (when the thickness of the shell is less than one-tenth of the inside radius) local buckling may occur at a unit load less than that required to cause failure of the whole vessel. The out of roundness of the shell is a very significant factor in the resulting instability. The formulas for investigation of elastic stability are given in this Handbook, developed by Wilson and Newmark. Elements of the vessel which are primarily used for other purposes (tray supports, downcomer bars) may be considered also as stiffeners against buckling if closely spaced. Longitudinal stiffeners increase the rigidity of the tower more effectively than circumferential stiffeners. If the rings are not continuous around the shell, its stiffening effect shall be calculated with the restrictions outlined in the Code UG-29 (c).



FORMULAS	
ALLOWABLE STRESS (S)	
Without Stiffener	With Stiffener
$S = 1,500,000 \frac{t}{R} \left( \leq \frac{1}{3} \text{ yield point} \right)$	$S = \frac{1,500,000}{R} \sqrt{t_x t_s} \left( \leq \frac{1}{3} \text{ yield p.} \right)$

NOTATIONS:

$A_x$  = Cross sectional area of one longitudinal stiffener, sq. in.  
 $A_y$  = Cross sectional area of one circumferential stiffener, sq. in.  
 $d_x$  = Distance between longitudinal stiffeners, in.  
 $d_y$  = Distance between circumferential stiffeners, in.  
 $R$  = Mean radius of the vessel, in.  
 $S$  = Allowable compressive stress, psi  
 $t$  = Thickness of shell, in.  
 $t_x = t + \frac{A_x}{d_x}$  The equivalent thickness of the shell when longitudinally stiffened, in.  
 $t_y = t + \frac{A_y}{d_y}$  The equivalent thickness of the shell when circumferentially stiffened, in.

### EXAMPLE

Given:  $R = 18$  in.  
 $t = 0.25$  in.

Determine the allowable compressive stress (S)  
 $S = \frac{1,500,000 \times t}{R} = \frac{1,500,000 \times 0.25}{18} = 20,833 \text{ psi}$

Given:  $A_y = 1$  sq. in.  
 $d_y = 24$  in.

Determine the allowable compressive stress (S) using stiffener rings

Longitudinal stiffener is not used, then:

$t_x = t = 0.25$  in.

$$S = \frac{1,500,000}{R} \sqrt{t_x t_s} =$$

$t_y = t + \frac{1}{24} =$   
 $= 0.25 + 0.04 = 0.29$

$$\frac{1,500,000}{18} \sqrt{0.25 \times 0.29} = 22,438 \text{ PSI}$$

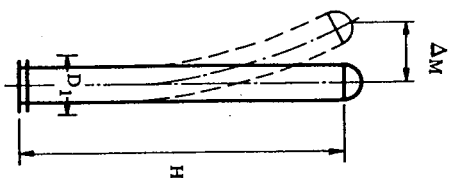
Reference: Wilson, W. M., and Newmark N. M.: The Strength of Thin Cylindrical Shells as Columns, Eng. Exp. Sta. Univ. Ill. bull. 255, 1933.



## DESIGN OF TALL TOWERS

### DEFLECTION

Towers should be designed to deflect no more than 6 inches per 100 feet of height. The deflection due to the wind load may be calculated by using the formula for uniformly loaded cantilever beam.



#### FORMULA

$$\Delta_M = \frac{P_w D_i H (12H)^3}{8EI}$$

#### NOTATIONS

$\Delta_M$  = Maximum deflection (at the top), in.  
 $D_i$  = Width of the tower with insulation, etc. ft.  
 $E$  = Modulus of elasticity, psi  
 $H$  = Length of vessel, included skirt, ft.  
 $I$  =  $R^3 \pi t$ , moment of inertia for thin cylindrical shell (when  $R > 10t$ )  
 $R$  = Mean radius of the tower, in.  
 $t$  = Thickness of skirt, in.  
 $P_w$  = Wind pressure, psf

#### EXAMPLE

Determine the maximum deflection:  $\Delta_M$

Given:  
 $D_i = 2$  ft., 6 in.  
 $E = 30,000,000$   
 $H = 48$  ft., 0 in.  
 $I = R^3 \pi 0.3125$   
 $P_w = 30$  psf  
 $R = 12$  in.  
 $t = 0.3125$  in.

$$\Delta_M = \frac{P_w D_i H (12H)^3}{8EI} = \frac{30 \times 2.5 \times 48 (12 \times 48)^3}{8 \times 30,000,000 \times 12^3 \times 3.14 \times 0.3125} = 1.69 \text{ in.}$$

The maximum allowable deflection 6 inches per 100 ft. of height:

$$\text{for } 48'-0'' = \frac{48 \times 6}{100} = 2.88 \text{ in.}$$

Since the actual deflection does not exceed this limit, the designed thickness of the skirt is satisfactory.

A method for calculating deflection, when the thickness of the tower is not constant, given by S. S. Tang: "Short Cut Method for Calculating Tower Deflection," Hydrocarbon Processing November 1968.

## DESIGN OF TALL TOWERS

### COMBINATION OF STRESSES

The stresses induced by the previously described loadings shall be investigated in combination to establish the governing stresses.

Combination of wind load (or earthquake load), internal pressure and weight of the vessel:

At windward side	Stress Condition	At leeward side
+ Stress due to wind		– Stress due to wind
+ Stress due to int. press.		+ Stress due to int. press.
– Stress due to weight		– Stress due to weight

Combination of wind load (or earthquake load), external pressure and weight of the vessel:

At windward side	Stress Condition	At leeward side
+ Stress due to wind		– Stress due to wind
– Stress due to ext. press.		– Stress due to ext. press.
– Stress due to weight		– Stress due to weight

The positive signs denote tension and the negative signs denote compression. The summation of the stresses indicate whether tension or compression is governing. It is assumed that wind and earthquake loads do not occur simultaneously, thus the tower should be designed for either wind or earthquake load whichever is greater.

Bending stress caused by eccentricity shall be summarized with the stresses resulting from wind or earthquake load.

The stresses shall be calculated at the following locations:

1. At the bottom of the tower
2. At the joint of the skirt to the head
3. At the bottom head to the shell joint
4. At changes of diameter or thickness of the vessel

The stresses furthermore shall be examined in the following conditions:

1. During erection or dismantling
2. During test
3. During operation

Under these different conditions, the weight of the vessel and consequently, the stress conditions are also different. Besides, during erection or dismantling the vessel is not under internal or external pressure.

For analyzing the strength of tall towers under various loadings by this Handbook, the maximum stress theory has been applied.



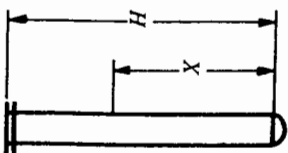
## COMBINATION OF STRESSES (cont.)

The bending moment due to wind is decreasing from the bottom to the top of the tower, thus the plate thickness can also be decreased accordingly.  
Table A and Figure B are convenient aids to find the distance down from the top of the tower for which a certain thickness is adequate.

$t_w/t_p$	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7
$m$	1.0	0.91	0.84	0.79	0.74	0.71	0.67	0.64	0.62	0.60	0.58	0.56	0.54
$t_p/t_w$	1.8	1.9	2.0	2.2	2.4	2.6	2.8	3.0	3.3	3.6	4.0	4.5	5.0
$m$	0.53	0.51	0.50	0.48	0.46	0.44	0.42	0.41	0.39	0.37	0.35	0.33	0.32

TABLE A. VALUES OF FACTOR  $m$ 

Since the longitudinal stress due to internal pressure is one half of the circumferential stress, one half of the required wall thickness for internal pressure is available to resist the bending force of the wind. From Table A, using factor  $m$  can be found the distance  $X$  down from the top tangent line within which the thickness calculated for internal pressure satisfactory also to resist the wind pressure.



EXAMPLE:

$X = H \times m$   
 $t_p$  = The required thickness for internal pressure (Hoop Tension) in.  
 $t_w$  = The required thickness for wind pressure at the bottom head joint to shell, in.  
 $t_p = 0.233$  in.,  $t_w = 0.644$  in.,  $t_w/t_p = 0.644/0.233 = 2.7$   
 $H = 100$  ft.  
 From Table  $m = 0.43$  and  $X = mH = 0.43 \times 100 = 43$  ft.

Figure B shows the moment diagram of a tower under wind pressure. The diagram can also be used to select the appropriate plate thickness at various heights.

EXAMPLE:

At the height of  $0.71H$  the required thickness is  $0.5$  times the thickness required at the bottom.

If the required thickness is:

for internal pressure,  $t_p = 0.250$  in.

for wind load,  $t_w = 0.625$  in.

at the bottom required  $t_p/2 + t_w = 0.750$  in.

at height  $0.71H$ :  $0.5 \times 0.750 = 0.375$  in.

thickness for internal pressure  $t_p/2 = 0.125$  in.

required thickness at  $0.71H = 0.500$  in.

Figure B shows the moment diagram of a tower under wind pressure. The diagram can also be used to select the appropriate plate thickness at various heights.

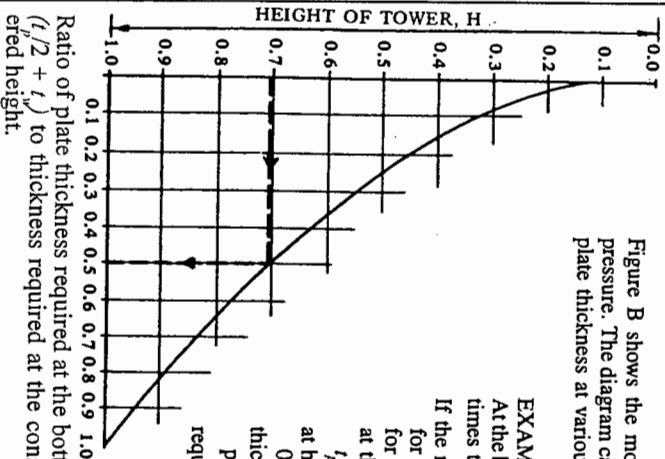
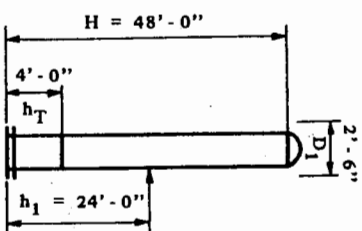


Fig. B

## DESIGN OF TALL TOWERS

## EXAMPLE - A

Required thickness of cylindrical shell under internal pressure and wind load.



## DESIGN CONDITIONS

$D = 2$  ft. 0 in. inside diameter of vessel

$D_1 = 2$  ft. 6 in. width of tower with insulation, etc.

$E = 0.85$  efficiency of welded joints

$H = 48$  ft. 0 in. length of tower

$h_1 = 4$  ft. 0 in. distance from the base to the bottom head to shell joint

$P = 250$  psi internal pressure

$P_w = 30$  psf wind pressure

$R = 12$  in. inside radius of vessel

$S = 15700$  psi stress value of SA 285 C material at 200°F temperature

$V =$  Total shear lb.

No allowance for corrosion.

Minimum required thickness for internal pressure considering the strength of the long seams:

$$t = \frac{PR}{SE - 0.6P} = \frac{250 \times 12}{15700 \times 0.85 - 0.6 \times 250} = \frac{3,000}{13,195} = 0.228 \text{ in.}$$

Minimum required thickness for internal pressure considering the strength of the girth seams:

$$t = \frac{PR}{2SE + 0.4P} = \frac{250 \times 12}{2 \times 15700 \times 0.85 + 0.4 \times 250} = \frac{3,000}{26,790} = 0.112 \text{ in.}$$

Required thickness for longitudinal bending due to wind pressure. Moment at the base ( $M$ ):

$$P_w \times D_1 \times H = V \times h_1 = M$$

$$30 \times 2.5 \times 48 = 3,600 \times 24 = 86,400 \text{ ft. lb.}$$

Moment at the bottom seam ( $M_T$ )

$$M_T = M - h_1(V - 0.5P_w D_1 h_1) = 86,400 - 4(3,600 - 0.5 \times 30 \times 2.5 \times 4)$$

$$= 86,400 - 13,800 = 72,600 \text{ ft. lb.} = 72,600 \times 12 = 871,200 \text{ in. lb.}$$

Required thickness:

$$t = \frac{M_T}{R^2 \pi SE} = \frac{871,200}{12^2 \times 3.14 \times 15,700 \times 0.85} = \frac{871,200}{6,037,135} = 0.145 \text{ in.}$$

The required thickness calculated with the strength of the bottom girth seam:

$$\text{For wind pressure} \quad 0.145 \text{ in.}$$

$$\text{For int. pressure} \quad 0.112 \text{ in.}$$

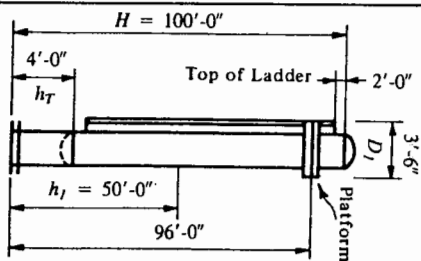
TOTAL 0.254

This is greater than the thickness calculated with the strength of the longitudinal seam therefore, this minimum thickness 0.257 in. shall be used.

For simple vessels where the moment due to wind is small, the above calculation is satisfactory. Vessels which are subject to larger loadings may need closer investigation with respect also to economical viewpoints. See pages 76-84 for skirt, base and anchor bolt design.



Required thickness of cylindrical shell under combined loadings of internal pressure, wind and weight of tower.



$D$  = 3 ft. 0 in. inside diameter  
 $D_1$  = 3 ft. 6 in. width of vessel with insulation, allowance for piping, etc.  
 $E$  = 0.85 efficiency of welded seams  
 $h_T$  = 4 ft. 0 in. distance from the base to the bottom head to shell joint.  
 $H$  = 100 ft. 0 in. length of tower  
 $P$  = 150 psi internal pressure  
 $P_w$  = 30 psf wind pressure  
 $R$  = 18 in. inside radius of vessel  
 $S$  = 15700 psi stress value of SA-285C material at 200°F temperature  
 $V$  = Total shear, lb.  
 Head: 2.1 seamless elliptical  
 $C_m$  = Circumference of shell on the mean diameter, in. (corrosion allowance not required)

Minimum required thickness for internal pressure considering the strength of the longitudinal seam of shell.

$$t = \frac{PR}{SE - 0.6P} = \frac{150 \times 18}{15700 \times 0.85 - 0.6 \times 150} = 0.204 \text{ in. Use } 0.25 \text{ in. plate}$$

Minimum required thickness for internal pressure considering the strength of the circumferential seam of shell.

$$t = \frac{PR}{2SE + 0.4P} = \frac{150 \times 18}{2 \times 15700 \times 0.85 + 0.4 \times 150} = 0.101 \text{ in.}$$

Minimum required thickness for head

$$t = \frac{PD}{2SE - 0.2P} = \frac{150 \times 36}{2 \times 15700 \times 0.85 - 0.2 \times 150} = 0.203 \text{ in.}$$

Wind Load	$P_w \times D_j \times H$	$= V$	$\times h_i$	$= M$
Vessel	$30 \times 3.5 \times 100$	$= 10,500$	$\times 50$	$= 525,040$
Platform	$30 \times 8 \text{ lin. ft.}$	$= 240$	$\times 96$	$= 23,040$
Ladder	$30 \times 98 \text{ lin. ft.}$	$= 2,940$	$\times 49$	$= 144,060$

Total shear  $V = 13,680$   $M = 692,100$  ft. lb. moment at

Moment at the bottom head seam ( $M_T$ )

$$M_T = M - h_T (V - 0.5 P_w D_j h_T) = 692,100 - 4 (13680 - 0.5 \times 30 \times 3.5 \times 4) = 638,220 \text{ ft. lb.}$$

$$t = \frac{12 M_t}{R^2 \pi SE} = \frac{12 \times 638,220}{182 \times 3.14 \times 15700 \times 0.85} = \frac{7,658,640}{13,583,556} = 0.564$$

Try 0.750 in. plate for the lower courses

For int. pressure	0.101
	<u>0.101</u>

Diagram of a 100'-0" long bridge deck. The spans are 4'-0", 24'-0", 32'-0", and 40'-0" long. The piers are 0.75", 0.50", and 0.25" thick. The bridge has a single lane with a 12-foot wide roadway and a 2-foot wide sidewalk on each side.

The preliminary calculation of the required wall thickness shows that at the bottom approximately 0.75 in plate is required, to withstand the wind load and internal pressure, while at the top the wind load is not factor and for internal pressure (hoop tension) only 0.25 plate is satisfactory. For economical reasons it is advisable to use different plate thicknesses at various heights of the tower.

The thickness required for hoop tension (0.25 in.) serves to resist also the wind load to a certain distance down from the top.

**Find this distance (X) from table A, Page 70**

$$tw/tp = 0.564/0.204 = 2.7 \text{ then } X = 0.43 \times H = 43 \text{ ft.}$$

From diagram B, Page 70 can be found the required thickness and length of the intermediate shell sections. Using 8 ft. wide plates, the vessel shall be constructed from:

(5)	0.25 thick	8 ft. wide	courses	40 ft.
(4)	0.50 thick	8 ft. wide	courses	32 ft.
(3)	0.75 thick	8 ft. wide	courses	24 ft.

**Total** 96 ft.

## (See tables beginning on page 374)

Shell 40 × 97	3880	Skirt 4 × 195	780
32 × 195	6240	Base ring	720
24 × 294	7056	Anchor ring	260
Head top 0.3125 nom.	160	Anchor lugs	120
bot. 0.8125 nom.	393		
Int. plate work	800	+ 6%	1880
Tray supports	110		113
Insulation rings	220		1993
Opening	900	Say	2000 lb
	19759	Insulation	4600
+ 6%	1184	Platform	1160
	20943 lb.	Ladder	2800
Say	21.000	Piping	1400
			9960

**TOTAL ERECTION WEIGHT: 33,000 lb.**

Say 10,000 lb.

### Trays

#### Operating liquid

600  
2400

+ Erection Wt.

3000 lb.  
33,000 lb.

**TOTAL OPERATING WEIGHT: 36.000 lb.**

Test water + Erection Wt.	42,000 lb. 33,000 lb.
---------------------------	--------------------------

42,000 lb.  
33,000 lb.

**TOTAL TEST WEIGHT: 75,000 lb.**

**For weight of water content, see Page 416**



## EXAMPLE B (CONT.)

Checking the stresses with the preliminary calculated plate thicknesses:

Stress in the shell at the bottom head to shell joint:

Plate thickness 0.75 in.

Stress due to internal pressure

$$S = \frac{PD}{4t} = \frac{150 \times 36.75}{4 \times 0.75} = 1837 \text{ psi}$$

Stress due to wind

$$S = \frac{12 M_x}{R^2 \pi t} = \frac{12 \times 638,220}{18.375^2 \times 3.14 \times 0.75} = 9,632 \text{ psi}$$

Stress due to weight, in erection condition in operating condition

$$S = \frac{C_m^t}{W} = \frac{115.5 \times 0.75}{31,000} = 358 \text{ psi}$$

$$S = \frac{C_m^t}{W} = \frac{115.5 \times 0.75}{34,000} = 392 \text{ psi}$$

## COMBINATION OF STRESSES

WINDWARD SIDE	LEEWARD SIDE
IN EMPTY (ERECTION) CONDITION	
Stress due to wind + 9,640	Stress due to wind - 9,640
Stress due to weight - 358	Stress due to weight - 358
+ 9,282 psi	- 9,998 psi
(No int. pressure during erection)	
IN OPERATING CONDITION	
Stress due to int. press. + 1,837	Stress due to wind - 9,640
Stress due to wind + 9,640	Stress due to weight - 392
+ 11,477	- 10,032
- 392	Stress due to int. press. + 1,837
+ 11,085 psi	- 8,195 psi

The tensile stress 11,085 psi in operating condition on the windward side governs. The allowable stress for the plate material with 0.85 joint efficiency is 13,345 psi. Thus the selected 0.75 in. thick plate at the bottom of the vessel is satisfactory.

Stress in the shell at 72 ft. down from the top of tower. Plate thickness 0.50 in.

Stress due to wind.

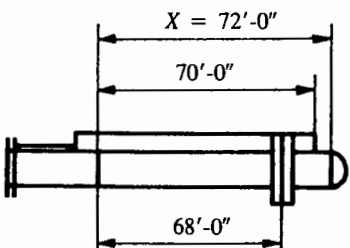
$$P_w \times D_1 \times X = V \times \frac{X}{2} = M_x$$

$$\begin{aligned} \text{Shell} & 30 \times 3.5 \times 72 = 7,560 \times 36 = 272,160 \\ \text{Platform} & 30 \times 8 \text{ lin.-ft.} = 240 \times 68 = 16,320 \\ \text{Ladder} & 30 \times 70 \text{ lin.-ft.} = 2,100 \times 35 = 73,500 \\ \text{Total Moment } M_x & = 361,980 \text{ ft.-lb.} \end{aligned}$$

$$S = \frac{12 M_x}{R^2 \pi t} = \frac{12 \times 361,980}{18.25^2 \times 3.14 \times 0.50} = 8,303 \text{ psi}$$

Stress due to internal pressure  
(As calculated previously)

$$\begin{aligned} & 1,837 \\ \text{Total} & 10,140 \text{ psi} \end{aligned}$$



The calculation of stresses at the bottom head has shown that the stresses on the windward side in operating condition govern and the effect of the weight is insignificant. Therefore without further calculation it can be seen that the tensile stress 10,140 psi does not exceed the allowable stress 13,345 psi. Thus the selected 0.50 in. thick plate is satisfactory.

## EXAMPLE B (CONT.)

Stress in the shell at 40 ft. down from the top of the tower. Plate thickness 0.25 in.

Stress due to wind.

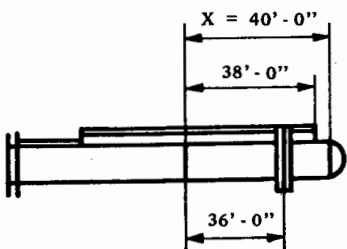
$$P_w \times D_1 \times X = V \times \frac{X}{2} = M_x$$

$$\begin{aligned} \text{Shell} & 30 \times 3.5 \times 40 = 4,200 \times 20 = 84,000 \\ \text{Platform} & 30 \times 8 \text{ lin.-ft.} = 240 \times 36 = 8,640 \\ \text{Ladder} & 30 \times 38 \text{ lin.-ft.} = 1,140 \times 19 = 21,660 \\ \text{Total Moment } M_x & = 114,300 \text{ ft.-lb.} \end{aligned}$$

$$S = \frac{12 M_x}{R^2 \pi t} = \frac{12 \times 114,300}{18.125^2 \times 3.14 \times 0.25} = 5,316 \text{ psi}$$

Stress due to internal pressure  
(As calculated previously)

$$\begin{aligned} & 1,837 \text{ psi} \\ \text{Total} & 7,153 \text{ psi} \end{aligned}$$



The 0.25 in. thick plate for shell at 40 ft. distance from top of the tower is satisfactory. No further calculation is required on the same reason mentioned above.



## DESIGN OF SKIRT SUPPORT

A skirt is the most frequently used and the most satisfactory support for vertical vessels. It is attached by continuous welding to the head and usually the required size of this welding determines the thickness of the skirt.

Figures A and B show the most common type of skirt to head attachment. In the calculation of the required weld size, the values of joint efficiency given by the Code (UW12) may be used.

### FORMULA

$$t = \frac{12 M_r}{R^2 \pi S E} + \frac{W}{D \pi S E}$$

### NOTATIONS

- $D$  = Outside diameter of skirt, in.  
 $E$  = Efficiency of skirt to head joint.  
 (0.6 for butt weld, Fig. A, 0.45 for lap weld, Fig. B)  
 $M_r$  = Moment at the skirt to head joint, ft. lb.  
 $R$  = Outside radius of skirt, in.  
 $S$  = Stress value of the head or skirt material whichever is smaller, psi.  
 $t$  = Required thickness of skirt, in.  
 $W$  = Weight of the tower above the skirt to the head joint, in operating condition.

NOTE: Using extremely high skirt, the stresses at the base may govern. To calculate the required thickness of the skirt, in this case the above formula can be used, considering the moment and weight at the base;  $E = 1$ .

### EXAMPLE

Given the same vessel considered in Example B.

- $D = 37.5$  in.  $S = 15,700$  stress value  
 $E = 0.60$  for butt joint of SA-285-C plate  
 $M_r = 638,220$  ft. lb.  $W = 31,000$  lb.  
 $R = 18.75$  in.

Determine the required skirt thickness.

For wind:  $t = \frac{12 M_r}{R^2 \pi S E} + \frac{12 \times 638,220}{18.75^2 \times 3.14 \times 15,700 \times 0.6} = 0.736$  in.

For weight:  $t = \frac{W}{D \times 3.14 \times S E} = \frac{31,000}{37.5 \times 3.14 \times 15,700 \times 0.6} = 0.028$  in.  
 TOTAL  $= 0.764$  in.  
 Use  $1\frac{3}{16}$ " thick plate for skirt.

REFERENCES: Thermal stresses are discussed in these works:  
 Brownell, Lloyd E., and Young, Edwin H., "Process Equipment Design," John Wiley and Sons, Inc., 1959. Weil, N. A., and J. J. Murphy Design and Analysis of Welded Pressure Vessel Skirt Supports, Asme. Trans. Industrial Engineering for Industry, Vol. 82, Ser. B., Feb., 1960.

## DESIGN OF ANCHOR BOLT

Vertical vessels, stacks and towers must be fastened to the concrete foundation, skirt or other structural frame by means of anchor bolts and the base (bearing) ring.

The number of anchor bolts. The anchor bolts must be in multiple of four and for tall towers it is preferred to use minimum eight bolts.

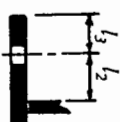
Spacing of anchor bolts. The strength of too closely spaced anchor bolts is not fully developed in concrete foundation. It is advisable to set the anchor bolts not closer than about 10 inches. To hold this minimum spacing, in the case of small diameter vessel the enlarging of the bolt circle may be necessary by using conical skirt or wider base ring with gussets.

Diameter of anchor bolts. Computing the required size of bolts the area within the root of the threads only can be taken into consideration. The root areas of bolts are shown below in Table A. For corrosion allowance one eighth of an inch should be added to the calculated diameter of anchor bolts.

For anchor bolts and base design on the following pages are described:

1. An approximate method which may be satisfactory in a number of cases.
2. A method which offers closer investigation when the loading conditions and other circumstances make it necessary.

TABLE A



Bolt Size	Bolt Root Area sq. in.	Dimension in.	
		l <sub>1</sub>	l <sub>2</sub>
1/2	0.126	7/8	5/8
5/8	0.202	1	3/4
3/4	0.302	1-1/8	13/16
7/8	0.419	1-1/4	15/16
1	0.551	1-3/8	1-1/16
1 1/8	0.693	1-1/2	1-1/8
1 1/4	0.890	1-3/4	1-1/4
1 3/8	1.054	1-7/8	1-3/8
1 1/2	1.294	2	1-1/2
1 5/8	1.515	2-1/8	1-5/8
1 3/4	1.744	2-1/4	1-3/4
1 7/8	2.049	2-3/8	1-7/8
2	2.300	2-1/2	2
2 1/4	3.020	2-3/4	2-1/4
2 1/2	3.715	3-1/16	2-3/8
2 3/4	4.618	3-3/8	2-5/8
3	5.621	3-5/8	2-7/8

TABLE B  
NUMBER OF ANCHOR BOLTS

Diameter of Bolt circle in.	Minimum	Maximum
24 to 36	4	4
42 to 54	8	8
60 to 78	12	12
84 to 102	12	16
108 to 126	16	20
132 to 144	20	24

TABLE C  
MAXIMUM ALLOWABLE STRESSES FOR BOLTS USED AS ANCHOR BOLT

Specification Number	Diameter in.	Max. allow. Stress psi.
SA 307	All diameters	15,000
SA 193 B 7	2 1/2 and under	19,000
SA 193 B 16	2 1/2 and under	17,000
SA 193 B 7	Over 2 1/2 to 4 incl.	18,000
SA 193 B 16	Over 2 1/2 to 4 incl.	15,000

\* For bolts with standard threads.



## DESIGN OF ANCHOR BOLT (Approximate Method)

A simple method for the design of anchor bolts is to assume the bolts replaced by a continuous ring whose diameter is equal to the bolt circle.

The required area of bolts shall be calculated for empty condition of tower.

### FORMULAS

Maximum Tension lb./lin. in. $T$	$T = \frac{12M}{A_b} - \frac{W}{C_b}$
Required Area of One Bolt Sq. - in. $B_A$	$B_A = \frac{TC_b}{S_b N}$
Stress in Anchor Bolt psi. $S_b$	$S_b = \frac{TC_b}{B_A N}$

### NOTATION

$A_b$  = Area within the bolt circle, sq. in.  
 $C_b$  = Circumference of bolt circle in.  
 $M$  = Moment at the base due to wind or earthquake, ft. lb.  
 $N$  = Number of anchor bolts  
 $S_b$  = Maximum allowable stress value of bolt material psi.  
 $W$  = Weight of the vessel during erection, lb.

### EXAMPLE

Given bolt circle = 30 in.; then: Determine the size and number of required anchor bolts.

$$A_b = 707 \text{ sq. in.}$$

$$C_b = 94 \text{ in.}$$

$$M = 86,400 \text{ ft. lb.}$$

$$W = 6000 \text{ lb. during erection.}$$

$$S_b = 15,000 \text{ psi. the maximum allowable stress value of the anchor bolt material.}$$

$$N = 4 \text{ number of bolts. (See Table B on the Preceding Page)}$$

$$T = \frac{12 \times 86,400}{94} - \frac{6,000}{94} = 1,402 \text{ lb./lin. in.}$$

$$B_A = \frac{1,402 \times 94}{15,000 \times 4} = 2.196 \text{ sq. in.}$$

From Table A, Page 77 the root area of 2" bolt is 2.300 sq. in.  
 Adding 0.125 in. for corrosion, use:  
 (4) 2 1/4" bolts.

Checking stress in anchor bolt:

$$S_b = \frac{1,402 \times 94}{2.300 \times 4} = 14,324 \text{ psi}$$

Since the maximum allowable stress is 15,000 psi, the selected number and size of bolts are satisfactory.

## DESIGN OF BASE RING (Approximate Method)

The formulas below are based on the following considerations:

1. The bearing surface of the base ring shall be large enough to distribute the load uniformly on the concrete foundation and thus not to exceed the allowable bearing load of the foundation.
2. The thickness of the base ring shall resist the bending stress induced by wind or earthquake.

### FORMULAS

Maximum Compression lb./lin. in. $P_c$	$P_c = \frac{12M}{A_s} + \frac{W}{C_s}$
Approximate Width of Base Ring, in. $l$	$l = \frac{P_c}{f_b}$
Approximate Thickness of Base Ring, in. $t_b$	$t_b = 0.32 l_1$
Bearing Stress, psi $S_1$	$S_1 = \frac{P_c C_s}{A_R}$
Bending Stress, psi $S_2$	$S_2 = \frac{3 \times S_1 l_1^2}{t_b^2}$

### NOTATION

$A_R$  = Area of base ring =  $0.7854 (D_o^2 - D_i^2)$  sq. in.  
 $A_s$  = Area within the skirt, sq. in.  
 $C_s$  = Circumference on O.D. of skirt, in.  
 $f_b$  = Safe bearing load on concrete, psi. See Table E, on Page 80  
 $l_1$  = Cantilever inside or outside, whichever is greater, in.  
 $l_1, l_2$  = Dimensions, as shown on sketch above. (For minimum dimensions see Table A on page 77)  
 $M$  = Moment at the base due to wind or earthquake, ft. lb.  
 $W$  = Weight of vessel during operation or test, lb.

### EXAMPLE

Determine the minimum width and thickness of base ring for operating condition.

Given:  
 $M = 86,400 \text{ ft. lb.}$   
 $f_b = 500 \text{ psi from Table E, Page 80}$   
 Anchor bolts: (4) 2 1/4 in. O.D. of skirt: 24.625 in.  
 Then  $A_s = 476 \text{ sq. in.}$   
 $C_s = 77 \text{ in.}$

$$P_c = \frac{12 \times 86,400}{476} + \frac{7,500}{77} = 2,275 \text{ lb./lin. in.}$$

$$l = \frac{2,275}{500} = 4.55 \text{ in., but from Table A, page 77 the minimum dimension for } l_1 = 2 \frac{1}{4} \text{ in. and for } l_2 = 2 \frac{1}{4} \text{ in., use } 6 \frac{1}{2} \text{ in. wide base ring.}$$

Checking stresses:

$$S_1 = \frac{2,275 \times 77}{574} = 305 \text{ psi}$$

Bearing stress

$$S_2 = \frac{3 \times 305 \times 5^2}{1.5^2} = 10,167 \text{ psi}$$

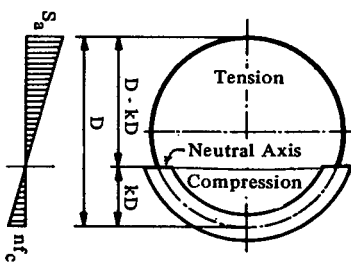
Bending Stress

Using SA 285 C plate for base ring, 15,700 psi allowable stress can be taken. Thus the width and thickness of the base ring are satisfactory.  
 The stresses should be checked also for test condition.



## DESIGN OF ANCHOR BOLT AND BASE RING

When a tower is under wind or earthquake load, on the windward side tensional stress arises in the steel and on the opposite side compressive stress in the concrete foundation. It is obvious then that the area of the bolting and the area of the base ring are related. As the anchor bolt area increased, the base ring area can be decreased. With the design method given here, the minimum required anchor bolt area for a practical size of base ring can be found. The strength of the steel and the concrete is different, therefore, the neutral axis does not coincide with the centerline of the skirt.



- Design procedure:
1. Determine the value of  $k$
  2. Calculate the required size and number of anchor bolts. See page 77 Table B
  3. Determine the inside and outside diameter of the base ring
  4. Check the stresses in the anchor bolts and foundation
  5. If the deviation between the allowable and actual stresses are too large, repeat the calculation
  6. Calculate the base ring thickness
  7. Use gusset plates, anchor chairs or compression ring if it is necessary for better stress distribution in the base ring or skirt

TABLE D  
Values of Constants  
as Functions of  $k$

$k$	$C_c$	$C_t$	$j$	$z$
0.00	0.000	3.142	0.750	0.500
.05	0.600	3.008	.766	.490
.10	0.852	2.887	.766	.480
.15	1.049	2.772	.771	.469
.20	1.218	2.661	.776	.459
.25	1.370	2.551	.779	.448
.30	1.510	2.442	.781	.438
.35	1.640	2.333	.784	.427
.40	1.765	2.224	.785	.416
.45	1.884	2.113	.785	.404
.50	2.000	2.000	.785	.393
.55	2.113	1.884	.783	.381
.60	2.224	1.765	.783	.367
.65	2.333	1.640	.783	.352
.70	2.442	1.510	.779	.336
.75	2.551	1.370	.776	.316
.80	2.661	1.218	.771	.302
.85	2.772	1.049	.766	.286
.90	2.887	0.852	.760	.270
.95	3.008	0.600	.750	.250
1.00	3.142	0.000	.750	.250

TABLE F  
Bending moment per unit length of section of a plate perpendicular to X and Y axes respectively. Use greater value,  $M_x$  or  $M_y$ .

$l_1/b$	$M_x$	$M_y$
0.000	0.000	-0.500 $f_c l_1^2$
0.333	0.0078 $f_c b^2$	-0.428 $f_c l_1^2$
0.500	0.0293 $f_c b^2$	-0.319 $f_c l_1^2$
0.667	0.0558 $f_c b^2$	-0.227 $f_c l_1^2$
1.000	0.0972 $f_c b^2$	-0.119 $f_c l_1^2$
1.500	0.123 $f_c b^2$	-0.124 $f_c b^2$
2.000	0.131 $f_c b^2$	-0.125 $f_c b^2$
3.000	0.133 $f_c b^2$	-0.125 $f_c b^2$
$\infty$	0.133 $f_c b^2$	-0.125 $f_c b^2$

TABLE E  
Properties of Concrete Four Mixtures

Ultimate 28 day Strength psi	2000	2500	3000	3750
Allowable comp. Strength $f_c$ psi	800	1000	1200	1500
Safe bearing load $f_b$ psi	500	625	750	938
Factor $n$	15	12	10	8

NOTE:  
See notation on facing page.

## DESIGN OF ANCHOR BOLT AND BASE RING

### FORMULAS

Value of constant, $k$ dimensionless	$k = \frac{1}{1 + (S_a/n f_c)}$
Total required area of anchor bolts $B_t$ sq. in.	$B_t = 2\pi \frac{12M - Wzd}{C_t S_a j d}$
Relationship between max. allowable compressive stress at the outside edge of base ring and at the bolt circle.	$f_c = f_o \frac{2kd + l}{2kd}$ $f_o = f_c \frac{2kd}{2kd + l}$
Tensile load on anchor bolts, $F_t$ lb.	$F_t = \frac{M - Wzd}{jD}$
Tensile stress in anchor bolts, $S_a$ psi.	$S_a = \frac{F_t}{l_t r C_t}$
Thickness of a ring which has an area equal to the area of anchor bolts, $l_t$ in.	$l_t = \frac{B_t}{\pi d}$
Compression load on the concrete, $F_c$ lb.	$F_c = F_t + W$
Compressive stress in the concrete at the bolt circle, $f_{cb}$ psi.	$f_{cb} = \frac{F_c}{(l_a + \pi l_t) r C_c}$
Relationship between tension in steel and compression in concrete.	$S_a = n f_c$
Base ring thickness without gusset plate, $t_b$ in.	$t_b = l_t \sqrt{3 f_c / S}$
Base ring thickness with gusset plate, $t_b$ in.	$t_b = \sqrt{\frac{6 M_{max}}{S}}$

### NOTATION

- $b$  = The distance between gusset plates, measured on arc of bolt circle in.
- $B_t$  = Total area required for anchor bolt sq. in.
- $C_c, C_t$  = Constants, see Table D on the preceding page.
- $d$  = Diameter of anchor bolt circle, in.
- $D$  = Diameter of anchor bolt circle, ft.
- $f_c$  = Compressive stress in the concrete at the outer edge of the base ring, psi.
- $f_{cb}$  = Compressive stress in the concrete at the bolt circle, psi.
- $j$  = Constant, see Table D on the preceding page.
- $l_t$  =  $l - l_s$  in. = width of the base ring, in.
- $M$  = Moment at the base due to wind or earthquake ft. lb.
- $M_{max}$  =  $M_x$  or  $M_y$ , whichever is greater. See Table F on the preceding page.
- $n$  = Ratio of modulus of elasticity of steel and concrete  $E_s/E_c$ . See Table E.
- $r$  = Radius of bolt circle, in.
- $S_a$  = Allowable tensile stress on anchor bolts, psi.
- $S$  = Maximum allowable stress value of base plate, psi.
- $W$  = Weight of the tower at the base, lb.
- $z$  = Constant. See Table D on the preceding page.



## DESIGN OF ANCHOR BOLT AND BASE RING

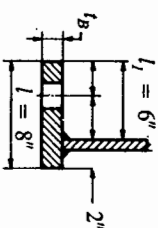
### EXAMPLE

#### DESIGN DATA:

- $D = 5$  ft., 0 in. diameter of anchor bolt circle.
- $d = 60$  in. diameter of anchor bolt circle.
- $n = 10$ , ratio of modulus of elasticity of steel and concrete (Table E, Page 80)
- $f_c = 1,200$  psi allowable compr. strength of concrete (Table E, Page 80)
- $S = 15,000$  psi allowable stress value of base ring.
- $S_a = 18,000$  psi allowable tensile stress in bolts.
- $W = 36,000$  lb. weight of the tower.
- $M = 692,100$  ft.-lb. moment at the base.

#### DETERMINE:

- The size and number of anchor bolts;
- The width and thickness of base ring.



#### SOLUTION:

Assume 8 in. wide base ring and a compressive stress at the bolt circle,  $f_{cb} = 1,000$  psi.

Then the constants from

Table D are:

$$k = \frac{1}{1 + \frac{S_a}{n f_{cb}}} = \frac{1}{1 + \frac{18,000}{10 \times 1,000}} = 0.35$$

$$C_c = 1.640$$

$$C_t = 2.333$$

$$j = 0.783$$

$$z = 0.427$$

$$f_{cb} = f_c \frac{2kd}{2kd + l} = 1,200 \frac{2 \times 0.35 \times 60}{2 \times 0.35 \times 60 + 8} = 1,008 \text{ psi}$$

This is in sufficient agreement with the assumed value of  $f_{cb} = 1,000$  psi

Required area of anchor bolts

$$B_t = 2 \pi \frac{12M - Wzd}{C_t S_a j d} = 6.28 \frac{12 \times 692,100 - 36,000 \times 0.427 \times 60}{2.333 \times 18,000 \times 0.783 \times 60} = 23.50 \text{ sq. in.}$$

Using 12 anchor bolts, the required root area for one bolt  $23.50/12 = 1.958$  in.

From Table A  $1\frac{1}{8}$  in. diameter bolt would be satisfactory but adding  $\frac{1}{8}$  in. for corrosion, use (12) -2 in. diameter anchor bolts.

Tensile load on the anchor bolts

$$F_t = \frac{M - Wz D}{j D} = \frac{692,100 - 36,000 \times 0.427 \times 5}{0.783 \times 5} = 157,150 \text{ lb.}$$

Tensile stress in the anchor bolts

$$S_a = \frac{F_t}{A_t C_t} = \frac{157,150}{0.125 \times 30 \times 2.333} = 17,960 \text{ psi}$$

$$t_b = \frac{B_t}{\pi d} = \frac{23.50}{3.14 \times 60} = 0.125 \text{ in.}$$

Compressive load on the concrete:  $l_b = l - t_b = 8.0 - 0.125 = 7.875$  in.

$$f_{cb} = \frac{F_c}{(l_b + n t_b) r C_c} = \frac{193,150}{(7.875 + 10 \times 0.125) 30 \times 1.640} = 430 \text{ psi}$$

## DESIGN OF ANCHOR BOLT AND BASE RING

### EXAMPLE (Cont.)

Checking value of  $k$  which was calculated with assumed values of  $f_{cb} = 1,000$  psi and  $S_a = 18,000$ .

$$k = \frac{1}{1 + \frac{S_a}{n f_{cb}}} = \frac{1}{1 + \frac{18,000}{10 \times 430}} = 0.19$$

Then the constants from

Table D are:

$$C_c = 1.184$$

$$C_t = 2.683$$

$$j = 0.775$$

$$z = 0.461$$

$$F_t = \frac{M - Wz D}{j D} = \frac{692,100 - 36,000 \times 0.461 \times 5}{0.775 \times 5} = 157,192 \text{ lb.}$$

$$S_a = \frac{F_t}{A_t C_t} = \frac{157,192}{0.125 \times 30 \times 2.683} = 15,624 \text{ psi}$$

$$F_c = F_t + W = 157,192 + 36,000 = 193,192 \text{ lb.}$$

$$f_{cb} = \frac{F_c}{(l_b + n t_b) r C_c} = \frac{193,192}{(7.875 + 10 \times 0.125) 30 \times 1.184} = 596 \text{ psi}$$

Compressive stress in the anchor bolts:

$$S_a = n f_{cb} = 10 \times 596 = 5,960 \text{ psi}$$

Compressive stress in the concrete at the outer edge of the base ring:

$$f_c = f_{cb} \times \frac{2kd + l}{2kd} = 596 \times \frac{2 \times 0.19 \times 60 + 8}{2 \times 0.19 \times 60} = 805 \text{ psi}$$

Required thickness of base ring  $l_b = 6$  in.

$$t_b = l_b \sqrt{3 f_c / S} = 6 \sqrt{\frac{3 \times 805}{15,000}} = 2.406 \text{ in.}$$

To decrease the thickness of the base ring, use gusset plates. Using (24) gusset plates, the distance between the gussets:

$$b = \frac{\pi d}{24} = 7.85''; \frac{l_b}{b} = \frac{6}{7.85} = 0.764$$

from Table F:

$$M_{mag} = M_b = 0.196 f_c l_b^2 = 0.196 \times 805 \times 6^2 = 5680 \text{ in.-lb.}$$

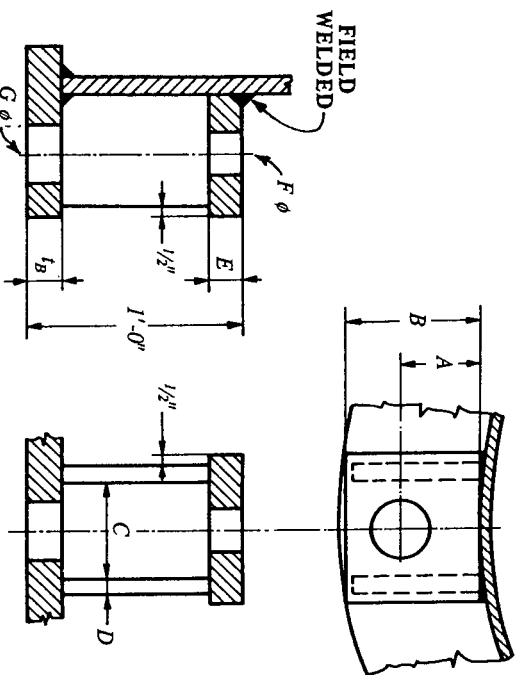
$$t_b = \sqrt{\frac{6 \times 680}{15,000}} = 1.5076 \text{ in. Use } 1\frac{1}{2} \text{ in., thick base plate.}$$



## ANCHOR BOLT CHAIR FOR TALL TOWERS

The chairs are designed for the maximum load which the bolt can transmit to them. The anchor bolt size and base plate shall be calculated as described on the foregoing pages.

All contacting edges of the plates shall be welded with continuous fillet weld. The leg size of the fillet weld shall be one half of the thinner joining plate thickness.



DIMENSIONS inches

Anchor bolt diam.	A	B	C	D	E	F	G
1	1 3/4	3	2 1/2	1/2	3/4	1 1/4	1 1/2
1 1/8	1 7/8	3	2 1/2	1/2	3/4	1 3/8	1 5/8
1 1/4	2	3	2 1/2	1/2	1	1 1/2	1 3/4
1 3/8	2 1/8	4	3	5/8	1	1 5/8	1 7/8
1 1/2	2 1/4	4	3	5/8	1 1/4	1 3/4	2
1 5/8	2 3/8	4	3	5/8	1 1/4	1 7/8	2 1/8
1 3/4	2 1/2	5	3 1/2	3/4	1 1/2	2	2 1/4
1 7/8	2 5/8	5	3 1/2	3/4	1 1/2	2 1/8	2 3/8
2	2 3/4	5	3 1/2	3/4	1 3/4	2 1/4	2 1/2
2 1/4	3	6	4	1	2	2 1/2	2 3/4
2 1/2	3 1/4	6	4	1 1/4	2 1/2	3	3 1/4
2 3/4	3 1/2	7	5	1 1/4	2 1/2	3 1/4	3 1/2
3	3 3/4	7	5	1 1/4	2 1/2	3 1/4	3 1/2

The above table is taken from Scheiman A.D. Short Cuts to Anchor Bolting and Base Ring Sizing, Petroleum Refiner, June 1963.

## NOTES



## STRESSES IN LARGE HORIZONTAL VESSELS SUPPORTED BY SADDLES

The design methods of supports for horizontal vessels are based on L. P. Zick's analysis presented in 1951. The ASME published Zick's work (Pressure Vessel and Piping Design) as recommended practice. The API Standard 2510 also refers to the analysis of Zick. The British Standard 1515 adopted this method with slight modification and further refinement. Zick's work has also been used in different studies published in books and various technical periodicals.

The design method of this Handbook is based on the revised analysis mentioned above. (Pressure Vessel and Piping; Design and Analysis, ASME, 1972)

A horizontal vessel on saddle support acts as a beam with the following deviations:

1. The loading conditions are different for a full or partially filled vessel.
2. The stresses in the vessel vary according to the angle included by the saddles.
3. The load due to the weight of the vessel is combined with other loads.

### LOADINGS:

1. Reaction of the saddles. It is a recommended practice to design the vessel for at least a full waterload.
2. Internal Pressure. Since the longitudinal stress in the vessel is only one half of the circumferential stress, about one half of the actually used plate thickness is available to resist the load of the weight.
3. External pressure. If the vessel is not designed for full vacuum because vacuum occurs incidentally only, a vacuum relief valve should be provided especially when the vessel outlet is connected to a pump.
4. Wind load. Long vessels with very small  $t/r$  values are subject to distortion from wind pressure. According to Zick "experience indicates that a vessel designed to 1 psi. external pressure can successfully resist external loads encountered in normal service."
5. Impact Loads. Experience shows, that during shipping, hardly calculable impact loads can damage the vessels. When designing the width of the saddles and the weld sizes, this circumstance is to be considered.

### LOCATION OF SADDLES.

The use of only two saddles is preferred both statically and economically over the multiple support system, this is true even if the use of stiffener rings is necessary. The location of the saddles is sometimes determined by the location of openings, sumps, etc., in the bottom of the vessel. If this is not the case, then the saddles can be placed at the statically optimal point. Thin walled vessels with a large diameter are best supported near the heads, so as to utilize the stiffening effect of the heads. Long thick walled vessels are best supported where the maximal longitudinal bending stress at the saddles is nearly equal to the stress at the midspan. This point varies with the contact angle of the saddles. The distance between the head tangent line and the saddle shall in no case be more than 0.2 times the length of the vessel. (1)

#### Contact Angle $\theta$

The minimum contact angle suggested by the ASME Code is  $120^\circ$ , except for very small vessels. (Code Appendix G-6). For unstiffened cylinders under external pressure the contact angle is mandatorily limited to  $120^\circ$  by the ASME Code. (UG-29).

Vessels supported by saddles are subject to:

1. Longitudinal bending stress
2. Tangential shear stress
3. Circumferential stress



**NOTATION:**  
 All dimensions in inches  
 Q = Load on one saddle lbs,  
 R = Radius of shell  
 S = Stress pound per sq. inch  
 t<sub>s</sub> = Wall thickness of shell  
 t<sub>h</sub> = Wall thickness of head  
 (Excluding corrosion allow.)  
 K = Constant, see page 90  
 θ = Contact angle of saddle degree

CIRCUMFERENTIAL		TANGENTIAL SHEAR		LONGITUDINAL BENDING		Stress
Stiffened or Unstiffened	L < 8R L ≥ 8R	SADDLES CLOSE TO HEAD A ≤ R/2		Saddles Away From Head A > R/2 See Note		Conditions
AT BOTTOM OF SHELL	UNSTIFFENED	ADDITIONAL STRESS IN HEAD	IN HEAD	IN SHELL	IN SHELL	Max. Stress Occurs
AT HORN OF SADDLE	$S_4 = \frac{Q}{4t_s(b+1.56\sqrt{Rt_s})} - \frac{3K_6 Q}{2t_s^2}$ $S_5 = \frac{Q}{4t_s(b+1.56\sqrt{Rt_s})} - \frac{12K_6 QR}{Lt_s^2}$	$S_3 = \frac{K_5 Q}{Rt_h}$	$S_2 = \frac{K_4 Q}{Rt_h}$	$S_2 = \frac{K_3 Q}{Rt_s} \left( \frac{L-2A}{L+4/3 H} \right)$	$S_2 = \frac{K_2 Q}{Rt_s} \left( \frac{L-2A}{L+4/3 H} \right)$	FORMULAS
AT THE SADDLES (Tension at the Top, Compression at the Bottom)	$S_1 = \pm \frac{QA \left( 1 - \frac{1}{L} + \frac{R^2 - H^2}{2AL} \right)}{1 + \frac{4H}{3L}}$ <p>*See note on facing page</p>	$S_1 = \pm \frac{QA \left( 1 - \frac{1}{L} + \frac{R^2 - H^2}{2AL} \right)}{1 + \frac{4H}{3L}}$ <p>*K R<sup>2</sup> t<sub>s</sub></p>	$S_1 = \pm \frac{QL}{4} \left( \frac{1 + 2 \frac{R^2 - H^2}{L^2}}{1 + \frac{4H}{3L}} - \frac{4A}{L} \right)$ <p>π R<sup>2</sup> t<sub>s</sub></p>	$S_1 = \pm \frac{QL}{4} \left( \frac{1 + 2 \frac{R^2 - H^2}{L^2}}{1 + \frac{4H}{3L}} - \frac{4A}{L} \right)$	$S_1 = \pm \frac{QL}{4} \left( \frac{1 + 2 \frac{R^2 - H^2}{L^2}}{1 + \frac{4H}{3L}} - \frac{4A}{L} \right)$	Max. Allow. Stress
<p>S<sub>4</sub> shall not exceed 1.50 times the allowable tensile stress value of shell material.</p> <p>S<sub>5</sub> shall not exceed 0.5 times the compression yield point of shell material.</p>		<p>NOTE: Use formula with factor K<sub>2</sub> if ring not used, or rings are adjacent to the saddle. Use formula with factor K<sub>3</sub> if ring used in plane of saddle.</p>		<p>S<sub>2</sub> shall not exceed 0.8 times the allowable stress value of vessel material.</p> <p>S<sub>3</sub> plus stress due to internal pressure shall not exceed 1.25 times the allowable tensile stress value of head material.</p>		<p>In tension S<sub>1</sub> plus the stress due to internal pressure (PR/2t<sub>s</sub>) shall not exceed the allowable stress value of shell material times the efficiency of girth seam.</p> <p>In compression the stress due to internal pressure minus S<sub>1</sub> shall not exceed one half of the compression yield point of the material or the value given by:</p> $S_1 \leq \left( \frac{E}{29} \right) (t/R) [2 - (2/3) (100) (t/R)]$

## STRESS

NOTES:

Positive values denote tensile stresses and negative values denote compression.

E = Modulus of elasticity of shell or stiffener ring material, pound per square inch.

## LONGITUDINAL BENDING

The maximum bending stress  $S_1$  may be either tension or compression.

Computing the tension stress in the formula for  $S_1$ , for factor  $K$  the values of  $K_1$  shall be used.

Computing the compression stress in the formula for  $S_1$ , for factor  $K$  the values of  $K_2$  shall be used.

When the shell is stiffened, the value of factor  $K = 3.14$  in the formula for  $S_1$ .

The compression stress is not factor in a steel vessel where  $t/R \geq 0.005$  and the vessel is designed to be fully stressed under internal pressure.

Use stiffener ring if stress  $S_1$  exceeds the maximum allowable stress.

## TANGENTIAL SHEAR

If wear plate is used, in formulas for  $S_2$  for the thickness  $t_s$  may be taken the sum of the shell and wear plate thickness, provided the wear plate extends  $R/10$  inches above the horn of the saddle near the head and extends between the saddle and an adjacent stiffener ring.

In unstiffened shell the maximum shear occurs at the horn of the saddle. When the head stiffness is utilized by locating the saddle close to the heads, the tangential shear stress can cause an additional stress ( $S_3$ ) in the heads. This stress shall be added to the stress in the heads due to internal pressure.

When stiffener rings are used, the maximum shear occurs at the equator.

**CIRCUMFERENTIAL**

If wear plate is used, in formulas for  $S_4$  for the thickness  $t_s$  may be taken the sum of the shell and wear plate thickness and for  $t_s^2$  may be taken the shell thickness squared plus the wear plate thickness squared, provided the wear plate extends  $R/10$  inches above the horn of the saddle, and  $A \leq R/2$ . The combined circumferential stress at the top edge of the wear plate should also be checked. When checking at this point:  $t_s$  = shell thickness,  $b$  = width of saddle,  $\theta$  = central angle of the wear plate but not more than the included angle of the saddle plus  $12^\circ$ . If wear plate is used, in formulas for  $S_5$  for the thickness  $t_s$  may be taken the sum of the shell and wear plate thickness, provided the width of the wear plate equals at least  $b + 1.56\sqrt{Rt_s}$ . If the shell is not stiffened, the maximum stress occurs at the horn of the saddle. This stress is not to be added to the internal pressure-stress. In a stiffened shell the maximum ring-compression is at the bottom of shell. Use stiffener ring if the circumferential bending stress exceeds the maximum allowable stress.



# STRESSES IN LARGE HORIZONTAL VESSELS SUPPORTED BY TWO SADDLES

## VALUES OF CONSTANT K (Interpolate for Intermediate Values)

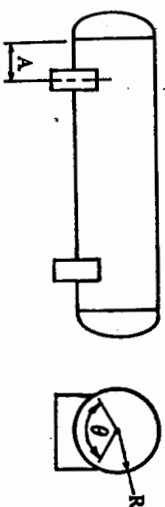
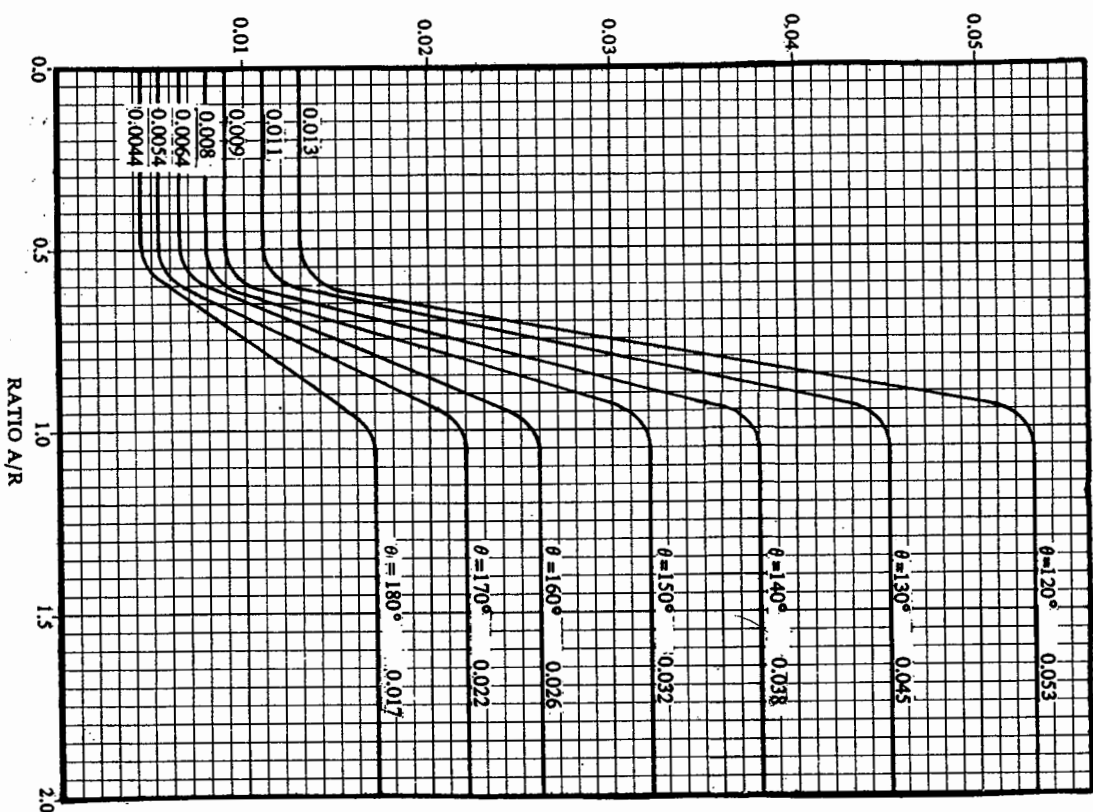
\* $K_1 = 3.14$  if the shell is stiffened by ring or head ( $A < R/2$ )

CONTACT ANGLE $\theta$	$K_1^*$	$K_2$	$K_3$	$K_4$	$K_5$	$K_6$	$K_7$	$K_8$
120	0.335	1.171		0.880	0.401		0.760	0.603
122	0.345	1.139		0.846	0.393		0.753	0.618
124	0.355	1.108		0.813	0.385		0.746	0.634
126	0.366	1.078		0.781	0.377		0.739	0.651
128	0.376	1.050		0.751	0.369		0.732	0.669
130	0.387	1.022		0.722	0.362		0.726	0.689
132	0.398	0.996		0.694	0.355		0.720	0.705
134	0.409	0.971		0.667	0.347		0.714	0.722
136	0.420	0.946		0.641	0.340		0.708	0.740
138	0.432	0.923		0.616	0.334		0.702	0.759
140	0.443	0.900	0.319	0.592	0.327		0.697	0.780
142	0.455	0.879	For	0.569	0.320	See	0.692	0.796
144	0.467	0.858	Any	0.547	0.314	chart	0.687	0.813
146	0.480	0.837	Con-	0.526	0.308	on	0.682	0.831
148	0.492	0.818	Tact	0.505	0.301	facing	0.678	0.853
150	0.505	0.799	Angles	0.485	0.295	page	0.673	0.876
152	0.518	0.781		0.466	0.289		0.669	0.894
154	0.531	0.763		0.448	0.283		0.665	0.913
156	0.544	0.746		0.430	0.278		0.661	0.933
158	0.557	0.729		0.413	0.272		0.657	0.954
160	0.571	0.713		0.396	0.266		0.654	0.976
162	0.585	0.698		0.380	0.261		0.650	0.994
164	0.599	0.683		0.363	0.256		0.647	1.013
166	0.613	0.668		0.350	0.250		0.643	1.033
168	0.627	0.654		0.336	0.245		0.640	1.054
170	0.642	0.640		0.322	0.240		0.637	1.079
172	0.657	0.627		0.309	0.235		0.635	1.097
174	0.672	0.614		0.296	0.230		0.632	1.116
176	0.687	0.601		0.283	0.225		0.629	1.137
178	0.702	0.589		0.271	0.220		0.627	1.158
180	0.718	0.577		0.260	0.216		0.624	1.183

# STRESSES IN LARGE HORIZONTAL VESSELS SUPPORTED BY TWO SADDLES

## VALUES OF CONSTANT $K_6$

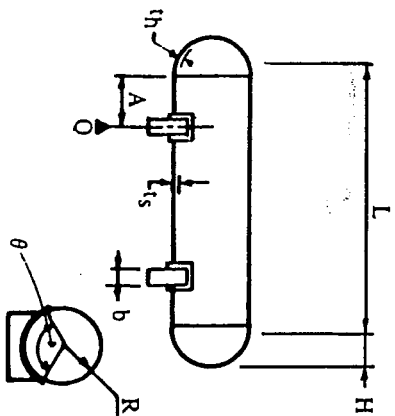
### VALUES OF CONSTANT $K_6$





## STRESSES IN LARGE HORIZONTAL VESSELS SUPPORTED BY TWO SADDLES

### EXAMPLE CALCULATIONS



**Design Data**

- A = 48 in. distance from tangent line of head to the center of saddle
- b = 24 in. width of saddle
- H = 21 in. depth of dish of head
- L = 960 in. length of vessel tan.-tan.
- P = 250 psi. internal design pressure
- Q = 300,000 lb. load on one saddle
- R = 60 in. outside radius of shell
- $t_s$  = 1.00 in. thickness of shell
- $\theta$  = 120 deg. contact angle
- Shell material: SA 515-70 plate
- Allowable stress value 17,500 psi.
- Yield point 38,000 psi.
- Joint Efficiency: 0.85

### LONGITUDINAL BENDING STRESS ( $S_1$ )

Stress at the saddles

$$S_1 = \frac{Q \left( 1 - \frac{1 - \frac{A}{L} + \frac{R^2 - H^2}{2AL}}{1 + \frac{4H}{3L}} \right)}{K_1 R^3 t_s} = \frac{300,000 \times 48 \left( 1 - \frac{1 - \frac{48}{960} + \frac{60^2 - 21^2}{2 \times 48 \times 960}}{1 + \frac{4 \times 21}{3 \times 960}} \right)}{0.335 \times 60^3 \times 1} = 522 \text{ psi.}$$

Stress at midspan

$$S_1 = \frac{\frac{QL}{4} \left( 1 + 2 \frac{R^2 - H^2}{L^2} - \frac{4A}{L} \right)}{\pi R^3 t_s} = \frac{300,000 \times 960}{4} \frac{\left( 1 + 2 \frac{60^2 - 21^2}{960^2} - \frac{4 \times 48}{960} \right)}{3.14 \times 60^3 \times 1} = 4959 \text{ psi}$$

Stress due to internal pressure:  $\frac{PR}{2t_s} = \frac{250 \times 60}{2 \times 1} = 7500 \text{ psi}$

The sum of tensional stresses:  $4959 + 7500 = 12,459 \text{ psi}$

It does not exceed the stress value of the girth seam:  $20,000 \times 0.85 = 17,000 \text{ psi}$

Compression stress is not a factor since  $t/R > 0.005$ ;  $1/60 = 0.017$

## STRESSES IN LARGE HORIZONTAL VESSELS SUPPORTED BY TWO SADDLES

### EXAMPLE CALCULATIONS (cont.)

### TANGENTIAL SHEAR STRESS ( $S_2$ )

Since  $A (48) > R/2 (60/2)$ , the applicable formula:

$$S_2 = \frac{K_2 Q \left( \frac{L - 2A}{L + 4/3 H} \right)}{R t_s} = \frac{1.171 \times 300,000}{60 \times 1} \left( \frac{960 - 2 \times 48}{960 + 4/3 \times 21} \right) = 5,120 \text{ psi}$$

$S_2$  does not exceed the stress value of shell material multiplied by 0.8;  $20,000 \times 0.8 = 16,000 \text{ psi}$

### CIRCUMFERENTIAL STRESS

Stress at the horn of saddle ( $S_4$ )

Since  $L (960) > 8R(480)$ ,  $A(48) > R/2 (60/2)$ , the applicable formula:

$$S_4 = -\frac{Q}{4t_s(b+1.56\sqrt{Rt_s})} - \frac{3K_4 Q}{2t_s^2}$$

$A/R = 48/60 = 0.8$ ;  $K = 0.036$  (from chart)

$$S_4 = -\frac{300,000}{4 \times 1 (24 + 1.56 \sqrt{60 \times 1})} - \frac{3 \times 0.036 \times 300,000}{2 \times 1} = -20,000 \text{ psi}$$

$S_4$  does not exceed the stress value of shell material multiplied by 1.5;  $20,000 \times 1.5 = 30,000 \text{ psi}$

Stress at bottom of shell ( $S_5$ )

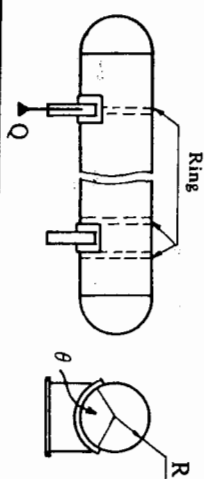
$$S_5 = -\frac{K_7 Q}{t_s(b+1.56\sqrt{Rt_s})}$$

$$S_5 = -\frac{0.760 \times 300,000}{1(24 + 1.56 \sqrt{60 \times 1})} = -6,319 \text{ psi}$$

$S_5$  does not exceed the compression yield point multiplied by 0.5;  $38,000 \times 0.5 = 19,000 \text{ psi}$



### STIFFENER RING FOR LARGE HORIZONTAL VESSELS SUPPORTED BY SADDLES



**NOTATION.**  
 $A$  = Cross sectional area of ring plus the effective area of shell, in<sup>2</sup>  
 $I$  = Moment of inertia, in<sup>4</sup>  
 $K$  = Constant, see next page  
 $Q$  = Load on one saddle, lbs.  
 $R$  = Radius of shell, in.  
 $S_6$  = Max. combined stress, psi.  
 $\theta$  = Contact angle, degree

TYPE OF RING	MAX. STRESS	FORMULAS	Max. Allow Stress
<b>A</b> 	Ring Inside. Compression at the Shell Governs	$S_6 = -\frac{K_9 Q}{A} - \frac{K_{10} QR}{I/c}$	
<b>B</b> 	Ring Outside. Stress at the Shell Ring Inside. Stress at the Tip of the Ring	$S_6 = -\frac{K_9 Q}{A} + \frac{K_{10} QR}{I/c}$	
<b>C</b> 	Ring Inside. Compression at the Shell Governs Ring Outside. Stress at the Shell	$S_6 = -\frac{K_9 Q}{A} - \frac{K_{10} QR}{I/c}$	
<b>D</b> 	Ring Inside. Stress at the Shell Ring Inside. Stress at the Tip of the Ring	$S_6 = -\frac{K_9 Q}{A} + \frac{K_{10} QR}{I/c}$	
<b>E</b> 	Ring Outside. Compression at the Shell Governs	$S_6 = -\frac{K_9 Q}{A} - \frac{K_{10} QR}{I/c}$	
<b>F</b> 	Ring Inside. Stress at the Shell Ring Inside. Stress at the Tip of the Ring	$S_6 = -\frac{K_9 Q}{A} + \frac{K_{10} QR}{I/c}$	

In tension the allowable stress value of shell or ring material whichever is smaller.  
 In compression 0.5 times the yield point of shell or ring material whichever is smaller.

### STIFFENER RING FOR LARGE HORIZONTAL VESSELS SUPPORTED BY SADDLES

#### VALUES OF CONSTANT, $K$ (Interpolate for Intermediate Values)

Contact Angle $\theta$	120°	130°	140°	150°	160°	170°	180°
$K_9$	.34	.33	.32	.30	.29	.27	.25
$K_{10}$	.053	.045	.037	.032	.026	.022	.017

#### NOTES:

1. In figures & formulas A-F positive signs denote tensile stresses and negative signs denote compression.
2. The first part of the formulas for  $S_6$  gives the direct stress and the second part gives the circumferential bending stress.
3. If the governing combined stress is tensional, the stress due to internal pressure,  $\frac{PR}{t}$  shall be added.

#### CALCULATION OF MOMENT OF INERTIA ( $I$ )

1. Determine the width of shell that is effective to resist the circumferential bending moment. The effective width =  $1.56\sqrt{R_s}$ ;  $0.78\sqrt{R_s}$  on both sides of stiffener ring.
2. Divide the stiffener ring into rectangles and calculate the areas ( $a$ ) of each rectangle, including the area of shell connection within the effective width. Add the areas ( $a$ ) total area =  $A$ .
3. Multiply the areas ( $a$ ) with the distances ( $Y$ ) from the shell to the center of gravity of the rectangles. Summarize the results and denote all  $AY$ .
4. Determine the neutral axis of the stiffening ring, the distance ( $C$ ) from the shell to the neutral axis  $C = \frac{AY}{A}$ .
5. Determine the distances ( $h$ ) from the neutral axis to the center of gravity of each rectangle of the stiffener.
6. Multiply the square of distances ( $h^2$ ) by the areas ( $a$ ) and summarize the results to obtain  $Ah^2$ .
7. Calculate the moment of inertia  $I_g$  of each rectangle  $I_g = \frac{b d^3}{12}$ , where  $b$  = the width and  $d$  = the depth of the rectangles.
8. The sum of  $Ah^2$  and  $\Sigma I_g$  gives the moment of inertia of the stiffener ring and the effective area of the shell.

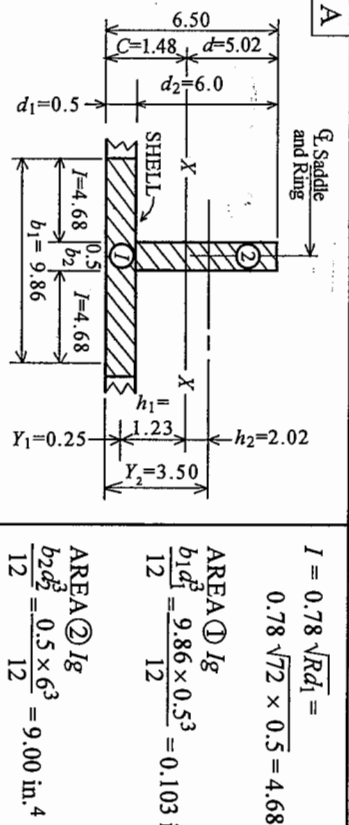
See example calculations on the following pages.



## STIFFENING RINGS

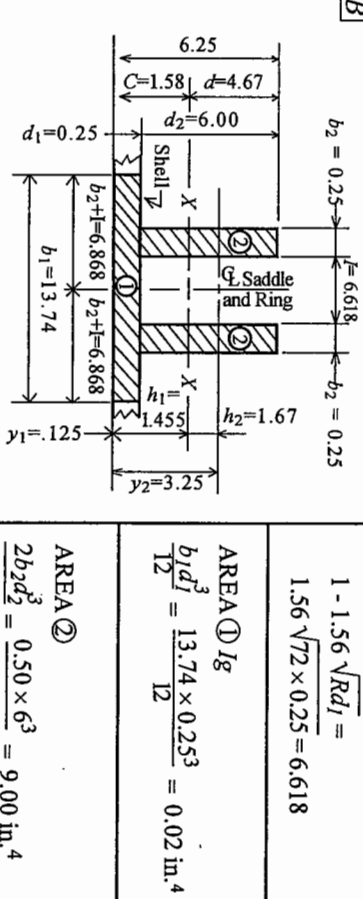
### Moment of Inertia ( $I$ ) — Example Calculations

(All dimensions in inches —  $R = 72$  in. outside radius of shell)



MARK OF AREAS	AREA $a$	$Y$	$a \times y$	$h$	$h^2$	$a \times h^2$	$\frac{b d^3}{12}$
1	4.93	0.25	1.23	1.23	1.51	7.44	0.10
2	3.00	3.50	10.50	2.02	4.08	12.24	9.00
TOTAL	$A=7.93$	—	$AY=11.73$	—	—	$AH^2=19.68$	$I_g=9.10$

$$C = \frac{AY}{A} = \frac{11.73}{7.93} = 1.48 \quad I = AH^2 + I_g = 19.68 + 9.10 = 28.78 \text{ in.}^4$$



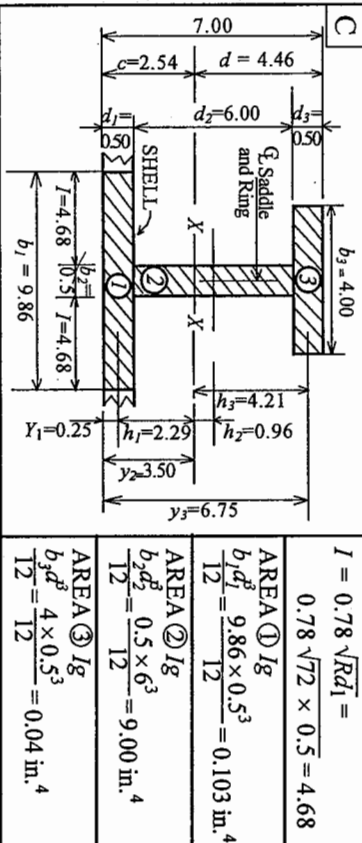
MARKS OF AREAS	AREA $a$	$y$	$a \times y$	$h$	$h^2$	$a \times h^2$	$\frac{b d^3}{12}$
①	3.43	0.125	0.43	1.455	2.12	7.27	0.02
②	3.00	3.250	9.75	1.670	2.79	8.37	9.00
TOTAL	$A=6.43$	—	$AY=10.18$	—	—	$AH^2=15.64$	$I_g=9.02$

$$C = \frac{AY}{A} = \frac{10.18}{6.43} = 1.58 \quad I = AH^2 + I_g = 15.64 + 9.02 = 24.66 \text{ in.}^4$$

## STIFFENING RINGS

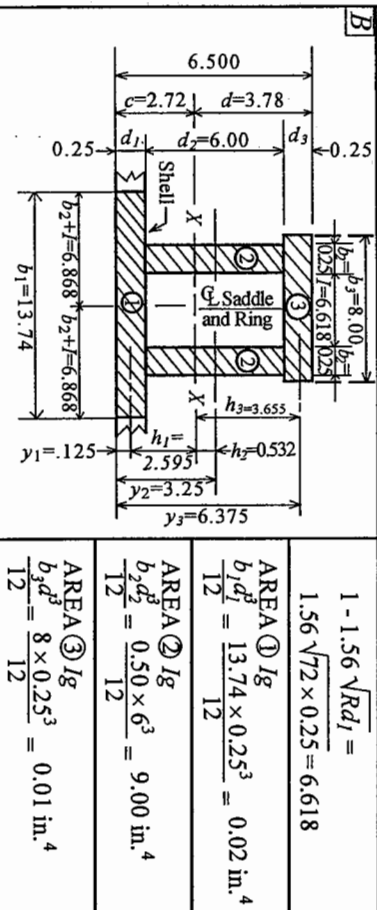
### Moment of Inertia ( $I$ ) — Example Calculations

(All dimensions in inches —  $R = 72$  in. outside radius of shell)



MARK OF AREAS	AREA $a$	$Y$	$a \times y$	$h$	$h^2$	$a \times h^2$	$\frac{b d^3}{12}$
1	4.93	0.25	1.23	2.29	5.24	25.83	0.10
2	3.00	3.50	10.50	0.96	0.92	2.76	9.00
3	2.00	6.75	13.50	4.21	17.72	35.44	0.04
TOTAL	$A=9.93$	—	$AY=25.23$	—	—	$AH^2=64.03$	$I_g=9.14$

$$C = \frac{AY}{A} = \frac{25.23}{9.93} = 2.54 \quad I = AH^2 + I_g = 64.03 + 9.14 = 73.17 \text{ in.}^4$$

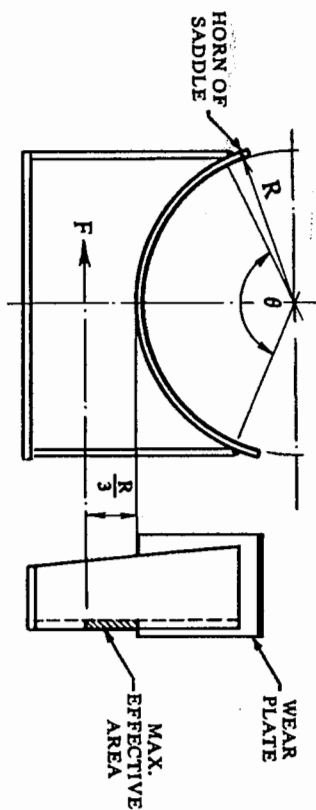


MARKS OF AREAS	AREA $a$	$y$	$a \times y$	$h$	$h^2$	$a \times h^2$	$\frac{b d^3}{12}$
1	3.43	0.125	0.43	2.59	6.72	23.09	0.02
2	3.00	3.250	9.75	0.53	0.28	0.84	9.00
3	2.00	6.375	12.75	3.66	13.40	26.80	0.01
TOTAL	$A=8.43$	—	$AY=22.93$	—	—	$AH^2=50.73$	$I_g=9.03$

$$C = \frac{AY}{A} = \frac{22.93}{8.43} = 2.72 \quad I = AH^2 + I_g = 50.73 + 9.03 = 59.76 \text{ in.}^4$$



## DESIGN OF SADDLES



- The saddle at the lowest section must resist the horizontal force ( $F$ ). The effective cross section of the saddle to resist this load is one third of the vessel radius ( $R$ ).  
 $F = K_{II} Q$  Where  $Q$  = the load on one saddle, lbs.  
 $K_{II}$  = constant as tabulated.  
 The average stress shall not exceed two thirds of the compression yield point of the material. (See example below.)

### VALUES OF CONSTANT $K_{II}$

Contact Angle	120°	130°	140°	150°	160°	170°	180°
$K_{II}$	.204	.222	.241	.259	.279	.298	.318

### EXAMPLE:

Diameter of vessel = 8' - 6"

Weight of vessel = 375,000 lbs.

$Q = 187,500$  lbs.

Saddle material: SA 285 C

Web plate thickness = 0.25 in.

Contact angle = 120°

$K_{II} = 0.204$  from table above

$R/3 = 51/3 = 17$  inches

Force,  $F = K_{II} \times Q = 0.204 \times 187,500 = 38,250$  lb.

To resist this force the effective area of web plate =  $R/3 \times 0.25 = 4.25$  in.<sup>2</sup>  
 $38,250/4.25 = 9,000$  lbs. per square inch.

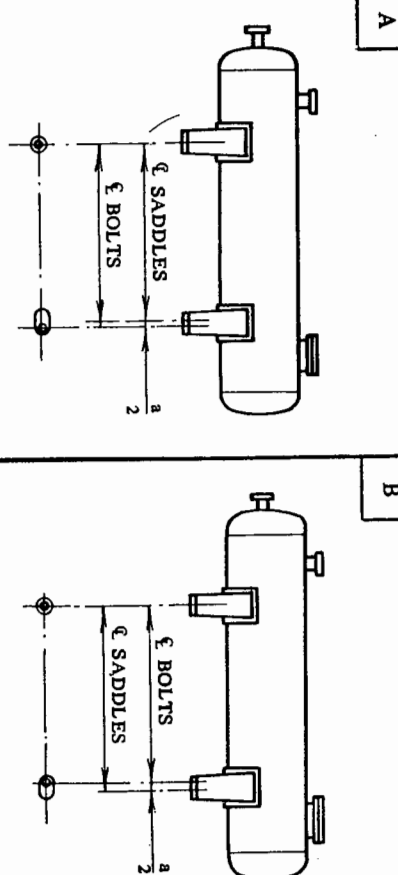
The allowable stress =  $\frac{2}{3} \times 30,000 = 20,000$  psi.

The thickness of the web plate is satisfactory for horizontal force ( $F$ ).

2. The base plate and wear plate should be thick enough to resist longitudinal bending over the web.

3. The web plate should be stiffened with ribs against the buckling.

## EXPANSION AND CONTRACTION OF HORIZONTAL VESSELS



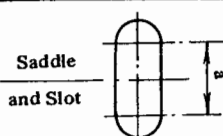
### EXPANDING VESSEL

### CONTRACTING VESSEL

For thermal expansion and contraction, one of the saddles, preferably the one on the opposite side of the pipe connections, must be allowed to move. In this saddle for the anchor bolts slots are to be used instead of holes. The length of the slots shall be determined by the expected magnitude of the movement. The coefficient of linear expansion for carbon steel per unit length and per degree  $F = 0.000067$ . The table below shows the minimum length of the slot. Dimension " $a$ " calculated for the linear expansion of carbon steel material between 70°F and the indicated temperature. When the change in the distance between the saddles is more than  $3/8$ " inch long, a slide (bearing) plate should be used. When the vessel is supported by concrete saddles, an elastic, waterproof sheet at least  $1/4$ " thick is to be applied between the shell and the saddle.

### MINIMUM LENGTH OF SLOT (DIM. " $a$ ")

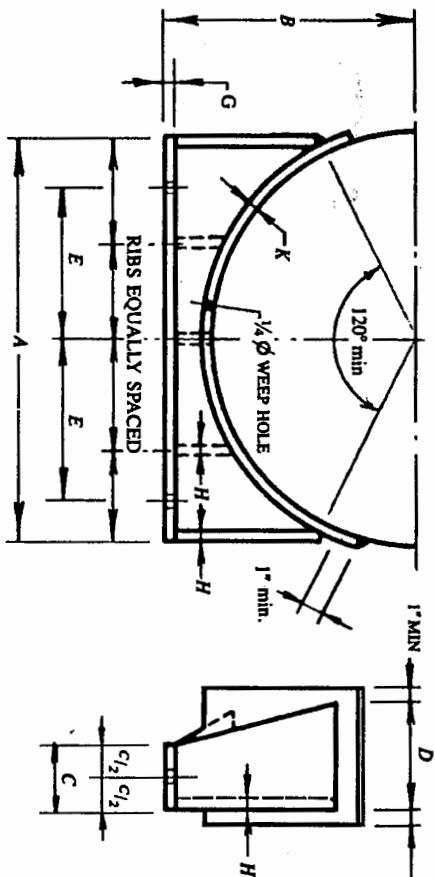
DISTANCE BETWEEN SADDLES Ft.	FOR TEMPERATURE OF									
	-50	100	200	300	400	500	600	700	800	900
10	0	0	0	1/4	3/8	3/8	1/2	5/8	3/4	3/4
20	0	0	1/4	3/8	5/8	3/4	1	1-1/8	1-1/4	1-3/8
30	1/4	1/8	3/8	5/8	7/8	1-1/8	1-3/8	1-5/8	1-5/8	2
40	1/4	1/8	3/8	3/4	1-1/8	1-1/2	1-7/8	2-1/8	2-3/8	2-1/2
50	3/8	1/4	1/2	1	1-3/8	1-5/8	2-1/4	2-5/8	3	3-3/8
60	3/8	1/4	5/8	1-1/4	1-5/8	2-1/8	2-3/4	3-1/8	3-5/8	4-1/8
70	1/2	1/4	3/4	1-3/8	1-7/8	2-1/2	3-1/8	3-5/8	4-1/4	4-5/8
80	1/2	3/8	3/4	1-1/2	2-1/8	2-7/8	3-5/8	4-1/8	4-7/8	5-3/8
90	5/8	3/8	7/8	1-3/4	2-3/8	3-1/4	4	4-5/8	5-3/8	6
100	5/8	3/8	1	1-7/8	2-5/8	3-5/8	4-1/2	5-1/8	6	6-5/8



The width of the slot equals the diam. of anchor bolt +  $1/4$ "



## SADDLE FOR SUPPORT OF HORIZONTAL VESSELS



The design based on:

1. the vessel supported by two saddles
  2. to resist horizontal force ( $F$ ) due to the maximum operating weight of vessel as tabulated.
  3. the maximum allowable stress is  $\frac{2}{3}$  of the compression yield point:  $\frac{2}{3}$  of 30,000 = 20,000 psi.
  4. the maximum allowable load on concrete foundation 500 psi.
  5. the minimum contact angle of shell and saddle 120°.
- Weld:  $\frac{1}{4}$ " continuous fillet weld all contacting plate edges.
- Drill and tap  $\frac{1}{4}$ " weep holes in wear plate.

At the sliding saddle the nuts of the anchor bolts shall be hand-tight and secured by tack welding.

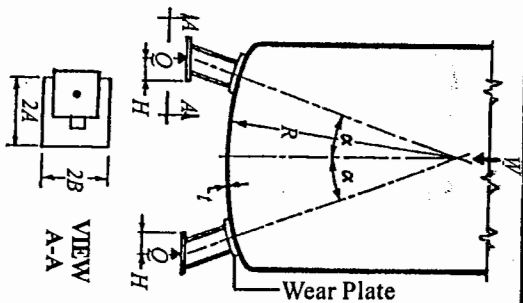
SEE FACING PAGE FOR DIMENSIONS

## SADDLE

NOMINAL DIAM. OF VESSEL FT.-IN.	DIMENSIONS					NO. OF RIBS	PLATE THICKNESS INCHES			MAXIMUM WEIGHT ON VESSEL	
	A FT.-IN.	B FT.-IN.	C IN.	D IN.	E FT.-IN.		BOLT DIAM. INCH	BASE G	WEAR FLANGE, RIBS H		WEAR K
1-0	0-10½	1-0	4	4	0-3½	½	0	¼	¼	—	42000
1-2	1-½	1-1	4	4	0-4	½	0	¼	¼	—	50000
1-4	1-2	1-2	4	4	0-5	½	0	¼	¼	—	56000
1-6	1-3½	1-3	4	4	0-6	½	0	¼	¼	—	62000
1-8	1-5½	1-4	4	4	0-6½	½	0	¼	¼	—	70000
1-10	1-7	1-5	4	6	0-7	½	0	¼	¼	—	76000
2-0	1-9	1-6	4	6	0-7½	½	0	¼	¼	—	84000
2-2	1-10½	1-7	4	6	0-8	½	0	¼	¼	¼	90000
2-4	2-½	1-8	4	6	0-8½	½	0	½	¼	¼	98000
2-6	2-2	1-9	4	6	0-9	½	0	½	¼	¼	104000
2-8	2-4	1-10	4	6	0-9½	½	0	½	¼	¼	112000
2-10	2-5	1-11	6	11	0-10	½	0	½	¼	¼	128000
3-0	2-6½	2-0	6	11	0-11	½	0	½	¼	¼	134000
3-2	2-9	2-1	6	11	1-0	¾	0	½	¼	¼	144000
3-4	2-11	2-2	6	11	1-1	¾	0	½	¾	¾	210000
3-6	3-½	2-3	6	11	1-2	¾	0	½	¾	¾	220000
4-0	3-6	2-6	6	11	1-4	¾	0	¾	¾	¾	252000
4-6	3-11	3-0	6	11	1-6	¾	0	¾	¾	¾	282000
5-0	4-4	3-3	6	11	1-8	¾	1	¾	¾	¾	312000
5-6	4-9½	3-6	6	11	1-10	¾	1	¾	¾	¾	344000
6-0	5-2½	3-9	9	18	2-0	¾	1	¾	¾	¾	402000
6-6	5-8	4-0	9	18	2-2	¾	1	¾	¾	¾	436000
7-0	6-1	4-3	9	18	2-4	1	1	¾	¾	¾	470000
7-6	6-6	4-6	9	18	2-6	1	1	¾	¾	¾	502000
8-0	6-11½	4-9	9	18	2-8	1	1	1	¾	¾	536000
8-6	7-4½	5-0	9	18	2-10	1	2	1	½	½	760000
9-0	7-9½	5-3	9	18	3-0	1	2	1	½	½	806000
9-6	8-3½	5-6	9	24	3-2	1½	2	1	¾	½	852000
10-0	8-8	5-9	9	24	3-4	1½	2	1	¾	½	896000
10-6	9-1½	6-0	9	24	3-6	1½	2	1	¾	½	940000
11-0	9-6½	6-3	9	24	3-8	1½	2	1	¾	½	986000
11-6	10-0	6-6	9	24	3-10	1½	3	1	¾	½	1030000
12-0	10-5	6-9	9	24	4-0	1½	3	1	¾	½	1076000



## STRESSES IN VESSELS ON LEG SUPPORT



NOTATION:	
$W$	= Weight of vessel, pounds
$n$	= Number of legs
$Q$	= $\frac{W}{n}$ Load on one leg, pounds
$R$	= Radius of head, inch
$H$	= Lever arm of load, inch
$2A, 2B$	= Dimension of wear plate
$S$	= Stress, pound per square inch
$t$	= Wall thickness of head, inch
$K$	= Factors, see charts
$C$	= $\sqrt{AB}$ , inch
$D$	= Radius of circular wear plate, inch
	= $1.82 \frac{C}{R} \sqrt{\frac{R}{t}}$

### LONGITUDINAL STRESS:

$$S_1 = \frac{Q}{t^2} \left[ \cos \alpha (K_1 + 6K_2) + \frac{H}{R} \sqrt{\frac{R}{t}} (K_3 + 6K_4) \right]$$

### CIRCUMFERENTIAL STRESS:

$$S_2 = \frac{Q}{t^2} \left[ \cos \alpha (K_5 + 6K_6) + \frac{H}{R} \sqrt{\frac{R}{t}} (K_7 + 6K_8) \right]$$

### NOTES:

Positive values denote tensile stresses and negative values denote compression.

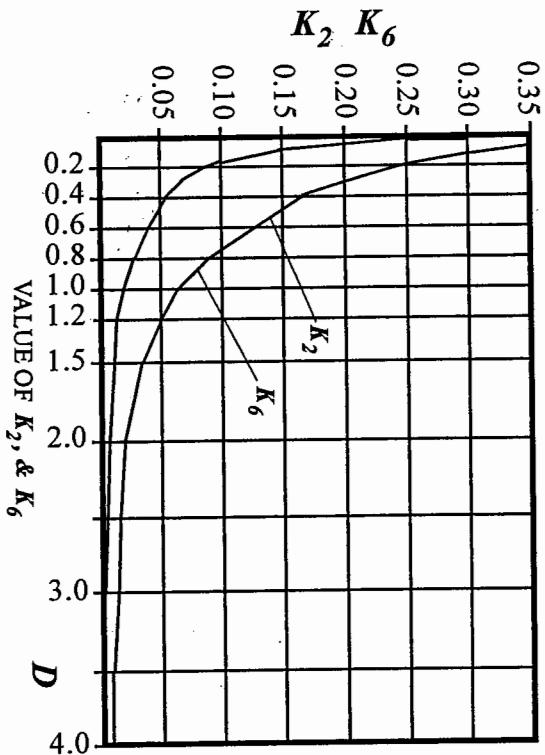
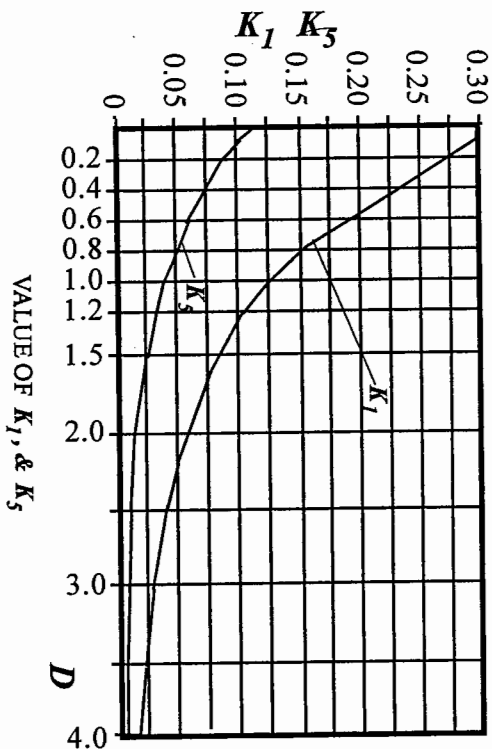
Computing the maximum tensile stresses, in formulas for  $S_1$ ,  $S_2$  and  $K_1$ ,  $K_3$ ,  $K_5$  and  $K_7$  denote negative factors and  $K_2$ ,  $K_4$ ,  $K_6$  and  $K_8$  denote positive factors.

Computing the maximum compression stresses in formulas for  $S_1$ ,  $S_2$  and  $K_1$ ,  $K_3$ ,  $K_5$ ,  $K_7$  and  $K_8$  denote negative factors.

The maximum tensile stresses  $S_1$  and  $S_2$  respectively, plus the tensile stress due to internal pressure shall not exceed the allowable tensile stress value of head material.

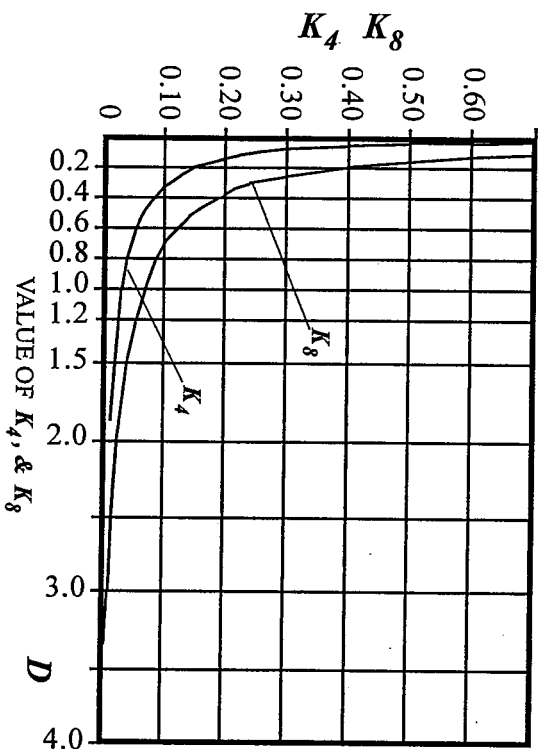
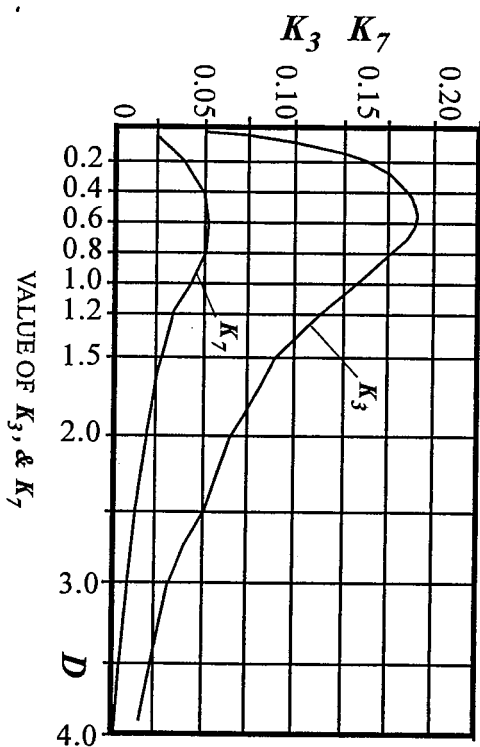
The maximum compression stresses  $S_1$  and  $S_2$  respectively, plus the tensile stress due to internal pressure shall not exceed the allowable compression stress value of head material.

## STRESSES IN VESSELS ON LEG SUPPORT





## STRESSES IN VESSELS ON LEG SUPPORT

STRESSES IN VESSELS ON LEG SUPPORT  
EXAMPLE CALCULATIONS

## DESIGN DATA

$W = 800,000$  lb. weight of vessel

$n = 4$ , number of legs

$$Q = \frac{W}{n} = \frac{800,000}{4} = 200,000 \text{ lb. load on one leg}$$

$R = 100$  inch, radius of head

$H = 5$  inch, lever arm of load

$2A = 30$  inch,  $2B = 30$  inch, dimensions of wear plate

$t = 1.8$  inch thickness of head

$\cos \alpha = 0.800$

$P = 100$  psi, internal pressure

Head material: SA 515-70

Allowable stress value: 20,000 psi

Joint Efficiency: 0.85

Yield Point: 38,000 psi

Factors  $K$  (see charts):

$$C = \sqrt{AB} = \sqrt{15 \times 15} = 15 \text{ inch}$$

$$D = 1.82 \frac{C}{R} \sqrt{\frac{R}{t}} = 1.82 \frac{15}{100} \sqrt{\frac{100}{1.8}} = 2.03$$

$$\begin{array}{ll} K_1 = 0.065, & K_2 = 0.030 \\ K_5 = 0.020, & K_6 = 0.010 \end{array} \quad \begin{array}{ll} K_3 = 0.065 & K_4 = 0.025 \\ K_7 = 0.022 & K_8 = 0.010 \end{array}$$

## LONGITUDINAL STRESSES:

1.) Maximum tensile stress:

$$S_l = \frac{Q}{t^2} \left[ \cos \alpha (-K_1 + 6K_2) + \frac{H}{R} \sqrt{\frac{R}{t}} (-K_3 + 6K_4) \right]$$

$$S_l = \frac{200,000}{1.8^2} \left[ 0.800 (-0.065 + 6 \times 0.030) + \frac{5}{100} \sqrt{\frac{100}{1.8}} \right] = +7,634 \text{ psi}$$

The stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 100}{2 \times 1.8} = +2778 \text{ psi}$$

The sum of tensional stresses:

$$7,634 + 2,778 = 10,412 \text{ psi}$$

It does not exceed the stress value of the girth seam:

$$20,000 \times 0.85 = 17,000.$$



## STRESSES IN VESSELS ON LEG SUPPORT EXAMPLE CALCULATIONS

### 2.) Maximum compressional stress:

$$S_1 = \frac{Q}{t^2} \left[ \cos \alpha (-K_1 - 6K_2) + \frac{H}{R} \sqrt{\frac{R}{t}} (-K_3 - 6K_4) \right]$$

$$S_1 = \frac{200,000}{1.8^2} \left[ 0.800 (-0.065 - 6 \times 0.030) + \frac{5}{100} \sqrt{\frac{100}{1.8}} (-0.065 - 6 \times 0.025) \right] \\ = -17,044 \text{ psi}$$

The stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 100}{2 \times 1.8} = +2,778 \text{ psi}$$

The sum of stresses:

$$-17,044 + 2,778 = -14,266 \text{ psi}$$

It does not exceed the stress value of the girth seam:  
 $20,000 \times 0.85 = 17,000 \text{ psi}$

### Circumferential stress:

#### 1.) Maximum tensile stress:

$$S_2 = \frac{Q}{t^2} \left[ \cos \alpha (-K_5 + 6K_6) + \frac{H}{R} \sqrt{\frac{R}{t}} (-K_7 - 6K_8) \right]$$

$$S_2 = \frac{200,000}{1.8^2} \left[ 0.800 (-0.020 + 6 \times 0.010) + \frac{5}{100} \sqrt{\frac{100}{1.8}} (-0.022 + 6 \times 0.010) \right] \\ = +2,849 \text{ psi}$$

The stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 100}{2 \times 1.8} = +2,778 \text{ psi}$$

The sum of tensile stresses:

$$-2,849 + 2,778 = -5,627 \text{ psi}$$

It does not exceed the stress value of the girth seam:  
 $20,000 \times 0.85 = 17,000 \text{ psi}$

### 2.) Maximum compressional stress:

$$S_2 = \frac{Q}{t^2} \left[ \cos \alpha (-K_5 - 6K_6) + \frac{H}{R} \sqrt{\frac{R}{t}} (-K_7 - 6K_8) \right]$$

$$S_2 = \frac{200,000}{1.8^2} \left[ 0.800 (-0.020 - 6 \times 0.010) + \frac{5}{100} \sqrt{\frac{100}{1.8}} (-0.022 - 6 \times 0.010) \right] \\ = -5,837 \text{ psi}$$

## STRESSES IN VESSELS ON LEG SUPPORT EXAMPLE CALCULATIONS

The stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 100}{2 \times 1.8} = +2,778 \text{ psi}$$

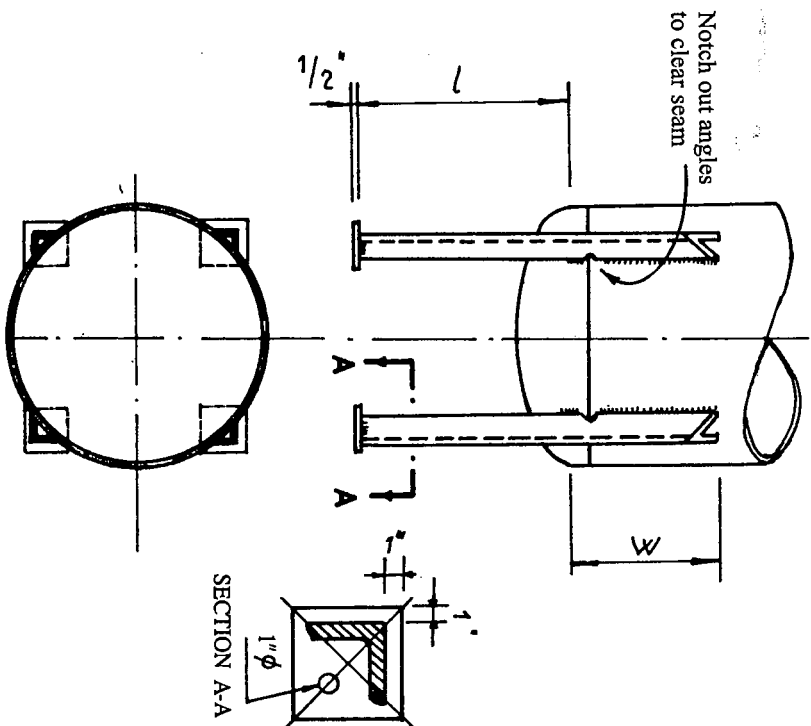
The sum of stresses:

$$-5,837 + 2,778 = -3,059 \text{ psi}$$

It does not exceed the stress value of the girth seam:  
 $20,000 \times 0.85 = 17,000 \text{ psi}$

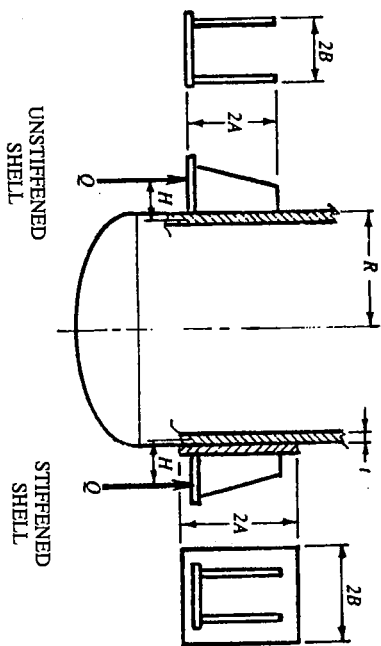


## LEG SUPPORT



VESSEL DIA	VESSEL HEIGHT MAX	ANGLE SIZE	1 max	W
2'-6"	8'-0"	3" x 3" x 3/8"	5'-0"	4"
3'-0"				
3'-6"				
4'-0"	10'-0"	3.5" x 3.5" x 3/8"	5'-0"	6"
4'-6"				
5'-0"				
5'-6"	14'-0"	4" x 4" x 1/2"	7'-0"	7"
6'-0"				
6'-6"				
7'-0"	16'-0"	5" x 5" x 1/2"	7'-0"	10"
7'-6"				
7'-6"	18'-0"	6" x 6" x 5/8"	7'-0"	1'-0"

## STRESSES IN VESSELS DUE TO LUG SUPPORT



## NOTATION:

$W$  = Weight of vessel, lb  
 $n$  = Number of lugs  
 $Q = \frac{W}{n}$  = Load on one lug, lb  
 $R$  = Radius of shell, in  
 $H$  = Lever arm of load, in  
 $2A, 2B$  = Dimensions of wear plate  
 $S$  = Stress, pound per sq. in  
 $t$  = Wall thickness of shell, in  
 $C$  = Shape factor, see table  
 $K$  = Factors, see charts  
 $D = \frac{A}{R} \sqrt[3]{\frac{B}{A}}$

## LONGITUDINAL STRESS:

$$S_l = \pm \frac{QH}{DR^2t} \left( C_1K_1 + 6 \frac{K_2R}{C_2t} + \frac{D}{2(1.17 + B/A)} \times \frac{R^2}{HA} \right)$$

NOTE: In tension  $S_l$  plus the stress due to internal pressure  $PR/2t$  shall not exceed the stress value of shell material times the efficiency of girth seam.

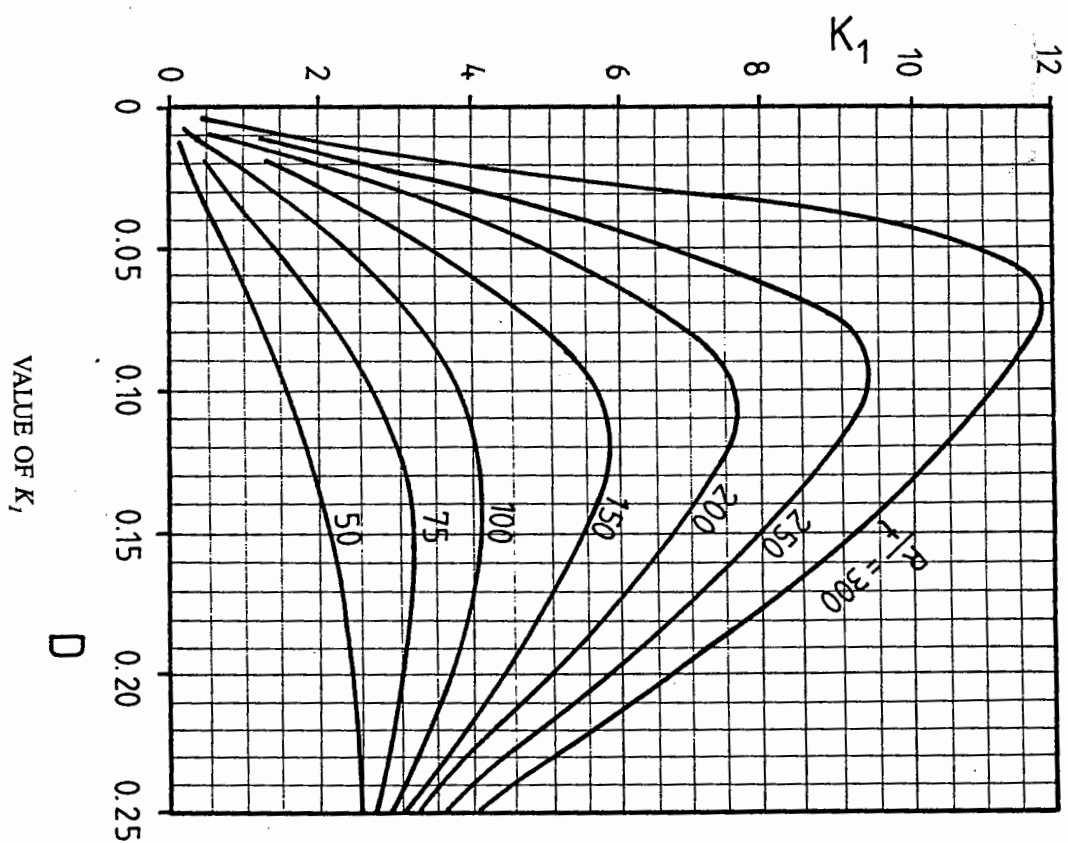
## CIRCUMFERENTIAL STRESS:

$$S_2 = \pm \frac{QH}{DR^2t} \left( C_3K_3 + 6 \frac{K_4R}{C_4t} \right)$$

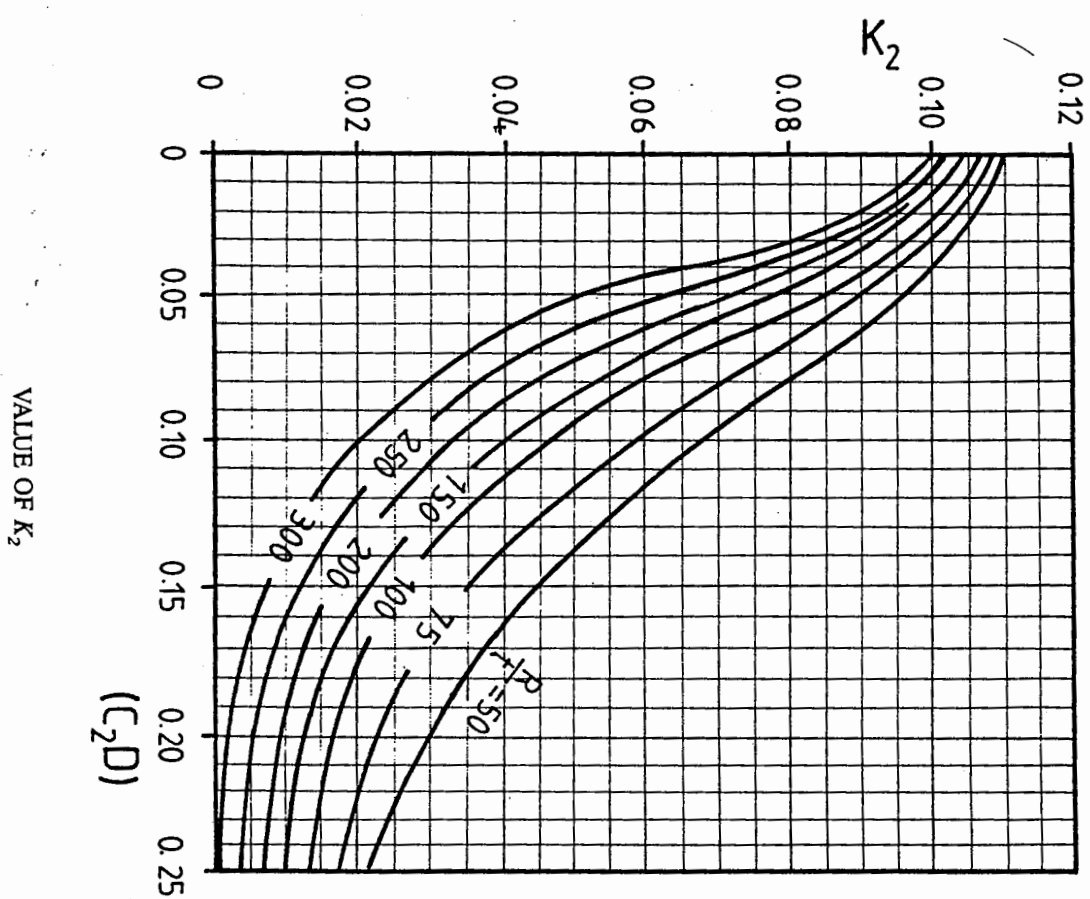
NOTE: In tension  $S_2$  plus the stress due to internal pressure  $PR/t$  shall not exceed the stress value of shell material multiplied by 1.5.



## STRESSES IN VESSELS DUE TO LUG SUPPORT

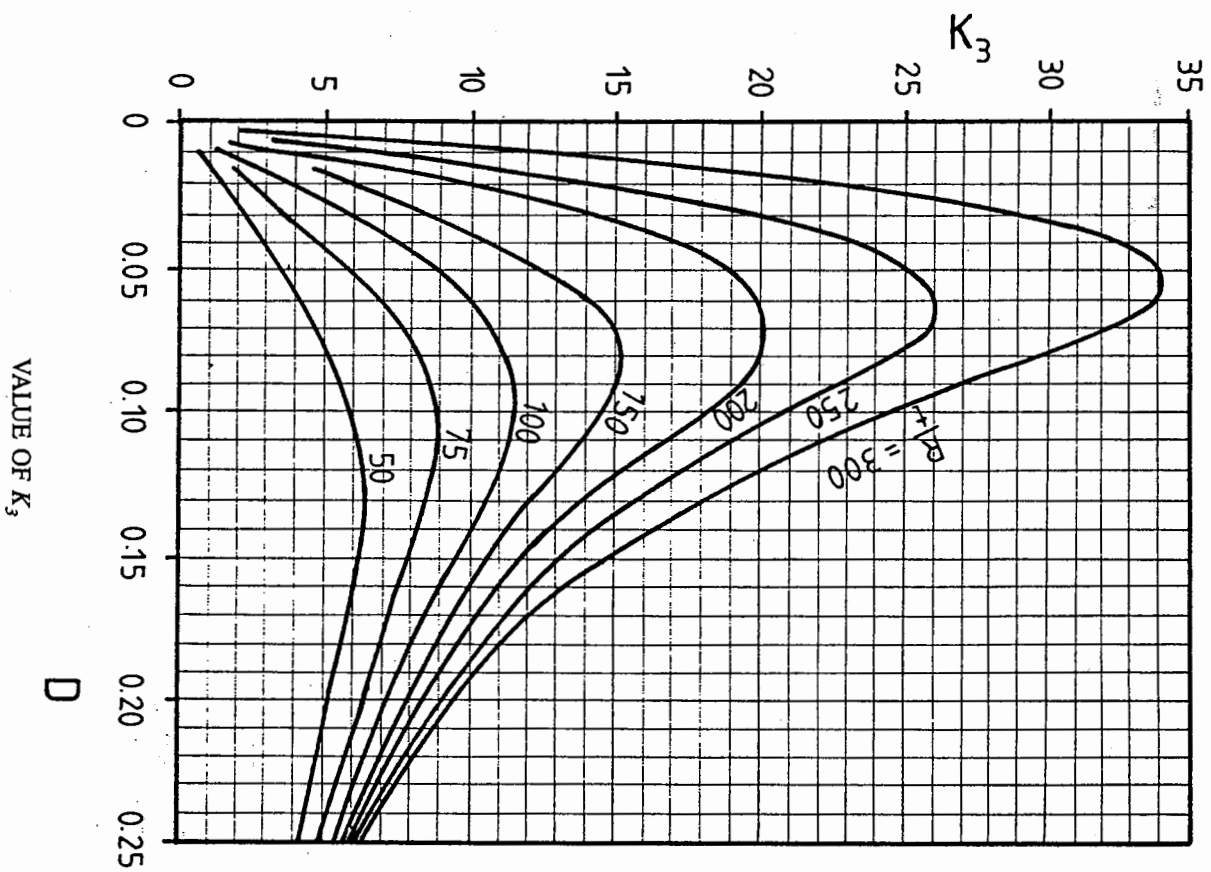


## STRESSES IN VESSELS DUE TO LUG SUPPORT

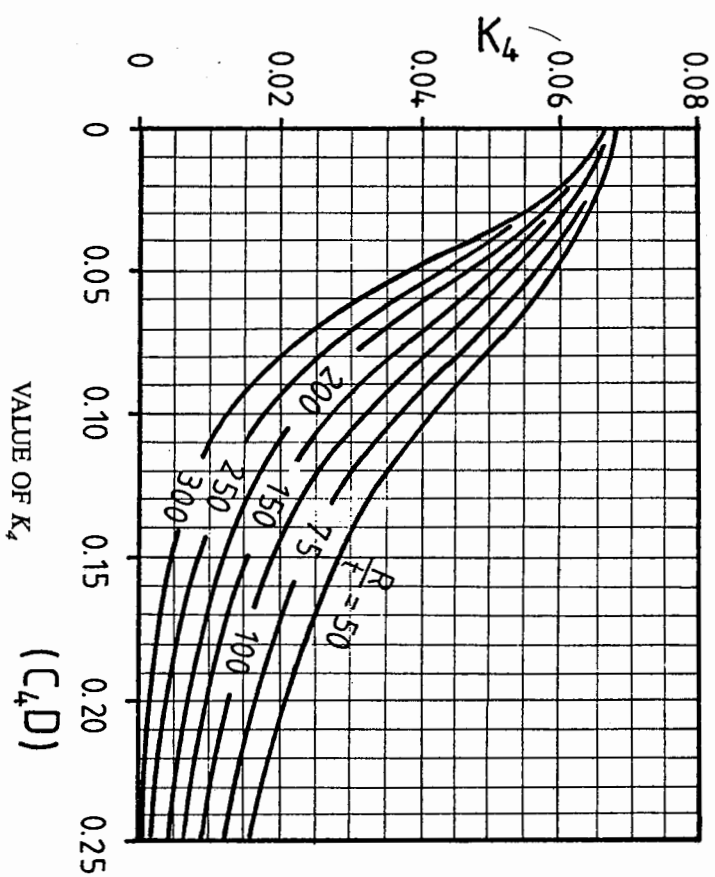




## STRESSES IN VESSELS DUE TO LUG SUPPORT



## STRESSES IN VESSELS DUE TO LUG SUPPORT



B/A	R/t	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>
1/2	50	0.72	1.03	0.95	1.07
	100	0.68	1.02	0.97	1.06
	200	0.64	1.02	1.04	1.05
1	300	0.60	1.02	1.10	1.04
	50	1	1	1	1
	100	1	1	1	1
2	200	1	1	1	1
	300	1	1	1	1
2	50	0.85	1.10	0.85	0.92
	100	1.15	1.07	0.81	0.89
	200	1.32	0.98	0.80	0.84
	300	1.50	0.90	0.79	0.79

VALUE OF C



## STRESSES IN VESSELS DUE TO LUG SUPPORT

## EXAMPLE CALCULATIONS

## DESIGN DATA

$W = 1,200,000$  lb. weight of vessel

$n = 4$  number of lugs

$$Q = \frac{W}{n} = \frac{1,200,000}{4} = 300,000 \text{ lb. load on one lug}$$

$R = 90$  in, radius of shell

$H = 5$  in, leverarm of load

$2A = 30$  in,  $2B = 30$  in, dimensions of wear plate

$t = 1.5$  in, thickness of shell

$P = 100$  psi internal pressure

Shell material: SA - 515-70

Allowable stress value 20,000 psi

Yield point 38,000 psi

Joint Efficiency: 0.85

Shape factors  $C$ , (see table):

$$R/t = \frac{90}{1.5} = 60, \quad B/A = 15/15 = 1.0$$

$$C_1 = C_2 = C_3 = C_4 = 1.0$$

The factors  $K$ , (see charts)

$$D = \frac{A}{R} \sqrt{\frac{B}{A}} = \frac{15}{90} \sqrt{\frac{15}{15}} = 0.167, \quad R/t = \frac{90}{1.5} = 60$$

$$K_1 = 2.8, \quad K_2 = 0.025, \quad K_3 = 6.8, \quad K_4 = 0.021$$

## Longitudinal Stress:

$$S_l = \pm \frac{QH}{DR^2t} \left( C_1 K_1 + 6 \frac{K_2 R}{C_2 t} + \frac{D}{2(1.17 + B/A)} \times \frac{R^2}{HA} \right)$$

$$S_l = \frac{300,000 \times 5}{0.167 \times 90^2 \times 1.5} \left( 1 \times 2.8 + 6 \frac{0.025 \times 90}{1 \times 1.5} + \frac{0.167}{2(1.17 + 15/15)} \times \frac{90^2}{5 \times 15} \right) = 11,795 \text{ psi}$$

Stress due to internal pressure:

$$\frac{PR}{2t} = \frac{100 \times 90}{2 \times 1.5} = 3000 \text{ psi}$$

The sum of tensional stresses:  
11,795 + 3000 = 14,795 psi

It does not exceed the stress value of the girth seam:

$$20,000 \times 0.85 = 17,000 \text{ psi.}$$

## STRESSES IN VESSELS DUE TO LUG SUPPORT

## Circumferential Stress:

$$S_2 = \pm \frac{QH}{DR^2t} \left( C_3 K_3 + 6 \frac{K_4 R}{C_4 t} \right)$$

$$S_2 = \frac{300,000 \times 5}{0.167 \times 90^2 \times 1.5} \left( 1 \times 6.8 + 6 \frac{0.021 \times 90}{1 \times 1.5} \right) = 10,616 \text{ psi}$$

Stress due to internal pressure:

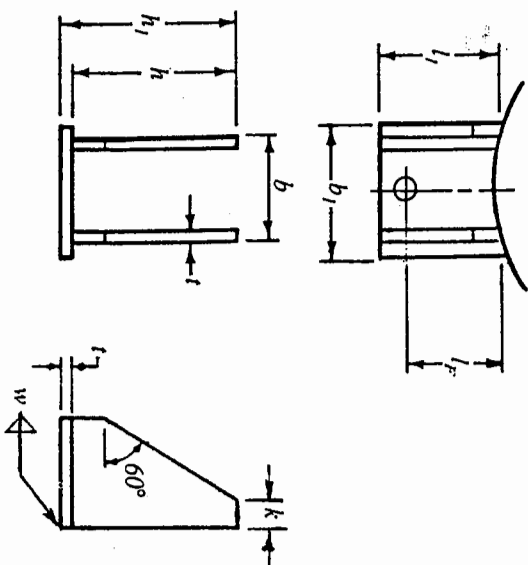
$$\frac{PR}{t} = \frac{100 \times 90}{1.5} = 6000 \text{ psi}$$

The sum of tensional stresses:  
10,616 + 6000 = 16,616 psi

It does not exceed the stress value of shell material multiplied by 1.5:  
 $20,000 \times 1.5 = 30,000$



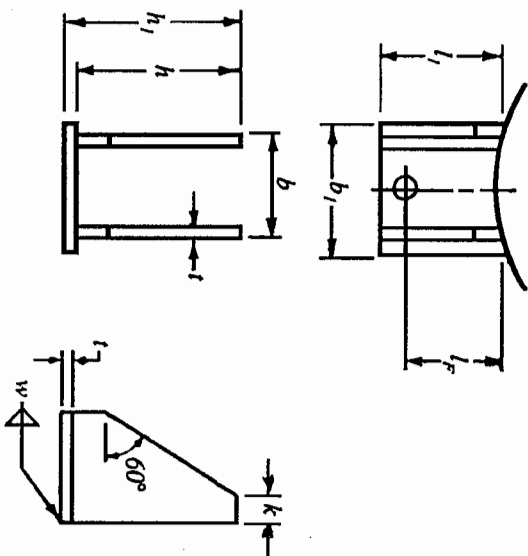
### LUG SUPPORT FOR INSULATED VESSELS



Maximum Allowable Load on One Lug, Lbs.	DIMENSIONS									Weight of One Lug, Lbs.
	$l_1$	$b$	$b_1$	$h$	$h_1$	$k$	$l_f$	$t$	$w$	
1,400	6½	5	5½	3¾	4	¾	5¼	¼	¼	7
2,200	6¾	5½	6	5	5¼	¾	5½	¼	¼	9
3,600	8¼	6¾	7¼	6¾	7	¾	6¾	¼	¼	16
5,600	10¼	8¾	9¼	9¾	9¾	1	8½	¼	¼	24
9,000	12½	10¾	11½	14¼	14½	1	10½	¾	¾	58
14,000	13¾	11½	12¼	17	17¾	1	11½	¾	¾	72
22,000	15½	13	13¾	18½	18¾	1¼	12½	½	¾	126
36,000	17½	14¾	15½	22	22¾	1¾	14	¾	½	165
56,000	20½	17½	18½	28¾	29	1¾	16½	¾	½	235
90,000	22¾	18½	19½	31½	32¼	1¾	18	¾	½	388
140,000	25¼	20½	21½	34¾	35¾	2	20	¾	½	482

All dimensions are in inches  
Stresses in vessel shall be checked.  
Use wear plate if necessary

### LUG SUPPORT FOR UNINSULATED VESSELS

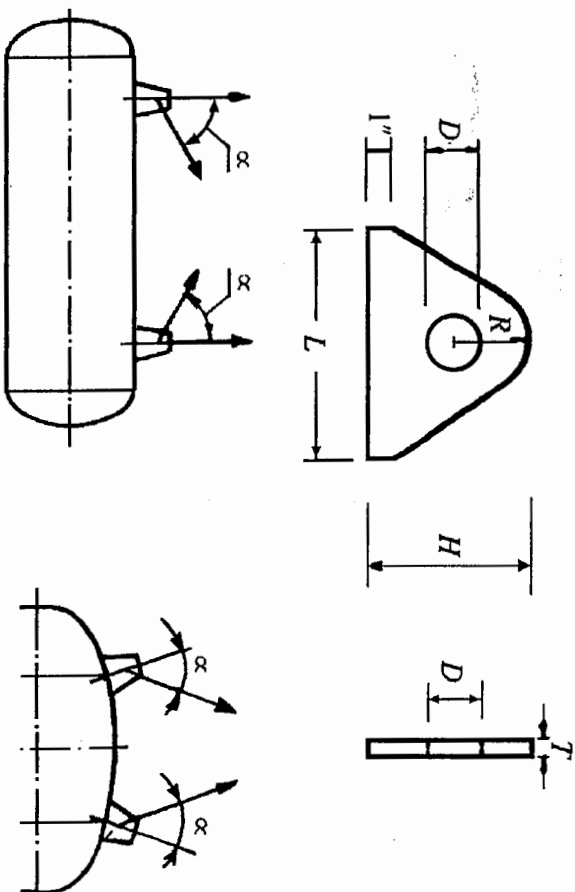


Maximum Allowable Load on One Lug, Lbs.	DIMENSIONS									Weight of One Lug, Lbs.
	$l_1$	$b$	$b_1$	$h$	$h_1$	$k$	$l_f$	$t$	$w$	
1,400	2½	2	2½	4	4¾	¾	1½	¾	full	1
2,200	3¼	2½	3	5¼	5½	¾	2	¾	full	2
3,600	4	3¼	3¾	6¾	6¾	¾	2½	¾	full	4
5,600	5¾	5¾	6¼	9¾	10	1	4	¼	¼	9
9,000	7¾	7	7¾	14¼	14¾	1	5½	5/16	¼	21
14,000	9½	8½	9¼	17	17½	1	6½	5/16	¼	28
22,000	10	9½	10¼	18	18¾	1¼	7	¾	¼	45
36,000	12	11½	12½	22	22½	1¼	9	½	¾	80
56,000	15	15	16¼	28½	29¼	1¼	12	9/16	¾	148
90,000	16½	15¾	17	31½	32¼	1¾	13	5/8	¾	218
140,000	18	17½	18¼	34¾	35¾	2	14	5/8	¾	260

All dimensions are in inches.  
Stresses in vessel shall be checked.  
Use wear plate if necessary.



## LIFTING LUG

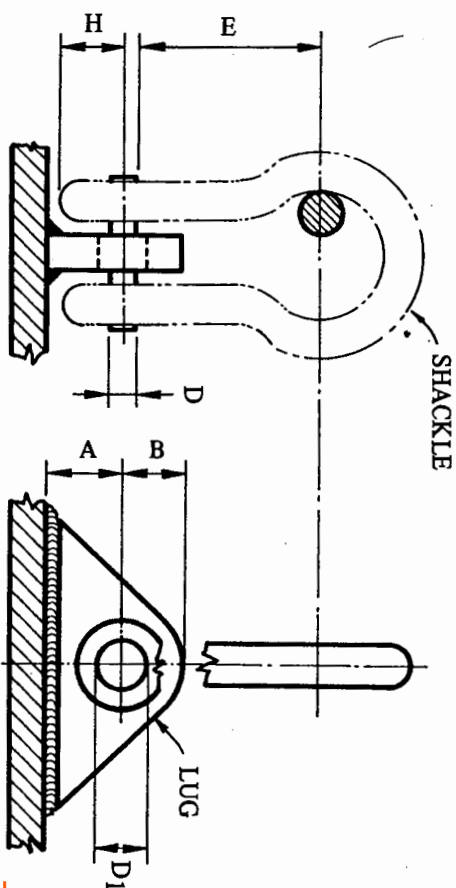


VESSEL WEIGHT (lbs)	D (in)	T (in)	R (in)	H (in)	L (in)	WELD (Min)
12,000	1	1/2	1 1/2	5	10	Double-bevel groove weld with T/4 (max. 3/8 in.) fillet weld all around.
20,000	1 1/8	3/4	2	6	10	
30,000	1 3/8	1	2 1/8	6	10	
50,000	1 5/8	1 1/4	2 1/2	7	12	
70,000	2 1/8	1 1/4	3 1/2	8	12	
100,000	2 1/2	1 1/2	4 1/2	9	16	
150,000	3	1 3/4	5	10	16	
200,000	4	2	6	12	18	
250,000	4 1/4	2	6 1/2	13	18	
300,000	4 1/2	2 1/2	7	14	20	

## Notes:

- All dimensions are in inches.
- The design is based on conditions:
  - $\alpha = 45^\circ$  maximum
  - Minimum tensile strength of lug material 70,000 psi.
  - Direction of force is in the plane of lugs.

## LIFTING ATTACHMENTS



## MINIMUM DIMENSIONS OF LIFTING LUGS USING SHACKLE

Load lbs.	Shackle Pin Diam. D	Hole Diam. in Lug D1	H	A	Sheared Edge B	Rolled Gas- cut B	Arm of Moment E
710	5/16	3/8	.50	.65			.84
1060	3/8	7/16	.56	.73			.97
1600	7/16	1/2	.63	.82	7/8	3/4	1.16
2170	1/2	5/8	.69	.90	1-1/8	7/8	1.44
2820	5/8	3/4	.94	1.22	1-1/4	1	1.75
4420	3/4	7/8	1.13	1.47	1-1/2	1-1/8	2.12
6375	7/8	1	1.19	1.55	1-3/4	1-1/4	2.25
8650	1	1-1/8	1.31	1.70	2	1-1/2	2.59
11300	1-1/8	1-1/4	1.50	1.95	2-1/4	1-5/8	2.94
13400	1-1/4	1-3/8	1.63	2.12	2-7/16	1-3/4	3.06
16500	1-3/8	1-1/2	1.75	2.28	2-5/8	1-7/8	3.62
20000	1-1/2	1-5/8	1.88	2.45	2-7/8	2	4.06
23750	1-5/8	1-3/4			3-1/16	2-3/16	4.19
32350	2	2-1/8	2.25	2.93	3-3/4	2-5/8	4.75
42500	2-1/4	2-3/8	2.56	3.33	4-1/8	3	5.25
54000	2-1/2	2-5/8	2.81	3.66	4-9/16	3-1/4	6.00
67600	2-3/4	2-7/8	2.94	3.82	5	3-9/16	7.00
81000	3	3-1/8			5-7/16	3-7/8	8.61
97000	3-1/4	3-3/8			5-7/8	4-1/4	9.74



## LIFTING ATTACHMENTS (cont.)

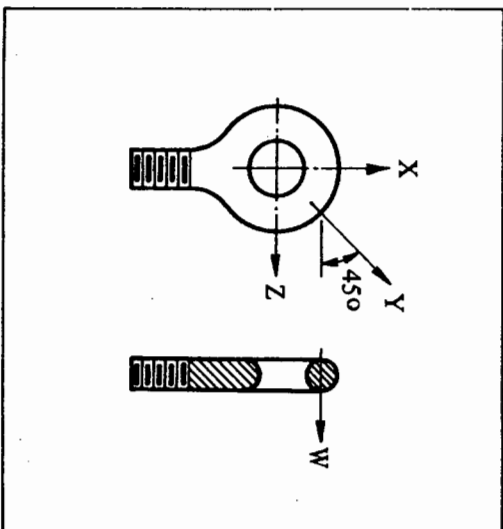
**RECOMMENDED MATERIAL:** A 515-70, A 302 or equivalent. The thickness and length of the lifting lug shall be determined by calculation.\*

**WELD:** When fillet welds are used, it is recommended that throat areas be at least 50 per cent greater than the cross sectional area of the lug.

To design the lugs the entire load should be assumed to act on one lug.

All possible directions of loading should be considered (during shipment, storage, erection, handling.) When two or more lugs are used for multileg sling, the angle between each leg of the sling and the horizontal should be assumed to be 30 degrees.

## EYE - BOLT



Threaded fasteners smaller than 5/8" diameter should not be used for lifting because of the danger of overtightening during assembly.

Commercial eyebolts are supplied with a rated breaking strength in the X direction.

For loadings other than along the axis of the eyebolt, the following ratings are recommended. These are expressed as percentage of the rating in the axial direction.

X = 100%    Y = 33%  
Z = 20%    W = 10%

## EXAMPLE:

An eyebolt of 1 in. diameter which is good for 4960 lb. load in tension (direction x) can carry only  $4960 \times 0.33 = 1637$  lb. load if it acts in direction y.

The above dimensions and recommendations are taken from C. V. Moore: Designing Lifting Attachments, Machine Design, March 18, 1965.

\* Assuming shear load only thru the minimum section, the required thickness may be calculated by the formula:



$$t = \frac{P}{2S (R \cdot D \cdot 2)}$$

where  $t$  = required thickness of lug, in.  
 $P$  = load, lbs.

## SAFE LOADS FOR ROPES AND CHAINS

The stress in ropes and chains under load is increasing with the reduction of the angle between the sling and the horizontal. Thus the maximum allowable safe load shall be reduced proportionally to the increased stress.

If the allowable load for a single vertical rope is divided by the cosecant of the angle between one side of the rope and the horizontal, the result will indicate the allowable load on one side of the inclined sling.

Example:

The allowable load for a rope in vertical position is 8000 lb. If the rope applied to an angle of 30 degrees, in this position the allowable load on one side will be  $8000 / \csc 30 \text{ deg.} = 8000 / 2 = 4000$  lb. For the two-rope sling the total allowable load 2 times  $4000 = 8000$  lb. The table shows the load-bearing capacity of ropes and chains in different positions. Multiplying with the factors shown in the table the allowable load for a certain rope or chain, the product will indicate the allowable load in inclined position.

## FACTORS TO CALCULATE SAFE LOADS FOR ROPES AND CHAINS

Angle of Inclination	90°	60°	45°	30°	10°
On One End	1.00	0.85	0.70	0.50	0.17
On Two Ends	—	1.70	1.40	1.00	0.34



## OPENINGS WITHOUT REINFORCING PAD

Below the most commonly used types of welded attachments are shown. For other types see Code, Fig. UW-16.1.

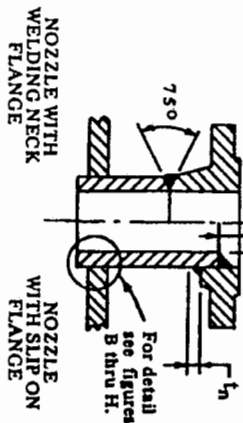
### NOTATIONS:

$\alpha$  = Min. weld size =  $t$  or  $t_n$  or 0.375 in., whichever is the smallest, in.  
 $a_1 + a_2 = 1\frac{1}{2} \times$  the smallest of  $t$ ,  $t_n$  or 1 in.  
 $a_1$  or  $a_2$  = the smallest of  $t$ ,  $t_n$  or 0.375 in.  
 $b$  = No minimum size requirement

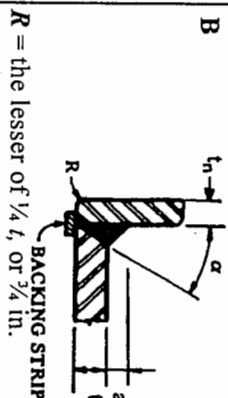
$\alpha$  = The angle of beveling shall be such as to permit complete joint penetration and complete fusion. Depends on plate thickness, welding procedure.  
 $t$  = Thickness of vessel wall less corrosion allowance, in.  
 $t_n$  = Nominal thickness of nozzle wall less corrosion allowance, in.

### NOTES:

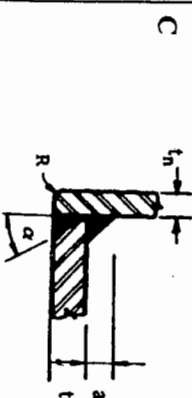
- When complete joint penetration cannot be verified by visual inspection or other means permitted by the Code, backing strips shall be used with full penetration weld deposited from only one side.
- The purpose of weld  $b$  is to eliminate the irregularities of the groove weld at the root and secure full penetration. It is usually one pass only and may be omitted if not needed for the above purpose.
- The weld sizes defined here are the minimum requirements. For calculation of strength of welds, see page 136.
- Strength calculation of welds for pressure loading are not required for attachments shown in fig. B, C, E, F, G, and for openings:  
 3 in. pipe size attached to vessel walls of 3/8 in. or less in thickness.  
 2 in. pipe size attached to vessel walls over 3/8 in. thickness. (Code UG-36 (c) (3))



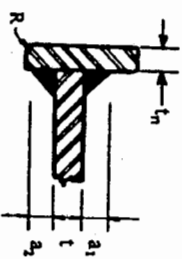
NOZZLE WITH WELDING NECK  
NOZZLE WITH SLIP ON FLANGE



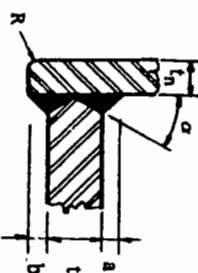
R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



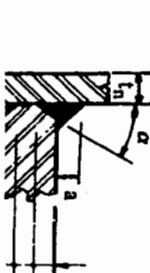
R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



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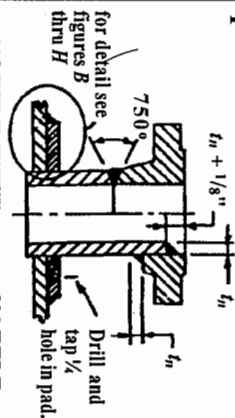


R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.

## OPENINGS WITH REINFORCING PAD

Below the most commonly used types of welded attachments are shown. For other types see Code, Fig. UW-16.1.

### I

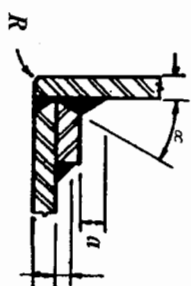


NOZZLE WITH WELDING NECK  
NOZZLE WITH SLIP ON FLANGE

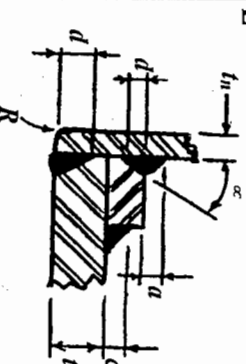
### NOTATION:

Minimum weld sizes, inches. Use the smallest values.  
 $a = t_n$  or  $t_e$  or 0.375 in.  
 $b$  = No minimum size requirement.  
 $c = 0.7t$ , or 0.7 $t_e$ , or 0.5 in.  
 $d = 0.7t$ , or 0.7 $t_n$ , or 0.7 $t_e$ , or 0.75 in.  
 $e = t$ , or  $t_p$ , or 1 in.  
 $\alpha$  = The angle of bevel shall be such as to permit complete joint penetration and complete fusion. Depends on plate thickness and welding techniques.  
 $t$  = Thickness of vessel wall less corrosion allowance, in.  
 $t_e$  = Thickness of reinforcing pad less corrosion allowance, in.  
 $t_n$  = Nominal thickness of nozzle wall less corrosion allowance, in.  
 $t_p$  = Thickness of pad type flange, in.  
 SEE NOTES ON FACING PAGE

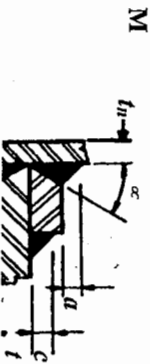
R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



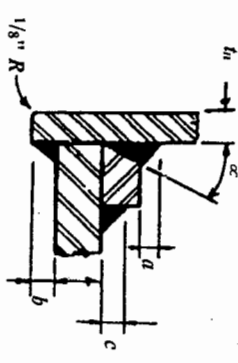
R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



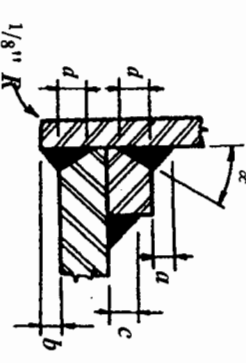
R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



R = the lesser of  $\frac{1}{4}t$ , or  $\frac{3}{4}$  in.



## OPENINGS

### SHAPE OF OPENINGS:

Openings in pressure vessels shall preferably be circular, elliptical or obround. An obround opening is one which is formed by two parallel sides and semicircular ends. The opening made by a pipe or a circular nozzle, the axis of which is not perpendicular to the vessel wall or head, may be considered an elliptical opening for design purposes.

Openings may be of shapes other than the above. Code UG-36(a)(2)

### SIZE OF OPENINGS:

Openings are not limited as to size.

The rules, construction details of this handbook conform to the Code UG-36 through UG-43 and apply to openings:

- for maximum 60 in. inside-diameter-vessel one half of the vessel diameter, but maximum 20 in.
- for over 60 in. inside-diameter-vessel one third of the vessel diameter, but maximum 40 in.

For openings exceeding these limits, supplemental rules of Code Appendix 1-7 shall be satisfied Code UG-36(b)(1)

For nozzle neck thickness see page 140.

### WHERE EXTERNAL PIPING IS CONNECTED TO THE VESSEL, THE SCOPE OF THE CODE INCLUDES:

- the welding end connection for the first circumferential joint for welded connections,
- the first threaded joint for screwed connections,
- the face of the first flange for bolted, flanged connections,
- the first sealing service for proprietary connections or fittings. Code U-1(e)(1)

## INSPECTION OPENINGS

All pressure vessels for use with compressed air and those subject to internal corrosion, erosion or mechanical abrasion, shall be provided with suitable manhole, handhole, or other inspection openings for examination and cleaning. The required inspection openings shown in the table below are selected from the alternatives allowed by the Code, UG-46, as they are considered to be the most economical.

INSIDE DIAMETER OF VESSEL	INSPECTION OPENING REQUIRED	INSPECTION OPENINGS ARE NOT REQUIRED:
over 12 in. less than 18 in. I.D.	two - 1½ in. pipe size threaded opening	1. for vessels 12 in. or less inside diameter if there are at least two minimum ¾ in. pipe size removable connections. 2. for vessels over 12 in. but less than 16 in. inside diameter, that are to be installed so that they must be disconnected from an assembly to permit inspection, if there are at least two removable connections not less than 1½ in. pipe size. UG-46(e).
18 in. to 36 in. inclusive I.D.	min. 16 in. I.D. manhole or two - 2 in. pipe size threaded opening	3. for vessels over 12 in. inside diameter under air pressure which also contain other substances which will prevent corrosion, providing the vessel contains suitable openings through which inspection can be made conveniently, and providing such openings are equivalent in size and number to the requirement of the table. UG-46(c).
over 36 in. I.D.	min. 16 in. I.D. manhole or two - 6 in. pipe size nozzle	4. for vessels (not over 36 in. I.D.) which are provided with tetralite holes (one hole min. per 10 sq. ft.) complying with the provisions of the Code UG-25, which are subject only to corrosion and are not in compressed air service. UG-46(b).

The preferable location of small inspection openings is in each head or near each head.

In place of two smaller openings a single opening may be used, provided it is of such size and location as to afford at least an equal view of the interior.

Compressed air as used here is not intended to include air which has had moisture removed to the degree that it has an atmospheric dew point of -50 F or less. The manufacturer's Data Report shall include a statement "for non-corrosive service" and Code paragraph number when inspection openings are not provided.

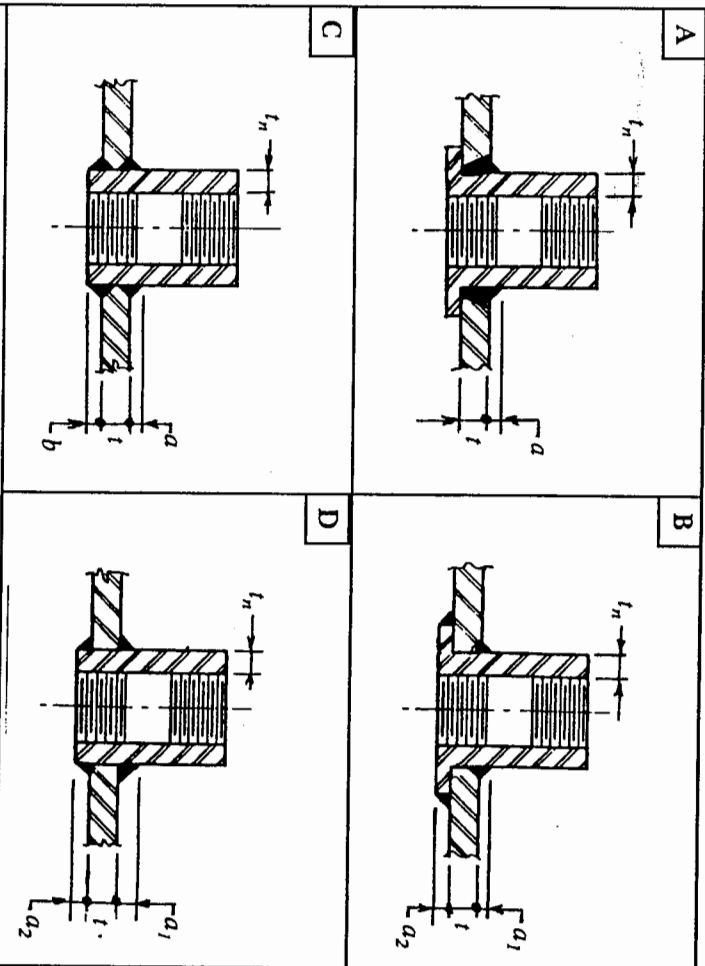
### NOZZLE NECK THICKNESS

The wall thickness of a nozzle neck or other connection used as means of



### THREADED AND WELDED FITTINGS

THE FIGURES BELOW SHOW THE MOST COMMONLY USED TYPES OF WELDED CONNECTIONS. SEE CODE FIG. UW-16.1 FOR OTHER TYPES



#### NOTATION

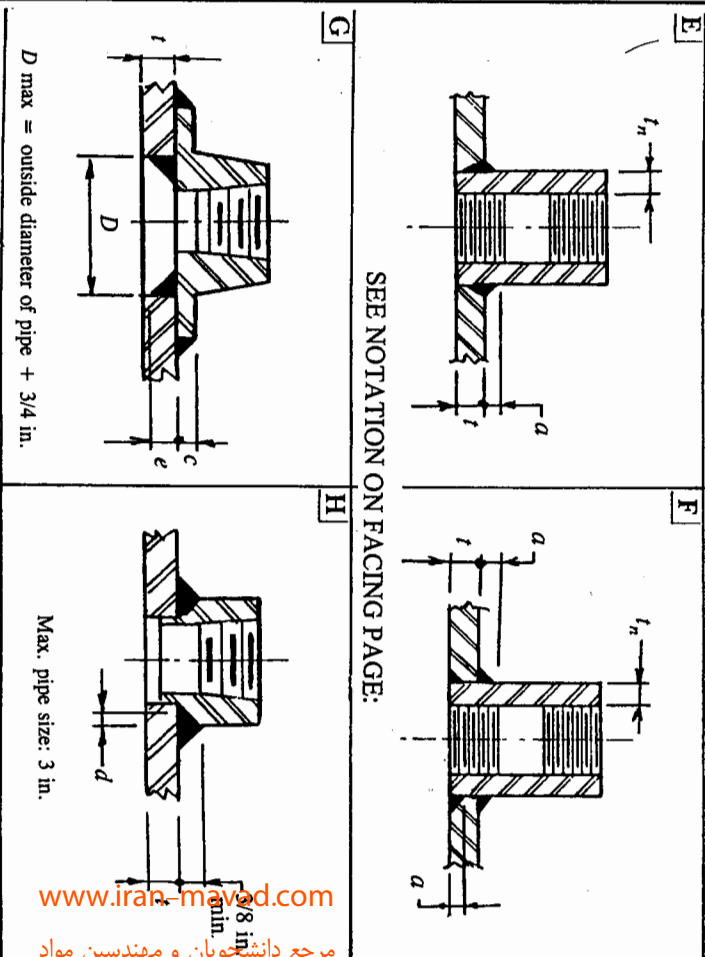
- $a = t, t_n$  or  $0.375$ , whichever is the smallest, in.
- $a_1 + a_2 = 1-1/4$  times the smallest of  $t, t_n$  or  $1$  in.
- $a_1$  or  $a_2$  = the smallest of  $t, t_n$  or  $0.375$  in.
- $b$  = no minimum size requirement
- $c$  = the smallest of  $t$  or  $1/2$  in.
- $d$  = the thickness of Sch 160 pipe wall, in.
- $e$  = the smallest of  $t$  or  $3/4$  in.
- $t$  = thickness of vessel wall, less corrosion allowance, in.
- $t_n$  = nominal thickness of fitting wall less corrosion allowance, in.

The weld sizes defined here are the minimum requirements.

SEE NOTATION ON FACING PAGE

### THREADED AND WELDED FITTINGS

THE FIGURES BELOW SHOW THE MOST COMMONLY USED TYPES OF WELDED CONNECTIONS. SEE CODE FIG. UW-16.1 FOR OTHER TYPES



SEE NOTATION ON FACING PAGE:

$D$  max = outside diameter of pipe +  $3/4$  in.

Max. pipe size: 3 in.

#### FITTINGS NOT EXCEEDING 3 IN. PIPE SIZE.

In some cases the welds are exempt from size requirements, or fittings and bolting pads may be attached to the vessels by fillet weld deposited from the outside only with certain limitations (Code UW-16 (f) (2) and (3)) such as:

1. The maximum vessel thickness:  $3/8$  in.
2. The maximum size of the opening is limited to the outside diameter of the attached pipe plus  $3/4$  in.
3. The weld throat shall be the greater of the minimum nozzle neck thickness required by the Code UG-45(a) or that necessary to satisfy the requirements of UW 18 for the applicable loadings of UG 22.
4. The welding may effect the threads of couplings. It is advisable to keep the threads above welding with a minimum  $1/4$  in. or cut the threads after welding.
5. Strength calculation of attachments is not required for attachments shown in Figs. A, C and E, and for openings:

3 in. pipe size fittings attached to vessel walls of  $3/8$  in. or less in thickness. 2 in.

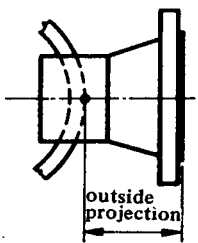


### SUGGESTED MINIMUM EXTENSION OF OPENINGS

The tables give the approximate minimum outside projection of openings. When insulation or thick reinforcing pad are used it may be necessary to increase these dimensions.

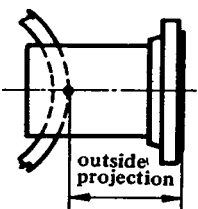
#### OUTSIDE PROJECTION, INCHES USING WELDING NECK FLANGE

NOM. PIPE SIZE	PRESSURE RATING OF FLANGE LB					
	150	300	600	900	1500	2500
2	6	6	6	8	8	8
3	6	6	8	8	8	10
4	6	8	8	8	8	12
6	8	8	8	10	10	14
8	8	8	10	10	12	16
10	8	8	10	12	14	20
12	8	8	10	12	16	22
14	8	10	10	14	16	
16	8	10	10	14	16	
18	10	10	12	14	18	
20	10	10	12	14	18	
24	10	10	12	14	20	



#### OUTSIDE PROJECTION, INCHES USING SLIP ON FLANGE

NOM. PIPE SIZE	PRESSURE RATING OF FLANGE LB					
	150	300	600	900	1500	2500
2	6	6	6	8	8	8
3	6	6	8	8	8	10
4	6	8	8	8	10	10
6	8	8	8	10	12	12
8	8	8	10	10	12	12
10	8	8	10	12	12	14
12	8	10	10	12	12	16
14	10	10	10	12		
16	10	10	12	12		
18	10	10	12	12		
20	10	10	12	12		
24	10	12	12	12		



### REINFORCEMENTS OF OPENINGS DESIGN FOR INTERNAL PRESSURE

Vessels shall be reinforced around the openings, except single, welded and fluted openings not subject to rapid pressure fluctuations do not require reinforcement if not larger than:

3 1/2 in. diameter in not over 3/8 in. thick vessel wall;  
2 3/8 in. diameter in over 3/8 in. vessel wall.

Threaded, studed or expanded connections for which the hole cut is not greater than 2 3/8 in. diameter.

(Code UG-36(c)(3)(a))

The design procedure described on the following pages conforms to Code UG-36 through UG-43.

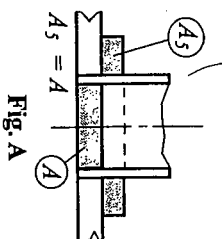


Fig. A

For openings exceeding these limits supplemental rules of Code 1-7 shall be applied in addition to UG-36 through UG-43.

For reinforcement of openings in flat heads see Code UG-39.

A brief outline of reinforcement design for better understanding of the procedure is described in the following pages.

The basic requirement is that around the opening the vessel must be reinforced with an equal amount of metal which has been cut out for the opening. The reinforcement may be an integral part of the vessel and nozzle, or may be an additional reinforcement pad. (Fig. A)

This simple rule, however, needs further refinements as follows:

1. It is not necessary to replace the actually removed amount of metal, but only the amount which is required to resist the internal pressure ( $A_1$ ). This required thickness of the vessel at the openings is usually less than at other points of the shell or head.
2. The plate actually used and nozzle neck usually are thicker than would be required according to calculation. The excess in the vessel wall ( $A_1$ ) and nozzle wall ( $A_2$ ) serve as reinforcements. Likewise the inside extension of the opening ( $A_3$ ) and the area of the weld metal ( $A_4$ ) can also be taken into consideration as reinforcement.
3. The reinforcement must be within a certain limit.
4. The area of reinforcement must be proportionally increased if its stress value is lower than that of the vessel wall.
5. The area required for reinforcement must be satisfied for all planes through the center of opening and normal to vessel surface.

The required cross sectional area of the reinforcement shall then be:

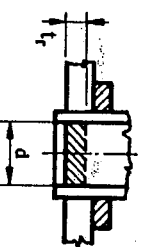
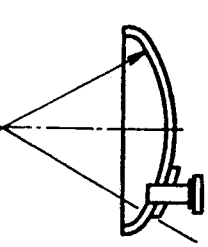
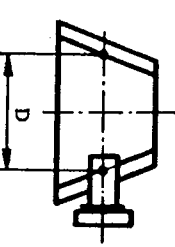
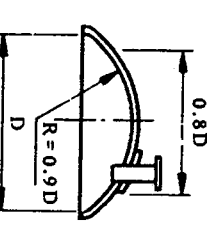
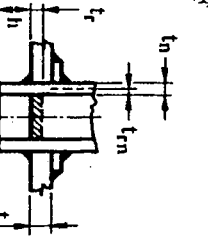
The required area for the shell or head to resist the internal pressure ( $A_1$ ). From this area subtract the excess areas within the limit ( $A_1, A_2, A_3, A_4$ ). If the sum of the areas available for reinforcement ( $A_1 + A_2 + A_3 + A_4$ ) is equal or greater than the area to be replaced ( $A_1$ ), the opening is adequately reinforced. Otherwise the difference must be supplied by reinforcing pad ( $A_5$ ).

Some manufacturers follow a simple practice using reinforcing pads with a cross-sectional area which is equal to the metal area actually removed for the opening. This



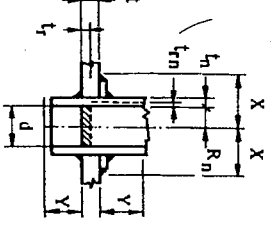
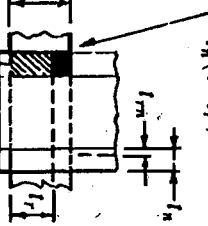
# **REINFORCEMENT FOR OPENINGS DESIGN FOR INTERNAL PRESSURE**

(continued)

	<p><b>B</b></p> <p><b>1. AREA OF REINFORCEMENT</b></p> <p>For vessels under internal pressure the total cross-sectional area required for reinforcement of openings shall not be less than:</p> $A = d \times t_r, \text{ where}$ <p><math>d</math> = the inside diameter of opening in its corroded condition, inches.</p> <p><math>t_r</math> = the required thickness of shell or head computed by the applicable formulas using <math>E = 1.0</math> when the opening is in solid plate or in a category B joint. When opening passes through any other welded joint, <math>E</math> = the efficiency of that joint. When the opening is in a vessel which is radiographically not examined, <math>E = 0.85</math> for type No. 1 joint and <math>E = 0.80</math> for type No. 2 joint.</p>
	<p><b>C</b></p> <p>When the opening and its reinforcement are entirely within the spherical portion of a flanged and dished head, <math>t_r</math> is the thickness required by the applicable formulas using <math>M = 1</math>.</p> <p>When the opening is in a cone, <math>t_r</math> is the thickness required for a seamless cone of diameter, <math>D</math> measured where the nozzle axis intersects with the wall of the cone.</p>
	<p><b>D</b></p> <p>When the opening and its reinforcement are in a 2:1 ellipsoidal head and are located entirely within a circle the center of which coincides with the center of the head and the diameter of which is equal to 0.8 times the head diameter, <math>t_r</math> is the thickness required for seamless sphere of radius 0.9 times the diameter of the head.</p>
	<p><b>E</b></p> <p>If the stress value of the opening's material is less than that of the vessel material, the required area <math>A</math> shall be increased. (See next page for examples.)</p>
	<p><b>F</b></p> <p><b>2. AVAILABLE AREAS OF REINFORCEMENT</b></p> <p><math>A_1</math> = Area of excess thickness in the vessel wall <math>(t - t_r)</math> <math>d</math> or <math>(t - t_r)(t_n + t)/2</math> use the larger value, square inches.</p> <p>If the stress value of the opening's material is less than that of the vessel material, area <math>A_1</math> shall be decreased. (See next page for examples.)</p> <p><math>A_2</math> = Area of excess thickness in the nozzle wall <math>(t_n - t_n)</math> <math>5t</math> or <math>(t_n - t_n) 5t_n</math> use — the smaller value, square inches.</p> <p><math>A_3</math> = Area of inside extension of nozzle square inches <math>(t_n - c)2h</math>.</p> <p><math>A_4</math> = Area of welds, square inches.</p> <p>If the sum of <math>A_1</math>, <math>A_2</math>, <math>A_3</math> and <math>A_4</math> is less than the area for reinforcement.</p>

# **REINFORCEMENT FOR OPENINGS DESIGN FOR INTERNAL PRESSURE**

(continued)

	<p><b>G</b></p> <p><b>3. LIMITS OF REINFORCEMENT</b></p> <p>The metal used as reinforcement must be located within the limits.</p> <p>The limit measured parallel to the vessel wall <math>X = d</math> or <math>R_n + t_n + t</math>, use larger value.</p> <p>The limit measured parallel to the nozzle wall <math>Y = 2.5t</math> or <math>2.5t_n</math>, use smaller value.</p> <p>When additional reinforcing pad is used, the limit, <math>Y</math> to be measured from the outside surface of the reinforcing pad.</p> <p><math>R_n</math> = inside radius of nozzle in corroded condition, inches.</p> <p>For other notations, see the preceding page.</p>
<p><b>NOTATION:</b></p> <p><math>t</math> = thickness of the vessel wall less corrosion allowance, inches.</p> <p><math>t_r</math> = see preceding page</p> <p><math>t_n</math> = nominal thickness of nozzle wall irrespective of product form, less corrosion allowance, inches.</p> <p><math>t_{rn}</math> = required thickness of seamless nozzle wall, inches.</p> <p><math>h</math> = distance nozzle projects beyond the inner surface of the vessel wall less corrosion allowance, inches.</p> <p><math>c</math> = corrosion allowance, inches.</p> <p><math>d</math> = see preceding page.</p>	<p><b>4. STRENGTH OF REINFORCEMENT</b></p> <p>If the strength of materials in <math>A_1</math>, <math>A_2</math>, <math>A_3</math>, <math>A_4</math>, and <math>A_5</math> or the material of the reinforcing pad are lower than that of the vessel material, their area considered as reinforcement shall be proportionately decreased and the required area <math>A</math> in inverse proportion increased. The strength of the deposited weld metal shall be considered as equivalent to the weaker material of the joint.</p> <p>It is advisable to use for reinforcing pad material identical with the vessel material.</p> <p>No credit shall be taken for additional strength of reinforcement having higher stress value than that of the vessel wall.</p>
	<p><b>H</b></p> <p><math>t_n(1 - t_r)</math></p> <p><math>t_n</math></p> <p><math>t_r</math></p> <p><math>t</math></p> <p><b>EXAMPLES:</b></p> <ol style="list-style-type: none"> <li>a. The stress value of nozzle material: 17,100 psi. The stress value of shell material: 20,000 psi. Ratio 17,100/20,000 = 0.855 To the required area, <math>A</math> shall be added: <math>+ 2t_n t_r(1 - 0.855)</math></li> <li>b. From the area <math>A_1</math> shall be subtracted: <math>- 2t_n X(t - t_r)(1 - 0.855)</math></li> </ol> <p>2. Using identical material for the vessel and reinforcing pad, the required area for reinforcement is 12 square inches.</p> <p>If the stress value of vessel material = 20,000 psi., the stress value of the nozzle material = 17,100 psi., ratio 20,000/17,100 = 1.17</p> <p>In this proportion shall be increased the area of reinforcement.</p>



# REINFORCEMENT FOR OPENINGS DESIGN FOR INTERNAL PRESSURE

(continued)

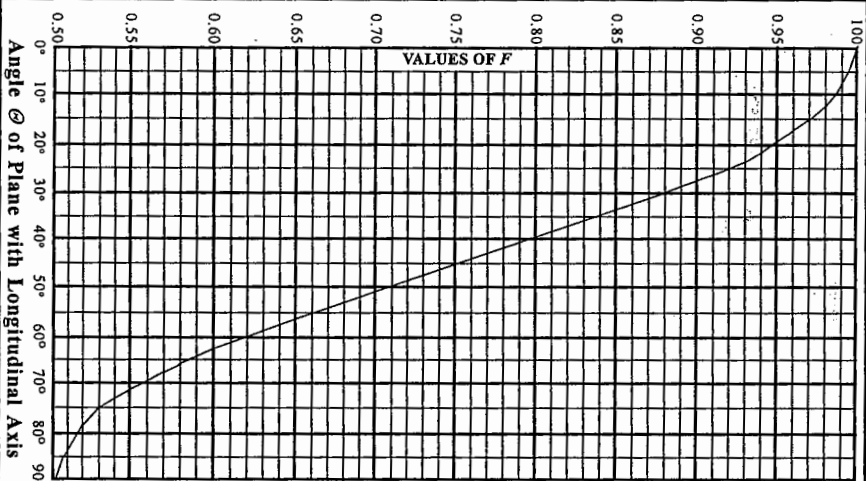
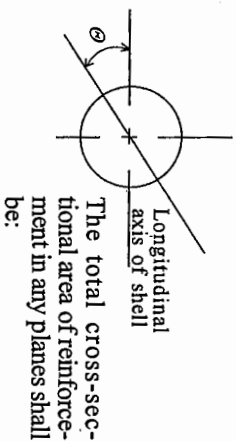
## 5. REINFORCEMENT IN DIFFERENT PLANES FOR INTERNAL PRESSURE

Since the circumferential stress in cylindrical shells and cones is two times greater than the longitudinal stress, at the opening the plane containing the axis of the shell is the plane of the greatest unit loading due to pressure. On the plane perpendicular to the vessel axis the unit loading is one half of this.

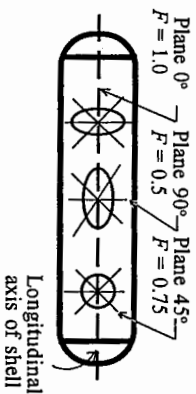
Chart shows the variation of the stresses on different planes. (Factor  $F$ )

When the long dimension of an elliptical or obround opening exceeds twice the short dimensions, the reinforcement across the short dimensions shall be increased as necessary to provide against excessive distortion due to twisting moment Code UG-36(a)(1).

Factor  $F$  shall not be less than 1.0, except for integrally reinforced openings in cylindrical shells and cones it may be less.

Factor  $F$  - Fig. UG-37

(Notations on preceding pages.)

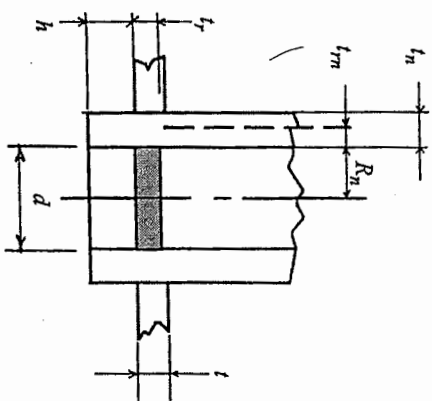


**DESIGN FOR EXTERNAL PRESSURE**  
The reinforcement required for openings in a single-walled vessel subject to external pressure need be only 50 percent of that required for internal pressure where  $t_r$  is the wall thickness required by the rules for vessels under external pressure. Code UG-37(d)(1).

$$A = d \times t_r \times F$$

# REINFORCEMENT OF OPENINGS EXAMPLES

## EXAMPLE 1.



**DESIGN DATA:**  
Inside diameter of shell: 48 in.  
Design pressure: 250 psi at 200° F  
Shell material: SA-285-C  
 $S=15,700$  psi  $t = 0.625$  in.  
The vessel is spot radiographed.  
No allowance for corrosion.  
Nozzle material: SA-53-B  
 $S = 17,100$  psi,  $t_n = 0.432$  in.  
Nozzle nom. size: 6 in.  
Extension of nozzle inside the vessel: 1.5 in.  
 $h=2.5$ ,  $t_n=2.5 \times 0.432=1.08$  in.  
The nozzle does not pass through seams.  
Fillet weld size: 0.375 in.

Wall thickness required:

$$\text{for shell: } t_r = \frac{PR}{SE - 0.6} = \frac{250 \times 24}{15,700 \times 1.0 - 0.6 \times 250} = 0.386 \text{ in.}$$

$$\text{for nozzle: } t_m = \frac{PR_n}{SE - 0.6P} = \frac{250 \times 2.88}{17,100 \times 1.0 - 0.6 \times 250} = 0.043 \text{ in.}$$

## AREA OF REINFORCEMENT REQUIRED

$$A = d t_r = 5.761 \times 0.386 = 2.224 \text{ in.}$$

## AREA OF REINFORCEMENT AVAILABLE

$A_1$  = (Excess in shell.) Larger of the following:

$$(t - t_r) d = (0.625 - 0.386) \times 5.761 = 1.377 \text{ sq. in. or}$$

$$(t - t_r) (t_n + y) 2 = (0.625 - 0.386) \times (0.432 + 0.625) \times 2 = 0.505 \text{ sq. in.}$$

$$1.377 \text{ sq. in.}$$

$A_2$  = (Excess in nozzle neck.) Smaller of the following:

$$(t_n - t_m) 5t = (0.432 - 0.043) \times 5 \times 0.625 = 1.216 \text{ sq. in.}$$

$$(t_n - t_m) 5t_n = (0.432 - 0.043) \times 5 \times 0.432 = 0.843 \text{ sq. in.}$$

$$0.843 \text{ sq. in.}$$

(No credit for additional strength of nozzle material having higher stress value than that of the vessel wall.)

$$A_3 = (\text{Inside projection.}) t_n \times 2h = 0.432 \times 2 \times 1.08 = 0.933 \text{ sq. in.}$$

$$A_4 = (\text{Area of fillet weld}) 0.375^2 = 0.140 \text{ sq. in.}$$

$$A_5 = (\text{Area of fillet weld inside}) 0.375^2 = 0.140 \text{ sq. in.}$$

## TOTAL AREA AVAILABLE

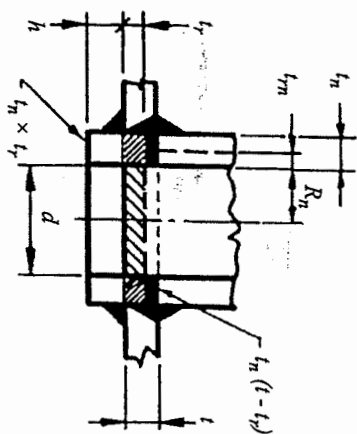
$$3.433 \text{ sq. in.}$$

Since this area is greater than the area required for reinforcement is not needed.



## REINFORCEMENT OF OPENINGS EXAMPLES

### EXAMPLE 2.



**DESIGN DATA:**  
 Inside radius of shell:  $R = 24$  in.  
 Design pressure:  $P = 300$  psi at  $200^\circ$  F.  
 Shell material:  $t = 0.500$  in. SA-516-70 plate,  
 $S = 20,000$  psi  
 The vessel is spot examined  
 There is no allowance for corrosion  
 Nozzle nominal size: 6 in.  
 Nozzle material: SA-53 B  
 $S = 17,100$  psi.  $t_n = 0.432$  in.  
 Extension of nozzle inside the vessel: 1.5 in.  
 Fillet weld size inside: 0.500 in.;  
 Fillet weld size outside: 0.625 in.  
 Ratio of stress values:  $17,100/20,000 = 0.855$

Wall thickness required:

$$\text{Shell, } t_r = \frac{PR}{SE - 0.6P} = \frac{300 \times 24}{20,000 \times 1 - 0.6 \times 300} = 0.364 \text{ in.}$$

$$\text{Nozzle, } t_{rn} = \frac{PR_n}{SE - 0.6P} = \frac{300 \times 2.88}{17,100 \times 1 - 0.6 \times 300} = 0.051 \text{ in.}$$

Since the strength of the nozzle material is lower than that of the vessel material, the required area for reinforcement shall be proportionally increased and the areas available for reinforcement proportionally reduced.

#### AREA OF REINFORCEMENT REQUIRED

$$A = d t_r 5.761 \times 0.364 =$$

$$\text{Area increased: } + 2 t_n \times t_r (1 - 17,100/20,000) = 2 \times 0.432 \times 0.364 \times (1 - 0.855) = 0.046 \text{ sq. in.}$$

$$2.097 \text{ sq. in.}$$

#### AREA OF REINFORCEMENT AVAILABLE

$A_1$  = (Excess in shell.) Larger of the following:

$$(t - t_r) d = (0.500 - 0.364) \times 5.761 = 0.784 \text{ sq. in. or}$$

$$(t - t_r) (t_n + t) 2 = (0.500 - 0.364) \times (0.432 + 0.500) \times 2 = 0.254 \text{ sq. in.}$$

$$\text{Area reduced: } - 2 \times t_n (t - t_r) (1 - 0.855) =$$

$$- 2 \times 0.432 \times (0.500 - 0.364) (1 - 0.855) = -0.017 \text{ sq. in.}$$

$A_2$  = (Excess in nozzle neck.) Smaller of following:

$$(t_n - t_{rn}) 5t = (0.432 - 0.051) 5 \times 0.500 = 0.953$$

$$(t_n - t_{rn}) 5t_n = (0.432 - 0.051) 5 \times 0.432 = 0.823$$

$$\text{Area reduced: } 0.855 \times 0.823 = 0.704 \text{ sq. in.}$$

Since the strength of the nozzle is lower than that of the shell, a decreased area shall be taken into consideration.

$$17,100/20,000 = 0.855,$$

$$0.855 \times 0.823 =$$

$$0.704 \text{ sq. in.}$$

$$A_3 = (\text{Inside projection.}) t_n \times 2h = 0.432 \times 2 \times 1.08 = 0.933$$

$$\text{Area decreased } 0.933 \times 0.855 =$$

$$0.797 \text{ sq. in.}$$

$$A_4 = (\text{Area of fillet weld}) 2 \times 0.5 \times 0.625^2 \times 0.855 =$$

$$0.334 \text{ sq. in.}$$

$$A_5 = (\text{Area of fillet weld inside}) 2 \times 0.5 \times 500^2 \times 0.855 =$$

$$0.214 \text{ sq. in.}$$

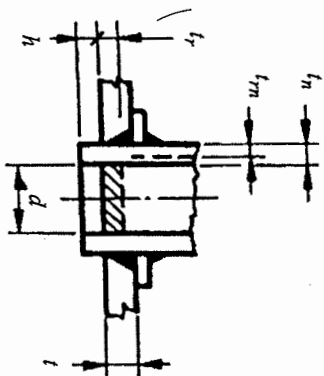
**TOTAL AREA AVAILABLE**

$$2.816 \text{ sq. in.}$$

Additional reinforcement not required.

## REINFORCEMENT OF OPENINGS EXAMPLES

### EXAMPLE 3.



**DESIGN DATA:**  
 Inside diameter of shell: 48 in.  
 Design pressure: 300 psi at  $200^\circ$  F.  
 Shell material: 0.500 in. SA-516-60 plate,  
 The vessel fully radiographed,  $E = 1$   
 There is no allowance for corrosion  
 Nozzle nominal size: 8 in.  
 Nozzle material: SA-53 B, 0.500 in. wall  
 Extension of nozzle inside the vessel: 0.5 in.  
 The nozzle does not pass through the main seams.  
 Size of fillet welds 0.375 in.  
 (Reinforcement pad to nozzle neck.)

Wall thickness required:

$$\text{Shell } t_r = \frac{PR}{SE - 0.6P} = \frac{300 \times 24}{17,100 \times 1 - 0.6 \times 300} = 0.426 \text{ in.}$$

$$\text{Nozzle, } t_{rn} = \frac{PR_n}{SE - 0.6P} = \frac{300 \times 3.8125}{17,100 \times 1 - 0.6 \times 300} = 0.068 \text{ in.}$$

#### AREA OF REINFORCEMENT REQUIRED

$$A = d \times t_r = 7.625 \times 0.426 =$$

$$3.249 \text{ sq. in.}$$

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#### AREA OF REINFORCEMENT AVAILABLE

$A_1$  = (Excess in shell.) Larger of the following:

$$(t - t_r) d = (0.500 - 0.426) 7.625 = 0.564$$

$$\text{or } (t - t_r) (t_n + t) 2 = (0.500 - 0.426) (0.500 + 0.500) 2 = 0.148 \text{ sq. in.}$$

$A_2$  = (Excess in nozzle neck.) Smaller of following:

$$(t_n - t_{rn}) 5t = (0.500 - 0.068) 5 \times 0.5 = 1.08 \text{ or}$$

$$(t_n - t_{rn}) 5t_n = (0.500 - 0.068) 5 \times 0.5 = 1.08$$

$A_3$  = (Inside projection.)  $t_n \times 2h = 0.500 \times 2 \times 0.5 =$

$$1.08 \text{ sq. in.}$$

$A_4$  = (Area of fillet weld) 0.375<sup>2</sup>

$$0.500 \text{ sq. in.}$$

$A_5$  = (The area of pad to shell weld disregarded)

$$0.141 \text{ sq. in.}$$

**TOTAL AREA AVAILABLE**

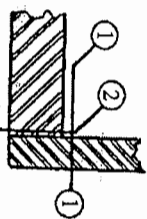
$$2.285 \text{ sq. in.}$$

This area is less than the required area, therefore the difference shall be provided by reinforcing element. It may be heavier nozzle neck, larger extension of the nozzle inside of the vessel or reinforcing pad. Using reinforcing pad, the required area of pad:  $3.249 - 2.285 = 0.964$  sq. in. Using 0.375 in. SA-516-60 plate for reinforcing pad the width of the pad  $0.964/0.375 = 2.571$   
 The outside diameter of reinforcing pad: Outside diameter of pipe: 8.625  
 width of reinforcing pad:  $2.571$   
 $11.196$  in.



## STRENGTH OF ATTACHMENTS JOINING OPENINGS TO VESSEL

A



Possible paths of failure:

1. Through ① - ①
2. Through ② - ②

At the attachments, joining openings to the vessel, failure may occur through the welds or nozzle neck in the combinations shown in figures A and B. The strength of the welds and the nozzle neck in those combinations shall be at least equal to the smaller of:

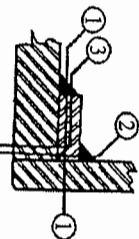
1. The strength in tension of the cross-sectional area of the element of reinforcement being considered, or
2. The strength in tension of area  $a$  ( $A = d \times t_n$ ) less the strength in tension of the excess in the vessel wall ( $A_1$ ).

The allowable stress value of the welds is the stress value of the weaker material connected by the welds multiplied by the following factors:

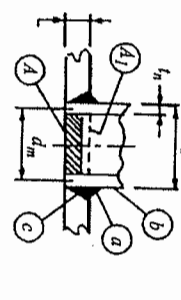
Groove-weld tension	0.74
Groove-weld shear	0.60
Fillet-weld shear	0.49

The allowable stress value of nozzle neck in shear is 0.70 times the allowable stress value of nozzle material.

- Possible paths of failure:
1. Through ① - ①
  2. Through ② - ②
  3. Through ③ - ③



### EXAMPLE 4.



$A = 2.397 \text{ sq. in.}$   $A_1 = 0.484 \text{ sq. in.}$   
 $d_o = 6.625 \text{ in.}$  outside diameter of nozzle  
 $d_m = 6.193 \text{ in.}$  mean diameter of nozzle  
 $S = 20,000 \text{ psi}$  allowable stress value of vessel material  
 $S_n = 17,100 \text{ psi}$  allowable stress value of nozzle material  
 $t_n = 0.432 \text{ in.}$  wall thickness of nozzle  
 $t = 0.500 \text{ in.}$  wall thickness of vessel  
 $0.375 \text{ in.}$  fillet weld leg.

Check the strength of attachment of nozzle load to be carried by welds.

Load to be carried by welds ( $A - A_1$ )  $S = (2.397 - 0.484) \times 20,000 = 38,260 \text{ lb.}$

STRESS VALUE OF WELDS:

Fillet-weld shear

$$0.49 \times 20,000 = 9,800 \text{ psi.}$$

Groove-weld tension

$$0.74 \times 20,000 = 14,800 \text{ psi.}$$

Stress value of nozzle wall shear

$$0.70 \times 17,100 = 11,970 \text{ psi.}$$

STRENGTH OF WELDS AND NOZZLE NECK:

a. Fillet-weld shear  $\frac{\pi d_o}{2} \times \text{weld leg} \times 9,800 = 10.4065 \times 0.375 \times 9,800 = 38,243 \text{ lb.}$

b. Nozzle-wall shear  $\frac{\pi d_o}{2} \times t_n \times 11,970 = 9.72 \times 0.432 \times 11,970 = 50,262 \text{ lb.}$

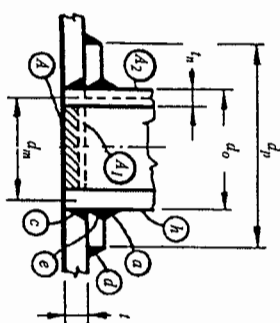
c. Groove-weld tension  $\frac{\pi d_o}{2} \times t \times 14,800 = 10.4065 \times 0.500 \times 14,800 = 77,008 \text{ lb.}$

POSSIBLE PATH OF FAILURES:

1. Through a. and b.  $38,243 + 50,262 = 88,505 \text{ lb.}$
  2. Through a. and c.  $38,243 + 77,008 = 115,251 \text{ lb.}$
- Both paths are stronger than the required strength 38,260 lb.

## STRENGTH OF ATTACHMENTS JOINING OPENINGS TO VESSEL

### EXAMPLE 5.



DESIGN DATA

$A = 3.172 \text{ sq. in.}$ ,  $A_1 = 0.641 \text{ sq. in.}$ ,  $A_2 = 0.907 \text{ sq. in.}$   
 $d_p = 12.845 \text{ in.}$  outside diameter of reinforcing pad.  
 $d_o = 8.625 \text{ in.}$  outside diameter of nozzle.  
 $d_m = 8.125 \text{ in.}$  mean diameter of nozzle.  
 $S = 20,000 \text{ psi}$  allowable stress value of vessel material  
 $S_n = 17,100 \text{ psi}$  allowable stress value of nozzle material  
 $t = 0.5000 \text{ in.}$  thickness of vessel wall.  
 $0.375 \text{ in.}$  leg of fillet - weld a  
 $0.250 \text{ in.}$  leg of fillet - weld d  
 $t_e = 0.250 \text{ in.}$  thickness of reinforcing pad.  
 Check the strength of attachment of nozzle.

LOAD TO BE CARRIED BY WELDS:

$$(A - A_1)S = (3.172 - 0.641) \times 20,000 = 50,620 \text{ lb.}$$

LOAD TO BE CARRIED BY WELDS a, c, e:

$$(A_2 + 2 t_e p)S = (0.907 + 2 \times 0.500 \times 0.500) \times 17,100 \text{ lb.} = 24,059$$

STRESS VALUE OF WELDS:

Fillet - weld shear  $0.49 \times 20,000 = 9,800 \text{ psi}$

Groove - weld tension  $0.74 \times 20,000 = 14,800 \text{ psi}$

STRESS VALUE OF NOZZLE WALL SHEAR:

$$0.70 \times 17,100 = 11,970 \text{ psi}$$

STRENGTH OF WELDS AND NOZZLE NECK:

a. Fillet weld shear  $\frac{\pi d_o}{2} \times \text{weld leg} \times 9,800 = 13.55 \times 0.375 \times 9,800 = 49,796 \text{ lb.}$

b. Nozzle wall shear  $\frac{\pi d_o}{2} \times t_n \times 11,970 = 12.76 \times 0.500 \times 11,970 = 76,368 \text{ lb.}$

c. Groove weld tension  $\frac{\pi d_o}{2} \times \text{weld leg} \times 14,800 = 13.55 \times 0.500 \times 14,800 = 100,270 \text{ lb.}$

d. Fillet weld shear  $\frac{\pi d_p}{2} \times \text{weld leg} \times 9,800 = 20.18 \times 0.25 \times 9,800 = 49,433 \text{ lb.}$

e. Groove weld tension  $\frac{\pi d_o}{2} \times \text{weld leg} \times 14,800 = 13.55 \times 0.25 \times 14,800 = 50,128 \text{ lb.}$

POSSIBLE PATH OF FAILURE:

1. Through b and d  $76,368 + 49,433 = 125,801 \text{ lb.}$

2. Through c and d  $100,270 + 49,433 = 149,703 \text{ lb.}$

3. Through a, c and e  $49,796 + 100,270 + 50,128 = 200,194 \text{ lb.}$

Paths 1. and 2. are stronger than the total strength of 50,620 lb.

The outer fillet weld d strength 49,433 lb. is greater than the reinforcing pad strength of  $(d_p - d_o)t_e \times S = (12.845 - 8.625) \times 0.25 \times 20,000 = 21,100 \text{ lb.}$



## LENGTH OF COUPLINGS AND PIPE FOR OPENINGS

	<p><b>NOZZLE IN SPHERE OR CYLINDER</b></p> $C = R_1 - \sqrt{R_1^2 - r^2}$ <p>EXAMPLE:</p> <p>Given: <math>R_1 = 15</math> in., <math>r = 8</math> in.</p> <p>Find: <math>C = 15 - \sqrt{15^2 - 8^2}</math></p> $= 15 - \sqrt{225 - 64} = 15 - 12.6886 = 2.3114$ in.
	<p><b>NOZZLE IN SPHERE OR CYLINDER</b></p> $X = G - Y \quad Y = \sqrt{R_1^2 - (F + r)^2}$ <p>EXAMPLE:</p> <p>Given: <math>R_1 = 15</math> in., <math>G = 24</math> in., <math>F = 6</math> in., <math>r = 4.3125</math> in.</p> <p>Find: <math>X</math></p> $Y = \sqrt{15^2 - (6 + 4.3125)^2} = \sqrt{225 - 106} = \sqrt{119}$ $Y = 10.9 \quad X = 24 - 10.9 = 13.1$ in.
	<p><b>COUPLING IN SPHERE OR CYLINDER</b></p> $X = Y - Y \quad Y = \sqrt{R_1^2 - (F - r)^2} \quad Y = \sqrt{R_2^2 - (F + r)^2}$ <p>EXAMPLE:</p> <p>Given: <math>R_1 = 15</math> in., <math>R_2 = 16</math> in., <math>F = 6</math> in., <math>r = 1.25</math> in.</p> $Y = \sqrt{16^2 - (6 - 1.25)^2} = \sqrt{256 - 22.56} = 15.30$ in. $Y = \sqrt{15^2 - (6 + 1.25)^2} = \sqrt{225 - 52.56} = 13.12$ in. $X = 15.30 - 13.12 = 2.18$ in.
	<p><b>COUPLING IN SPHERE OR CYLINDER</b></p> $X = Y - Y, \quad \sin \beta = A/R_2, \quad Y = \alpha + \beta$ $F = \sin \gamma \times R_2$ <p>EXAMPLE:</p> <p>Given: <math>R_2 = 12</math> in., <math>\alpha = 15^\circ</math>, <math>A = 6</math> in.</p> <p>Find: <math>F</math></p> $\sin \beta = 6/12 = 0.500 = 30^\circ \quad \gamma = 30^\circ + 15^\circ = 45^\circ$ $F = \sin 45^\circ \times 6 = 0.7071 \times 6 = 4.243$ in. <p>When <math>F</math> is known, Find <math>X</math> as in Example C above.</p>
	<p><b>NOZZLE IN 2:1 ELLIPSOIDAL HEAD</b></p> $X = G - Y - SF \quad Y = \sqrt{R_1^2 - (F + r)^2}$ <p>EXAMPLE:</p> <p>Given: <math>R_1 = 24</math> in., <math>F = 12</math> in., <math>r = 8</math> in., <math>SF = 2</math> in.</p> <p>Find: <math>X</math></p> $Y = \sqrt{24^2 - (12 + 8)^2} = \sqrt{576 - 400} = 6.3$ in. $X = 20 - 6.63 - 2 = 11.37$ in.

## LENGTH OF COUPLING AND PIPE FOR OPENINGS

	<p><b>COUPLING IN 2:1 ELLIPSOIDAL HEAD</b></p> $X = V - Y, \quad V = \frac{\sqrt{R_2^2 - (F - r)^2}}{2}, \quad Y = \frac{\sqrt{R_1^2 - (F + r)^2}}{2}$ <p>EXAMPLE:</p> <p>Given: <math>R_1 = 29</math> in., <math>R_2 = 30</math> in., <math>F = 18</math> in., <math>r = 1</math> in.</p> <p>Find: <math>X</math></p> $V = \frac{\sqrt{30^2 - (18 - 1)^2}}{2} = \frac{\sqrt{900 - 289}}{2} = 12.36$ in. $Y = \frac{\sqrt{29^2 - (18 + 1)^2}}{2} = \frac{\sqrt{841 - 361}}{2} = 10.95$ in. $X = 12.36 - 10.95 = 1.41$ in.
	<p><b>NOZZLE IN FLANGED &amp; DISHED HEAD</b></p> $X = G - Y - SF, \quad Y = ID - C, \quad C = R_1 \cdot \sqrt{R_1^2 - (F + r)^2}$ <p>EXAMPLE:</p> <p>Given: Inside depth of dish, <math>ID = 8</math> in., <math>R_1 = 48</math> in., <math>R_2 = 49</math> in., <math>F = 24</math> in., <math>r = 2</math> in., <math>G = 18</math> in., <math>SF = 2</math> in.</p> <p>Find: <math>X</math></p> $C = 48 \cdot \sqrt{48^2 - (24 + 2)^2} = 7.70$ in. $X = 18 - 7.70 - 2 = 8.30$ in.
	<p><b>COUPLING IN FLANGED &amp; DISHED HEAD</b></p> $X = V - Y, \quad V = \sqrt{R_2^2 - (F - r)^2}, \quad Y = \sqrt{R_1^2 - (F + r)^2}$ <p>EXAMPLE:</p> <p>Given: <math>R_1 = 24</math> in., <math>R_2 = 25</math> in., <math>F = 8</math> in., <math>r = 1</math> in.</p> <p>Find: <math>X</math></p> $V = \sqrt{25^2 - (8 - 1)^2} = \sqrt{625 - 49} = 24$ in. $Y = \sqrt{24^2 - (8 + 1)^2} = \sqrt{576 - 81} = 22.25$ in. $X = 24 - 22.25 = 1.75$ in.
	<p><b>NOZZLE IN CONE</b></p> <p>When <math>\alpha</math> is less than <math>45^\circ</math></p> $X = G - Y, \quad Y = R_1 - (\tan \alpha \times (F + r))$ <p>EXAMPLE:</p> <p>Given: <math>R_1 = 24</math> in., <math>G = 30</math> in., <math>F = 12</math> in., <math>r = 2</math> in., <math>\alpha = 30^\circ</math></p> <p>Find: <math>X</math></p> $Y = 24 - (\tan 30^\circ (12 + 2)) = 24 - 8.08 = 15.92$ in. $X = 30 - 15.92 = 14.08$ in.
	<p><b>COUPLING IN CONE</b></p> $X = V + 2Y, \quad V = \frac{t_c}{\cos \alpha}, \quad Y = \tan \alpha \times r$ <p>EXAMPLE:</p> <p>Given: <math>t_c = 2</math> in., <math>r = 1</math> in., <math>\alpha = 30^\circ</math></p> <p>Find: <math>X</math></p> $V = \frac{2}{0.866} = 2.31 \quad Y = 0.5774 \times 1 = 0.5774$ $X = 2.31 + 2 \times 0.5774 = 3.46$ in.



## NOZZLE NECK THICKNESS

### Code UG-45

1. for Access Openings, Openings for Inspection only the minimum wall thickness of necks shall not be less than the thickness computed from the applicable loadings in UG-22 such as internal or external pressure, static, cyclic, dynamic, seismic, impact reactions, etc.
2. for Nozzles and other openings (except access and inspection openings) the minimum wall thickness of necks shall be the larger of the thickness computed from the applicable loadings in UG-22 or the smaller of wall thickness determined in 3, 4, 5, 6 below.

3. In vessels under internal pressure thickness of the shell or head required for internal pressure only, assuming  $E = 1.0$ .

4. In vessels under external pressure thickness of the shell or head for internal pressure using it as an equivalent value for external pressure, assuming  $E = 1.0$ .

5. In vessels under internal or external pressure the greater of the thickness determined in 3 and 4.

6. The minimum wall thickness of standard wall pipe.

7. The wall thickness of necks in no case shall be less than the minimum thickness specified in UG-16(b) for:
 

Shells and heads:	0.0625 in.
Unfired steam boilers:	0.2500 in.
In compressed air service:	0.0918 in.

8. Allowance for corrosion and threading - when required - shall be added to the thicknesses determined in 1. through 7. above.

Using pipe listed in Table of Std. ANSI B36.10, the minimum wall thickness equals 0.875 times the nominal wall thickness.

See Code UG-45 footnote No. 27 using pipe sizes 22, 26 and 30 inches.

For selection of required pipe under internal pressure, see table "Maximum Allowable Internal Working Pressure for Pipes" on the following pages.

EXAMPLES for using the table:

1. Opening Diameter:	18"
Internal Design Pressure:	800 psig
Corrosion Allowance	0.125"
The Required Pipe for Manway:	Sch. 60
The Required Pipe for Nozzle:	Sch. 60
2. Opening Diameter:	18"
Internal Design Pressure:	150 psig
Corrosion Allowance	0.125"
The Vessel Wall Thickness	0.3125"
The Required Pipe for Manway:	Sch. 10
The Required Pipe for Nozzle:	Std. Wt
	0.250" Wall
	0.375" Wall

## NOZZLE NECK THICKNESS

Code UG-45  
(Continued)

3. Opening Diameter: 18"  
 Internal Design Pressure: 140 psig  
 Corrosion Allowance: 0.125"  
 The Vessel Wall Thickness: 0.750"  
 The Required Pipe for Manway: Sch. 10  
 The Required Pipe for Nozzle: Sch. 40  
 Std. Wt. 0.328" + 0.125" Corr. Allow. 0.250" Wall  
 0.453" Wall (min.)

4. External Design Pressure:  $P = 35$  psi  
 Material SA 516-60:  $S = 17,100$   
 Outside diameter of cylindrical shell:  $D_0 = 96$  in.  
 Shell thickness:  $t = 1$  in.  
 The required thickness for 14 in. O.D., 12 in. long nozzle neck:

1. To withstand 35 psi external pressure approximately 0.05 in. wall required, but the thickness shall not be less than the smaller of:

2. The thickness required for the shell under 35 psi internal pressure (as equivalent external pressure)

$$t = \frac{PR}{SE - 0.6P} = \frac{35 \times 47}{17,100 - 32} = 0.097 \text{ in.}$$

3. The minimum thickness of standard wall pipe: 0.328 in. (0.375 in. nom.)  
 The smaller of 2. and 3. 0.097 for wall thickness of nozzle neck is satisfactory.

5. External Design Pressure:  $P = 15$  psi  
 Material SA 516-60:  $S = 17,100$   
 Outside diameter of cylindrical shell:  $D_0 = 36$  in.  
 Shell thickness:  $t = 0.3125$  in.

The required thickness for 14 in. O.D., 12 in. long nozzle neck:

1. To withstand 15 psi external pressure approximately 0.02 in. wall required, but the thickness shall not be less than the smaller of the following:

2. The thickness required for the shell under 15 psi internal pressure
- $$t = \frac{PR}{SE - 0.6P} = \frac{15 \times 17.6875}{17,100 - 9} = 0.016 \text{ in.}$$

3. The minimum thickness of standard wall pipe: 0.328 in. (0.375 in. nom.)  
 The smaller of 2. and 3. is 0.016 in., but the thickness of the nozzle neck shall be in no case less than 0.0625 in. UG-45(a)(2).



### MAXIMUM ALLOWABLE INTERNAL WORKING PRESSURE FOR PIPES

The Calculations Based on the Formula:

$$P = \frac{2SEt}{D + 1.2t}, \text{ where}$$

P = The max. allowable working pressure, psig.

S = 17,100 psig. the stress value of the most commonly used materials for pipe (A53B, A106B) at temperature - 20 to 650 °F. For higher temperature see notes at the end of the tables.

E = 1.0 joint efficiency of seamless pipe

D = Inside diameter of pipe, in.

t = Minimum pipe wall thickness, in. (.875 times the nominal thickness).

Norm. pipe size	Desig- nation	Pipe wall thickness		Corrosion allowance in.				
		Nom.	Min.	Max. Allow. Pressure psig.				
				0	1/16	1/8	3/16	1/4
1/2	STD.	0.109	0.095	4,252	1,365			
	X-STG.	0.147	0.129	5,987	2,888	163		
	SCH.160	0.187	0.164	7,912	4,575	1,649		
3/4	XX-STG.	0.294	0.257	13,854	9,719	6,146	3,030	287
	STD.	0.113	0.099	3,487	1,222			
	X-STG.	0.154	0.135	4,900	2,498	328		
1	SCH.160	0.218	0.191	7,280	4,638	2,263	114	
	XX-STG.	0.308	0.270	11,071	8,026	5,308	2,867	661
	STD.	0.133	0.116	3,245	1,437			
1-1/4	X-STG.	0.179	0.154	4,513	2,607	848		
	SCH. 160	0.250	0.219	6,570	4,498	2,592	834	
	XX-STG.	0.358	0.313	10,054	8,462	5,519	3,532	1,703
1-1/2	STD.	0.140	0.123	2,692	1,283			
	X-STG.	0.191	0.167	3,741	2,266	882		
	SCH.160	0.250	0.219	5,043	3,487	2,028	658	
2	XX-STG.	0.382	0.334	8,201	6,435	4,788	3,246	1,803
	STD.	0.145	0.127	2,414	1,192	35		
	X-STG.	0.200	0.175	3,399	2,124	918		
2	SCH.160	0.281	0.246	4,939	3,578	2,294	1,079	
	XX-STG.	0.400	0.350	7,388	5,886	4,473	3,139	1,878
	STD.	0.154	0.135	2,036	1,069	143		
2	X-STG.	0.218	0.191	2,938	1,933	971	50	
	SCH.160	0.343	0.300	4,805	3,716	2,676	1,683	731
	XX-STG.	0.436	0.382	6,312	5,155	4,050	2,997	1,988

### MAXIMUM ALLOWABLE WORKING PRESSURE (cont)

Norm. pipe size	Desig- nation	Pipe wall thickness		Corrosion allowance in.				
		Nom.	Min.	Max. Allow. Pressure Psig.				
				0	1/16	1/8	3/16	1/4
2 1/4	STD.	0.203	0.178	2,227	1,419	639		
	X-STG.	0.276	0.242	3,085	2,246	1,437	657	
	SCH.160	0.375	0.328	4,293	3,409	2,559	1,738	947
3	XX-STG.	0.552	0.483	6,637	5,664	4,728	3,829	2,962
	STD.	0.216	0.186	1,930	1,272	633	13	
	X-STG.	0.300	0.263	2,793	2,053	1,391	750	126
3 1/2	SCH.160	0.438	0.383	4,100	3,378	2,679	1,999	1,339
	XX-STG.	0.600	0.525	5,874	5,052	4,301	3,572	2,867
	STD.	0.226	0.198	1,762	1,190	632	88	
4	X-STG.	0.318	0.278	2,515	1,925	1,348	787	240
	XX-STG.	0.636	0.557	5,359	4,691	4,042	3,410	2,208
	STD.	0.237	0.208	1,640	1,134	639	156	
5	X-STG.	0.337	0.295	2,365	1,842	1,331	832	319
	SCH.120	0.438	0.383	3,122	2,582	2,054	1,539	1,035
	SCH.160	0.531	0.465	3,852	3,294	2,749	2,218	1,698
6	XX-STG.	0.674	0.590	5,009	4,423	3,852	3,294	2,749
	STD.	0.258	0.226	1,435	1,028	629	237	
	X-STG.	0.375	0.328	2,115	1,696	1,284	881	484
7	SCH.120	0.500	0.438	2,872	2,439	2,014	1,597	1,187
	SCH.160	0.625	0.547	3,649	3,201	2,761	2,330	1,907
	XX-STG.	0.750	0.656	4,452	3,988	3,534	3,088	2,650
8	STD.	0.280	0.245	1,303	963	628	298	
	X-STG.	0.432	0.378	2,044	1,692	1,346	1,005	670
	SCH.120	0.562	0.492	2,699	2,338	1,981	1,631	1,285
9	SCH.160	0.718	0.628	3,507	3,132	2,764	2,400	2,044
	XX-STG.	0.864	0.756	4,294	3,906	3,526	3,150	2,781
	SCH.20	0.250	0.219	885	629	375	128	
10	SCH.30	0.277	0.242	981	722	468	216	
	STD.	0.322	0.282	1,147	888	631	377	126
	SCH.60	0.406	0.355	1,454	1,191	931	673	419
11	X-STG.	0.500	0.438	1,809	1,542	1,277	1,016	758
	SCH.100	0.593	0.519	2,161	1,890	1,621	1,355	1,093
	SCH.120	0.718	0.628	2,643	2,365	2,091	1,820	1,552



## MAXIMUM ALLOWABLE WORKING PRESSURE (cont)

Nom. pipe size	Desig-nation	Pipe wall thickness		Corrosion allowance in.					
		Nom.	Min.	Max. Allow Pressure Psig.					
				0	1/16	1/8	3/16	1/4	
8	SCH.140	0.812	0.711	3,017	2,736	2,456	2,180	1,909	
	SCH.160	0.906	0.793	3,393	3,106	2,822	2,543	2,266	
	XX-STG.	0.875	0.766	3,269	2,983	2,701	2,423	2,148	
	SCH.20	0.250	0.219	707	502	300	102	57	
10	SCH.30	0.307	0.269	873	666	462	259	120	
	STD.	0.365	0.319	1,038	831	625	421	220	
	X-STG.	0.500	0.438	1,439	1,228	1,019	811	606	
	SCH.80	0.593	0.519	1,716	1,502	1,290	1,080	873	
	SCH.100	0.718	0.628	2,095	1,877	1,662	1,447	1,236	
	SCH.120	0.843	0.738	2,484	2,261	2,248	1,825	1,610	
	SCH.140	1.000	0.875	2,976	2,750	2,526	2,264	2,085	
	SCH.160	1.125	0.984	3,377	3,146	2,918	2,692	2,469	
12	SCH.20	0.250	0.219	595	422	253	86	103	
	SCH.30	0.330	0.289	788	615	443	273	103	
	STD.	0.375	0.328	897	723	550	379	209	
	SCH.40	0.406	0.355	973	799	625	453	282	
	X-STG.	0.500	0.438	1,207	1,030	856	681	554	
	SCH.60	0.562	0.492	1,361	1,183	1,006	832	658	
	SCH.80	0.687	0.601	1,674	1,494	1,315	1,137	962	
	SCH.100	0.843	0.738	2,074	1,891	1,710	1,528	1,349	
	SCH.120	1.000	0.875	2,482	2,295	2,110	1,926	1,744	
	SCH.140	1.125	0.984	2,812	2,623	2,435	2,248	2,063	
	SCH.160	1.312	1.148	3,317	3,123	2,932	2,740	2,552	
	SCH.10	0.250	0.219	541	385	230	78	55	
14	SCH.20	0.312	0.273	677	519	363	209	190	
	STD.	0.375	0.328	816	657	501	345	190	
	SCH.40	0.438	0.383	956	796	639	482	327	
	X-STG.	0.500	0.438	1,096	937	774	620	463	
	SCH.60	0.593	0.519	1,306	1,144	983	825	666	
	SCH.80	0.750	0.656	1,664	1,500	1,337	1,175	1,014	
	SCH.100	0.937	0.820	2,101	1,933	1,767	1,602	1,438	
	SCH.120	1.093	0.956	2,469	2,299	2,130	1,963	1,796	
	SCH.140	1.250	1.094	2,850	2,676	2,505	2,334	2,166	
	SCH.160	1.406	1.230	3,230	3,055	2,880	2,707	2,535	
	SCH.10	0.250	0.219	473	336	189	64	49	
	SCH.20	0.312	0.273	590	453	318	183	166	
16	SCH.30	0.375	0.328	712	574	437	302	166	
	STD.	0.500	0.438	956	817	679	541	404	
	SCH.40	0.500	0.438	956	817	679	541	404	
	X-STG.	0.656	0.574	1,263	1,121	981	841	703	
	SCH.60	0.843	0.738	1,637	1,493	1,350	1,209	1,068	
	SCH.80	1.031	0.902	2,018	1,873	1,727	1,583	1,439	
	SCH.100	1.218	1.066	2,406	2,257	2,110	1,963	1,818	
	SCH.120	1.438	1.258	2,869	2,717	2,566	2,416	2,268	
18	SCH.140	1.593	1.394	3,202	3,048	2,895	2,743	2,593	
	SCH.160	1.781	1.558	3,179	3,042	2,907	2,772	2,637	
	SCH.10	0.250	0.219	419	298	178	61	43	
	SCH.20	0.312	0.273	524	403	282	163	148	
	STD.	0.375	0.328	631	509	388	267	148	
	SCH.30	0.438	0.383	739	616	494	373	253	
	X-STG.	0.500	0.438	848	725	603	481	359	
	SCH.40	0.562	0.492	955	831	707	585	463	
20	SCH.60	0.750	0.656	1,287	1,157	1,032	908	785	
	SCH.80	0.937	0.820	1,616	1,488	1,362	1,235	1,110	
	SCH.100	1.156	1.012	2,013	1,883	1,754	1,625	1,497	
	SCH.120	1.375	1.203	2,414	2,282	2,151	2,020	1,890	
	SCH.140	1.562	1.367	2,764	2,631	2,496	2,364	2,232	
	SCH.160	1.781	1.558	3,179	3,042	2,907	2,772	2,637	
	SCH.10	0.250	0.219	377	263	160	54	133	
	SCH.20	0.375	0.328	567	458	348	240	133	
	STD.	0.500	0.438	761	650	541	432	323	
	SCH.30	0.593	0.519	906	794	684	573	463	
	X-STG.	0.812	0.711	1,250	1,137	1,026	914	802	
	SCH.60	1.031	0.902	1,599	1,485	1,370	1,257	1,144	
20	SCH.80	1.281	1.121	2,006	1,888	1,772	1,657	1,542	
	SCH.100	1.500	1.313	2,368	2,250	2,131	2,014	1,898	
	SCH.120	1.750	1.531	2,788	2,667	2,546	2,427	2,308	
	SCH.140	1.968	1.722	3,162	3,039	2,916	2,795	2,674	
	SCH.160	2.125	1.875	3,547	3,424	3,301	3,180	3,059	
	SCH.10	0.250	0.219	377	263	160	54	133	
	SCH.20	0.375	0.328	567	458	348	240	133	
	STD.	0.500	0.438	761	650	541	432	323	

## MAXIMUM ALLOWABLE WORKING PRESSURE (cont)

Nom. pipe size	Desig-nation	Pipe wall thickness		Corrosion allowance in.					
		Nom.	Min.	Max. Allow Pressure Psig.					
				0	1/16	1/8	3/16	1/4	
14	SCH.160	1.406	1.230	3,230	3,055	2,880	2,707	2,535	
	SCH.10	0.250	0.219	473	336	189	64	49	
	SCH.20	0.312	0.273	590	453	318	183	166	
	SCH.30	0.375	0.328	712	574	437	302	166	
16	STD.	0.500	0.438	956	817	679	541	404	
	SCH.40	0.500	0.438	956	817	679	541	404	
	X-STG.	0.656	0.574	1,263	1,121	981	841	703	
	SCH.60	0.843	0.738	1,637	1,493	1,350	1,209	1,068	
	SCH.80	1.031	0.902	2,018	1,873	1,727	1,583	1,439	
	SCH.100	1.218	1.066	2,406	2,257	2,110	1,963	1,818	
	SCH.120	1.438	1.258	2,869	2,717	2,566	2,416	2,268	
	SCH.140	1.593	1.394	3,202	3,048	2,895	2,743	2,593	
18	SCH.160	1.781	1.558	3,179	3,042	2,907	2,772	2,637	
	SCH.10	0.250	0.219	419	298	178	61	43	
	SCH.20	0.312	0.273	524	403	282	163	148	
	STD.	0.375	0.328	631	509	388	267	148	
	SCH.30	0.438	0.383	739	616	494	373	253	
	X-STG.	0.500	0.438	848	725	603	481	359	
	SCH.40	0.562	0.492	955	831	707	585	463	
	SCH.60	0.750	0.656	1,287	1,157	1,032	908	785	
20	SCH.80	0.937	0.820	1,616	1,488	1,362	1,235	1,110	
	SCH.100	1.156	1.012	2,013	1,883	1,754	1,625	1,497	
	SCH.120	1.375	1.203	2,414	2,282	2,151	2,020	1,890	
	SCH.140	1.562	1.367	2,764	2,631	2,496	2,364	2,232	
	SCH.160	1.781	1.558	3,179	3,042	2,907	2,772	2,637	
	SCH.10	0.250	0.219	377	263	160	54	133	
	SCH.20	0.375	0.328	567	458	348	240	133	
	STD.	0.500	0.438	761	650	541	432	323	
	SCH.30	0.593	0.519	906	794	684	573	463	
	X-STG.	0.812	0.711	1,250	1,137	1,026	914	802	
	SCH.60	1.031	0.902	1,599	1,485	1,370	1,257	1,144	
	SCH.80	1.281	1.121	2,006	1,888	1,772	1,657	1,542	
20	SCH.100	1.500	1.313	2,368	2,250	2,131	2,014	1,898	
	SCH.120	1.750	1.531	2,788	2,667	2,546	2,427	2,308	
	SCH.140	1.968	1.722	3,162	3,039	2,916	2,795	2,674	
	SCH.160	2.125	1.875	3,547	3,424	3,301	3,180	3,059	
	SCH.10	0.250	0.219	377	263	160	54	133	
	SCH.20	0.375	0.328	567	458	348	240	133	
	STD.	0.500	0.438	761	650	541	432	323	
	SCH.30	0.593	0.519	906	794	684	573	463	



# MAXIMUM ALLOWABLE WORKING PRESSURE (cont)

Nom. pipe size	Designation	Pipe wall thickness		Corrosion allowance in.				
				Max. Allow. Pressure Psig.				
		Nom.	Min.	0	1/16	1/8	3/16	1/4
22	SCH.10 SCH.20 STD. X-STG. SCH.30 SCH.40 SCH.60 SCH.80 SCH.100 SCH.120 SCH.140 SCH.160	0.250	0.219	343	243	145	50	35
		0.312	0.273	428	329	230	132	85
		0.375	0.328	515	416	316	218	120
		0.437	0.382	601	501	402	304	155
		0.500	0.438	690	591	491	392	294
		0.562	0.492	776	677	577	477	378
24	SCH.10 SCH.20 STD. X-STG. SCH.30 SCH.40 SCH.60 SCH.80 SCH.100 SCH.120 SCH.140 SCH.160	0.625	0.547	867	766	665	565	466
		0.688	0.602	956	855	753	653	554
		0.750	0.656	1,044	942	841	739	639
		0.250	0.219	313	223	133	45	110
		0.375	0.328	471	380	290	200	269
		0.500	0.438	632	541	450	359	246
26	SCH.10 SCH.20 STD. X-STG. SCH.30 SCH.40 SCH.60 SCH.80 SCH.100 SCH.120 SCH.140 SCH.160	0.562	0.492	712	620	528	437	346
		0.687	0.601	873	780	688	597	505
		0.968	0.847	1,241	1,146	1,053	959	861
		1.218	1.066	1,574	1,478	1,383	1,289	1,194
		1.531	1.340	1,998	1,900	1,803	1,707	1,610
		1.812	1.586	2,386	2,286	2,187	2,089	1,991
30	SCH.10 SCH.20 STD. X-STG. SCH.30 SCH.40 SCH.60 SCH.80 SCH.100 SCH.120 SCH.140 SCH.160	2.062	1.804	2,734	2,634	2,534	2,433	2,334
		2.343	2.050	3,135	3,032	2,930	2,829	2,728
		0.250	0.219	289	206	123	42	29
		0.312	0.273	361	278	194	111	102
		0.375	0.328	435	351	267	184	173
		0.437	0.382	508	424	339	256	248

NOTE: IF THE STRESS VALUE OF PIPE LESS THAN 17100 PSIG. DUE TO HIGHER TEMPERATURE, MULTIPLY THE MAX. ALLOWABLE PRESSURE GIVEN IN THE TABLES BY THE FACTORS IN THIS TABLE.

		TEMPERATURE NOT EXCEEDING DEGREE OF									
		650	700	750	800	850	900	950	1,000		
A53B	stress values	17,100	15,600	13,000	10,800	8,700	5,900	-	-		
A106B	psig	17,100	15,600	13,000	10,800	8,700	5,900	4,000	2,500		
Factor		1.000	0.9123	0.7602	0.6316	0.4971	0.3450	0.2339	0.1462		

Example:

The Maximum Allowance Pressure for 6" x Stg. Pipe With a Corrosion Allowance of 1/8" From Table = 1,346 psi. - at Temperature 800 °F  
The Max. Allow. Press.  $1,346 \times 0.6316 = 850$  psig.

Example to find max. allow. pressure for any stress values:

The Max. Allow. Press. 1,346 Psig. From Tables  
The Stress Value 13,000 psi.  
For This Pipe The Max. Allow. Pressure  $\frac{13,000}{17,100} \times 1,346 = 1,023$  psi.



## REQUIRED WALL THICKNESS FOR PIPES UNDER INTERNAL PRESSURE

The required wall thickness for pipes, tabulated on the following pages, has been computed with the following formula:

$$t = \frac{PR}{SE - 0.6P}, \text{ where}$$

t = the required minimum wall thickness of pipe, in.

P = internal pressure, psig.

S = 17,100 psig. the stress value of the most commonly used materials for pipe.  
A 53 B and A 106 B @ temperature -20 to 650°F.

E = Joint efficiency of seamless pipe

R = inside radius of the pipe, in.

For the inside diameter of the pipe round figures are shown. With interpolation the required thickness can be determined with satisfactory accuracy.

The thicknesses given in the tables do not include allowance for corrosion.

For the determination of the required pipe wall thickness in piping systems the various piping codes shall be applied.

Selecting pipe, the 12.5% tolerance in wall thickness shall be taken into consideration. The minimum thickness of the pipe wall equals the nominal thickness times .875.

## REQUIRED PIPE WALL THICKNESS FOR INTERNAL PRESSURE

I.S. DIAM.	PRESSURE PSIG.									
	50	100	150	200	250	300	350	400	450	500
1	0.002	0.003	0.005	0.006	0.008	0.009	0.011	0.012	0.014	0.015
2	0.003	0.006	0.009	0.012	0.015	0.018	0.021	0.024	0.027	0.030
3	0.005	0.009	0.014	0.018	0.022	0.027	0.031	0.037	0.040	0.045
4	0.006	0.012	0.018	0.024	0.030	0.036	0.042	0.048	0.054	0.060
5	0.008	0.015	0.022	0.030	0.037	0.045	0.052	0.060	0.067	0.075
6	0.009	0.018	0.027	0.036	0.045	0.054	0.063	0.072	0.081	0.090
7	0.011	0.021	0.031	0.042	0.052	0.062	0.073	0.083	0.094	0.105
8	0.012	0.024	0.036	0.047	0.059	0.071	0.083	0.095	0.107	0.119
9	0.013	0.027	0.040	0.053	0.065	0.080	0.094	0.107	0.121	0.134
10	0.015	0.030	0.044	0.059	0.074	0.089	0.104	0.112	0.134	0.149
11	0.016	0.033	0.049	0.065	0.081	0.098	0.114	0.131	0.147	0.164
12	0.018	0.036	0.053	0.071	0.089	0.107	0.125	0.143	0.161	0.179
13	0.019	0.038	0.058	0.077	0.096	0.116	0.135	0.155	0.174	0.194
14	0.021	0.041	0.062	0.083	0.104	0.124	0.145	0.166	0.188	0.209
15	0.022	0.044	0.066	0.089	0.111	0.133	0.156	0.178	0.201	0.224
16	0.024	0.047	0.071	0.095	0.118	0.142	0.166	0.190	0.214	0.238
17	0.025	0.050	0.075	0.100	0.126	0.151	0.176	0.202	0.228	0.253
18	0.027	0.053	0.080	0.106	0.133	0.160	0.187	0.214	0.241	0.268
19	0.028	0.056	0.084	0.112	0.140	0.169	0.197	0.226	0.254	0.283
20	0.030	0.059	0.089	0.118	0.148	0.178	0.208	0.238	0.268	0.298
21	0.031	0.062	0.093	0.124	0.155	0.187	0.218	0.249	0.281	0.313
22	0.033	0.065	0.097	0.130	0.163	0.195	0.228	0.261	0.294	0.328
23	0.034	0.068	0.102	0.136	0.170	0.204	0.239	0.273	0.308	0.343
24	0.035	0.071	0.106	0.142	0.177	0.213	0.249	0.285	0.321	0.357
25	0.037	0.074	0.111	0.148	0.185	0.222	0.259	0.297	0.335	0.372
26	0.038	0.077	0.115	0.153	0.192	0.231	0.270	0.309	0.348	0.387
27	0.040	0.080	0.119	0.159	0.199	0.240	0.280	0.321	0.361	0.402
28	0.041	0.083	0.124	0.165	0.207	0.249	0.290	0.332	0.375	0.417
29	0.043	0.085	0.128	0.171	0.214	0.257	0.301	0.344	0.388	0.432
30	0.044	0.088	0.133	0.177	0.222	0.266	0.311	0.356	0.401	0.447



### REQUIRED PIPE WALL THICKNESS FOR INTERNAL PRESSURE (cont.)

I.S. DIAM.	PRESSURE PSIG.									
	550	600	650	700	750	800	850	900	950	1,000
1	0.017	0.018	0.020	0.021	0.023	0.024	0.026	0.028	0.029	0.031
2	0.033	0.036	0.039	0.042	0.045	0.048	0.052	0.055	0.058	0.061
3	0.050	0.054	0.059	0.063	0.068	0.073	0.077	0.082	0.087	0.091
4	0.066	0.072	0.078	0.084	0.090	0.097	0.103	0.109	0.115	0.122
5	0.082	0.090	0.098	0.105	0.113	0.121	0.128	0.136	0.144	0.152
6	0.099	0.108	0.117	0.126	0.135	0.145	0.154	0.163	0.173	0.182
7	0.115	0.126	0.136	0.147	0.158	0.169	0.180	0.191	0.201	0.212
8	0.132	0.144	0.156	0.168	0.181	0.193	0.205	0.218	0.230	0.243
9	0.148	0.162	0.175	0.189	0.203	0.217	0.231	0.245	0.259	0.273
10	0.164	0.180	0.195	0.210	0.226	0.241	0.257	0.272	0.288	0.303
11	0.181	0.197	0.214	0.231	0.248	0.265	0.282	0.299	0.316	0.334
12	0.197	0.215	0.234	0.252	0.271	0.289	0.301	0.326	0.345	0.364
13	0.214	0.233	0.253	0.273	0.293	0.313	0.333	0.354	0.374	0.394
14	0.230	0.251	0.273	0.294	0.316	0.337	0.359	0.381	0.403	0.425
15	0.246	0.269	0.292	0.315	0.338	0.361	0.385	0.408	0.431	0.455
16	0.263	0.287	0.312	0.336	0.361	0.385	0.401	0.435	0.460	0.485
17	0.279	0.305	0.331	0.357	0.383	0.409	0.436	0.462	0.489	0.516
18	0.296	0.323	0.350	0.378	0.406	0.434	0.461	0.489	0.518	0.546
19	0.312	0.341	0.370	0.399	0.428	0.458	0.487	0.517	0.546	0.576
20	0.328	0.359	0.389	0.420	0.451	0.482	0.513	0.544	0.575	0.606
21	0.345	0.377	0.409	0.441	0.473	0.506	0.538	0.571	0.604	0.637
22	0.361	0.395	0.428	0.462	0.496	0.530	0.564	0.598	0.633	0.667
23	0.378	0.413	0.448	0.483	0.518	0.554	0.590	0.625	0.661	0.697
24	0.394	0.430	0.467	0.504	0.541	0.578	0.615	0.653	0.690	0.728
25	0.410	0.448	0.487	0.525	0.564	0.602	0.641	0.680	0.719	0.758
26	0.427	0.460	0.506	0.546	0.586	0.626	0.666	0.707	0.747	0.788
27	0.443	0.484	0.525	0.567	0.608	0.650	0.692	0.734	0.776	0.819
28	0.460	0.502	0.545	0.588	0.631	0.674	0.718	0.761	0.805	0.849
29	0.476	0.520	0.564	0.609	0.654	0.698	0.743	0.788	0.834	0.879
30	0.492	0.538	0.584	0.630	0.676	0.722	0.769	0.816	0.862	0.909

### REQUIRED PIPE WALL THICKNESS FOR INTERNAL PRESSURE (cont.)

I.S. DIAM.	PRESSURE PSIG.									
	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000
1	0.034	0.037	0.040	0.043	0.047	0.050	0.053	0.057	0.060	0.063
2	0.067	0.074	0.078	0.086	0.093	0.099	0.106	0.113	0.119	0.126
3	0.101	0.110	0.120	0.130	0.139	0.149	0.159	0.169	0.179	0.189
4	0.139	0.147	0.160	0.173	0.183	0.199	0.212	0.225	0.238	0.252
5	0.168	0.184	0.199	0.216	0.232	0.248	0.265	0.281	0.298	0.315
6	0.201	0.220	0.239	0.259	0.278	0.298	0.318	0.337	0.357	0.378
7	0.235	0.257	0.279	0.301	0.324	0.347	0.370	0.394	0.417	0.441
8	0.268	0.293	0.319	0.345	0.371	0.397	0.423	0.450	0.477	0.503
9	0.301	0.330	0.359	0.388	0.417	0.446	0.476	0.506	0.536	0.566
10	0.335	0.367	0.399	0.431	0.463	0.496	0.529	0.562	0.596	0.629
11	0.368	0.403	0.438	0.474	0.510	0.546	0.582	0.618	0.665	0.692
12	0.402	0.440	0.478	0.517	0.556	0.595	0.635	0.675	0.715	0.755
13	0.435	0.477	0.518	0.560	0.602	0.645	0.688	0.731	0.774	0.818
14	0.469	0.513	0.558	0.603	0.648	0.694	0.740	0.787	0.834	0.881
15	0.502	0.550	0.598	0.646	0.695	0.744	0.793	0.843	0.893	0.944
16	0.536	0.586	0.638	0.689	0.741	0.793	0.846	0.899	0.953	1.007
17	0.569	0.623	0.677	0.732	0.787	0.843	0.899	0.955	1.012	1.070
18	0.603	0.660	0.717	0.775	0.834	0.893	0.952	1.012	1.072	1.132
19	0.636	0.696	0.757	0.818	0.880	0.942	1.005	1.068	1.131	1.195
20	0.669	0.733	0.797	0.861	0.926	0.992	1.058	1.137	1.191	1.258
21	0.703	0.770	0.837	0.904	0.973	1.041	1.110	1.180	1.250	1.321
22	0.736	0.806	0.877	0.947	1.019	1.091	1.163	1.236	1.310	1.384
23	0.770	0.843	0.916	0.991	1.065	1.140	1.216	1.292	1.369	1.447
24	0.803	0.879	0.956	1.034	1.111	1.190	1.269	1.349	1.429	1.510
25	0.837	0.916	0.996	1.077	1.158	1.240	1.322	1.405	1.488	1.573
26	0.870	0.953	1.036	1.120	1.204	1.289	1.375	1.461	1.548	1.636
27	0.904	0.989	1.076	1.163	1.250	1.339	1.428	1.517	1.607	1.698
28	0.937	1.026	1.116	1.206	1.297	1.388	1.480	1.573	1.667	1.761
29	0.971	1.063	1.155	1.249	1.343	1.438	1.533	1.630	1.727	1.824
30	1.004	1.099	1.195	1.292	1.389	1.487	1.586	1.686	1.786	1.887

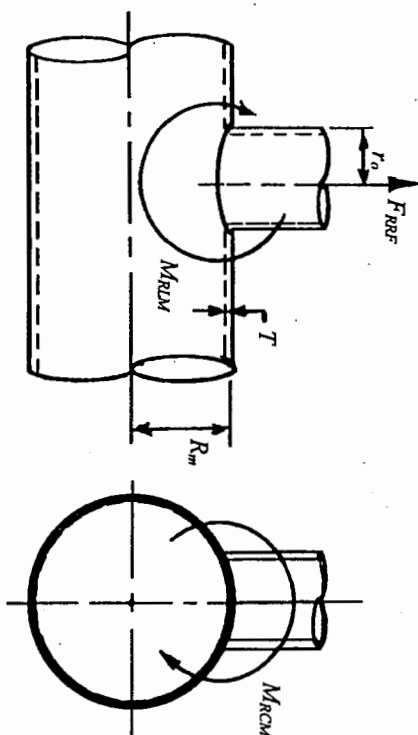


### REQUIRED PIPE WALL THICKNESS FOR INTERNAL PRESSURE (cont.)

I.S.	PRESSURE PSIG.										
	DIAM.	2,100	2,200	2,300	2,400	2,500	2,600	2,700	2,800	2,900	3,000
1	0.067	0.070	0.074	0.077	0.080	0.084	0.088	0.091	0.095	0.098	0.098
2	0.133	0.140	0.147	0.154	0.161	0.168	0.175	0.182	0.189	0.196	0.196
3	0.199	0.209	0.220	0.230	0.241	0.251	0.262	0.273	0.284	0.294	0.294
4	0.266	0.279	0.293	0.307	0.321	0.335	0.349	0.364	0.378	0.393	0.393
5	0.332	0.349	0.366	0.383	0.401	0.419	0.436	0.454	0.472	0.491	0.491
6	0.398	0.419	0.439	0.460	0.481	0.502	0.524	0.545	0.567	0.589	0.589
7	0.464	0.488	0.512	0.537	0.561	0.586	0.611	0.636	0.661	0.687	0.687
8	0.531	0.558	0.586	0.613	0.641	0.670	0.700	0.727	0.756	0.785	0.785
9	0.597	0.628	0.659	0.690	0.722	0.753	0.785	0.818	0.850	0.883	0.883
10	0.663	0.697	0.732	0.767	0.802	0.834	0.872	0.908	0.944	0.981	0.981
11	0.730	0.767	0.805	0.843	0.882	0.921	0.960	0.999	1.039	1.079	1.079
12	0.796	0.837	0.878	0.920	0.962	1.004	1.047	1.090	1.133	1.177	1.177
13	0.862	0.907	0.951	0.997	1.042	1.088	1.134	1.181	1.228	1.275	1.275
14	0.928	0.976	1.025	1.073	1.112	1.172	1.221	1.271	1.322	1.373	1.373
15	0.995	1.046	1.098	1.145	1.202	1.255	1.308	1.362	1.416	1.471	1.471
16	1.061	1.116	1.171	1.226	1.282	1.339	1.396	1.453	1.511	1.569	1.569
17	1.127	1.185	1.244	1.303	1.363	1.421	1.483	1.544	1.605	1.667	1.667
18	1.194	1.255	1.317	1.380	1.443	1.506	1.570	1.635	1.700	1.765	1.765
19	1.260	1.325	1.390	1.456	1.523	1.590	1.657	1.725	1.794	1.863	1.863
20	1.326	1.395	1.463	1.533	1.603	1.673	1.745	1.816	1.888	1.961	1.961
21	1.392	1.464	1.537	1.610	1.683	1.757	1.832	1.907	1.983	2.059	2.059
22	1.459	1.534	1.610	1.686	1.763	1.841	1.919	1.998	2.077	2.157	2.157
23	1.525	1.604	1.683	1.763	1.843	1.924	2.006	2.089	2.172	2.255	2.255
24	1.591	1.673	1.756	1.839	1.923	2.008	2.093	2.179	2.266	2.353	2.353
25	1.658	1.743	1.829	1.916	2.004	2.092	2.181	2.270	2.360	2.451	2.451
26	1.724	1.813	1.902	1.994	2.084	2.175	2.268	2.361	2.455	2.549	2.549
27	1.790	1.883	1.976	2.069	2.164	2.259	2.355	2.452	2.549	2.647	2.647
28	1.856	1.952	2.049	2.146	2.244	2.343	2.442	2.543	2.644	2.745	2.745
29	1.924	2.022	2.122	2.223	2.324	2.426	2.529	2.633	2.738	2.843	2.843
30	1.989	2.092	2.195	2.299	2.404	2.510	2.617	2.724	2.832	2.942	2.942

### NOZZLE EXTERNAL FORCES AND MOMENTS IN CYLINDRICAL VESSELS

Piping by the adjoining nozzles exert local stress in the vessel. The method, below, to determine the nozzle loads is based in part on the Bulletin 107 of Welding Research Council and represents a simplification of it. The vessels are not intended to serve as anchor points for the piping. To avoid excessive loading in the vessel, the piping shall be adequately supported.



#### External Forces & Moments

To calculate the maximum force and moment, first evaluate  $\beta$  and  $\gamma$ . Then determine  $\alpha$ ,  $\Sigma$ , and  $\Delta$  from Figures 1, 2 and 3, for the specified  $\beta$  and  $\gamma$ , substitute into the equations below, and calculate  $F_{RRF}$ ,  $M_{RCM}$  and  $M_{RLM}$ .

$$\beta = .875 \left( \frac{r_o}{R_m} \right) \quad \gamma = \frac{R_m}{T}$$

Determine  $\alpha$ ,  $\Sigma$  and  $\Delta$  from Figures 1, 2 and 3.

Calculate Pressure Stress ( $\sigma$ ).

$$\sigma = \left( \frac{2P}{T} \right) (R_m - \frac{T}{2})$$

If  $\sigma$  is greater than  $S_m$ , then use  $S_u$  as the stress due to design pressure.

$$F_{RRF} = \frac{R_m^2}{\alpha} (S_y - \sigma) \quad M_{RCM} = \frac{R_m^2 r_o S_y}{\Sigma} \quad M_{RLM} = \frac{R_m^2 r_o}{\Delta} (S_y - \sigma)$$



Plot the value of  $F_{RRF}$  as  $F_{RF}$  and the smaller of  $M_{RCM}$  and  $M_{RLM}$  as  $M_{RM}$ . The allowable nozzle loads are bounded by the area of  $F_{RF}$ , 0,  $M_{RM}$ .

EXAMPLE: Determine Resultant Force and Moment

$$R_m = 37.5 \quad T = .75" \quad S_y = 31,500 \text{ psi @ } 460^\circ$$

$$r_o = 15" \quad P = 150 \text{ psi} \quad S_u = 20,000 \text{ psi}$$

$$\beta = .875 \left( \frac{r_o}{R_m} \right) = .875 \left( \frac{15}{37.5} \right) = .35 \quad \gamma = \left( \frac{R_m}{T} \right) = \frac{37.5}{.75} = 50$$

From Figure 1,  $\alpha = 440$  From Figure 2,  $\Sigma = 1,070$  From Figure 3,  $\Delta = 340$



## NOZZLE EXTERNAL FORCES AND MOMENTS IN CYLINDRICAL VESSELS (continued)

Calculate Pressure Stress

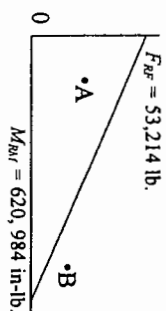
$$\sigma = \frac{2P}{T} \left( R_m - \frac{T}{2} \right) = \frac{2(150)}{7.5} \left( 37.5 - \frac{7.5}{2} \right) = 14,850 \text{ psi} < S_n = 20,000 \text{ psi.}$$

Use  $\sigma = 14,850$  in the equations for calculating  $F_{ref}$  and  $M_{RLM}$   
Calculate Allowable Forces and Moments

$$F_{ref} = \frac{R_m^2}{\alpha} (S_y - \sigma) = \frac{(3.75)^2}{440} (31,500 - 14,850) = 53,214 \text{ lb.}$$

$$M_{RCM} = \frac{R_m^2 r_o S_y}{\Sigma} = \frac{37.5^2 (15) (31,500)}{1,070} = 620,984 \text{ in.-lb.}$$

$$M_{RLM} = \frac{R_m^2 r_o}{\Delta} (S_y - \sigma) = \frac{(37.5)^2 (15)}{340} \times 31,500 - 14,850 = 1,032,973 \text{ in.-lb.}$$



Plot for the value of  $F_{ref}$  as  $F_{ref}$  and the smaller of  $M_{RCM}$  and  $M_{RLM}$  as  $M_{RLM}$ . The allowable nozzle loads are bounded by the area of  $F_{ref}$ ,  $O$ ,  $M_{RLM}$ .  
Therefore, a nozzle reaction of  $F = 20,000$  lbs. and  $M = 100,000$  in. lbs. would be allowable (point A) but a nozzle reaction of  $F = 5,000$  lbs. and  $M = 620,000$  in. lbs. would not be allowable (point B).  
\*Note: Use absolute values in the graph.

### NOTATION:

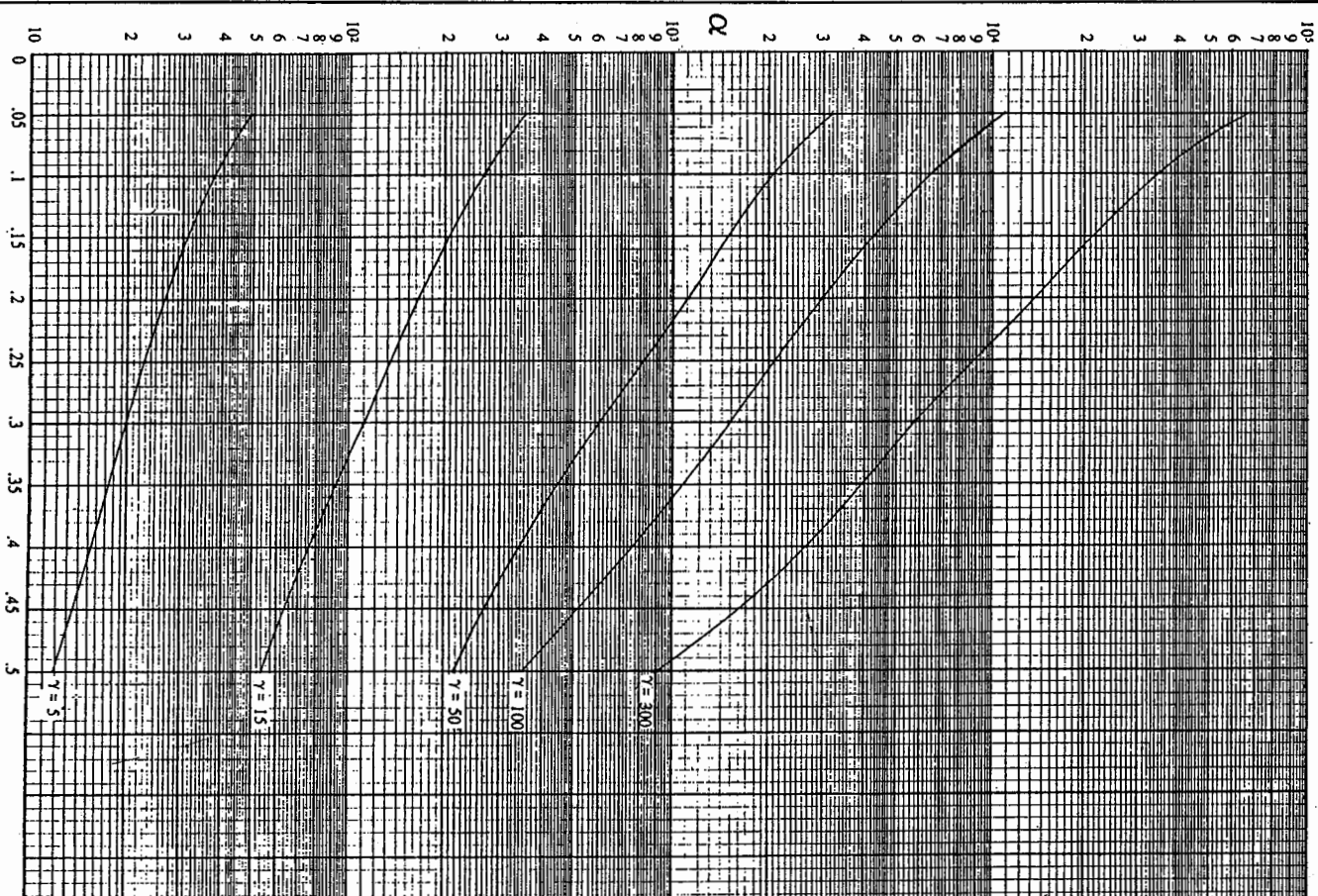
$P$ = Design Pressure, pounds per sq. in.	$\Sigma$ = Dimensionless Numbers
$r_o$ = Nozzle Outside Radius, inches	$\Delta$ = Dimensionless Numbers
$R_m$ = Mean Radius of Shell, inches	$F_{ref}$ = Maximum Resultant Radial Force, pounds*
$T$ = Shell Thickness, inches	$M_{RCM}$ = Maximum Resultant Circumferential Moment, inch-pounds*
$S_y$ = Yield Strength of Material at Design Temperature, pounds per square inch	$M_{RLM}$ = Maximum Resultant Longitudinal Moment, inch-pounds*
$\sigma$ = Stress Due to Design Pressure, pounds per square inch	$F_{ref}$ = Maximum Resultant Force, pounds*
$S_n$ = Stress Value of Shell Material, pounds per square inch	$F_{RLM}$ = Maximum Resultant Moment, inch-pounds*
$\beta$ = Dimensionless Numbers	
$\gamma$ = Dimensionless Numbers	
$\alpha$ = Dimensionless Numbers	

\*Use absolute values.

### REFERENCES:

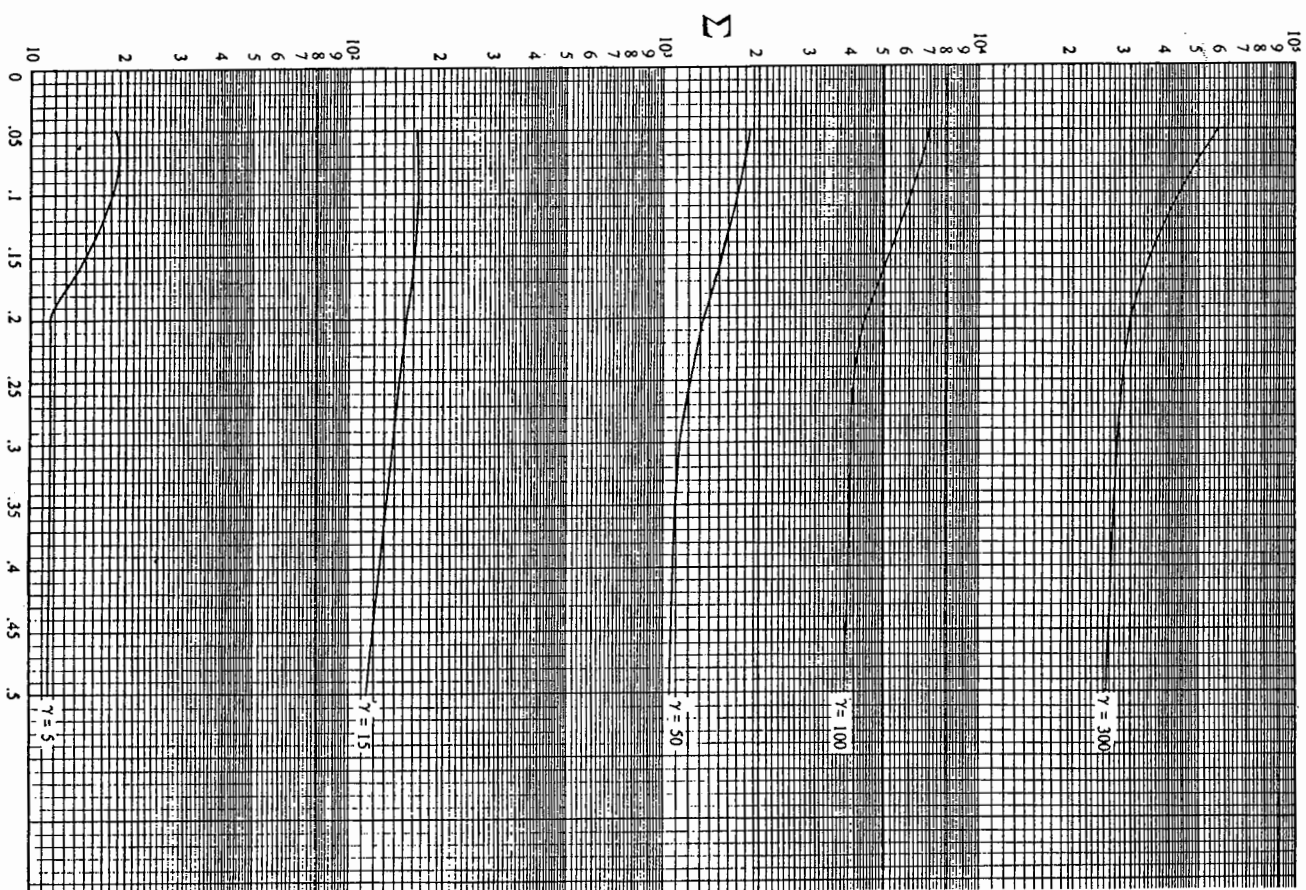
*Local Stresses in Spherical and Cylindrical Shells due to External Loadings*, K. R. Wichman, A. G. Hopper and J. L. Mershon — Welding Research Council. Bulletin 107/August 1965 — Revised Printing — December 1968.  
*Standards for Closed Feedwater Heaters*, Heat Exchange Institute, Inc., 1969.

## NOZZLE LOADS Fig. 1

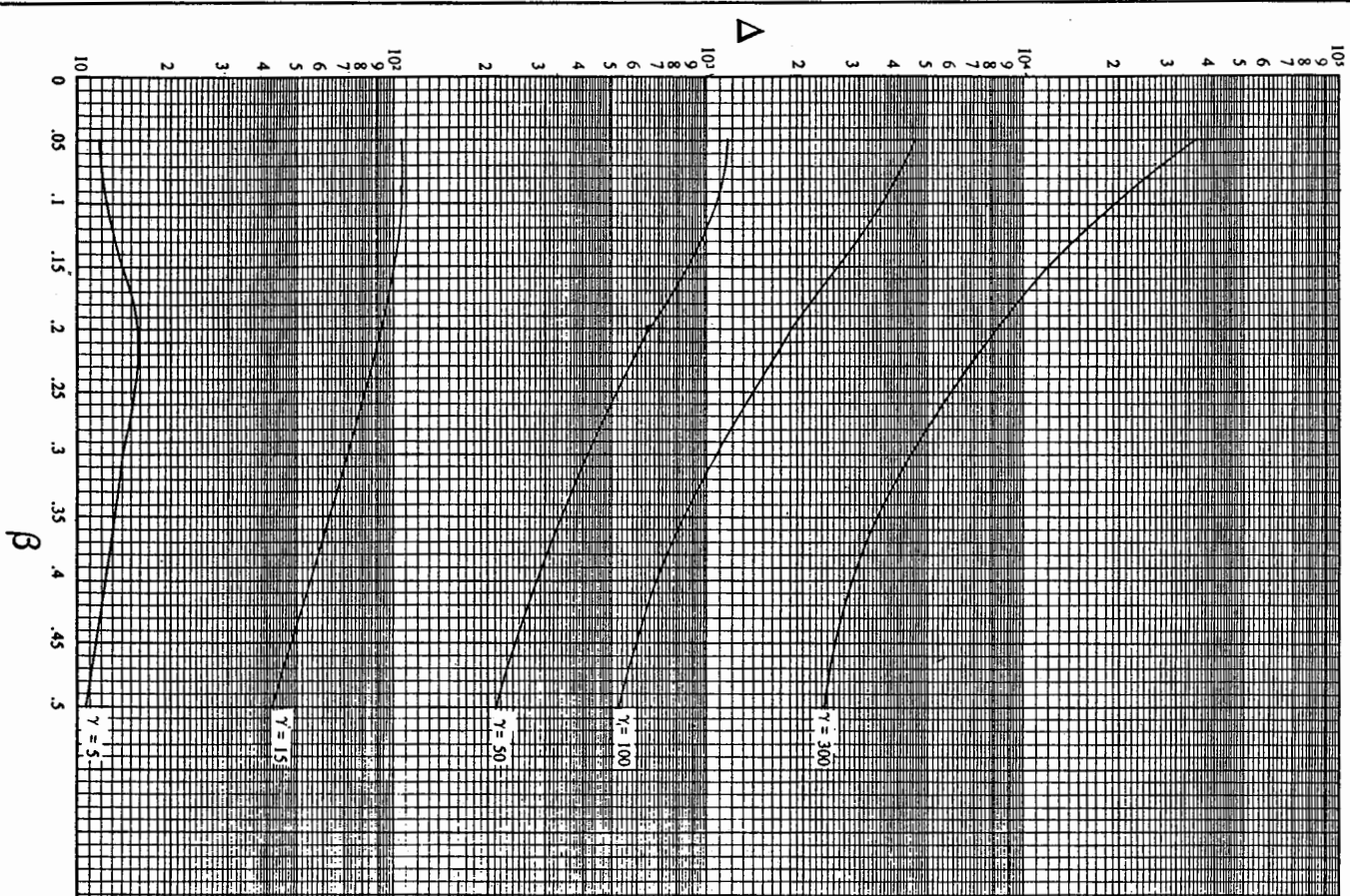




NOZZLE LOADS  
Fig. 2



NOZZLE LOADS  
Fig. 3





## NOTES

# REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER UNDER INTERNAL PRESSURE

At the junction of cone or conical section to cylinder (Fig. C and D) due to bending and shear, discontinuity stresses are induced which are with reinforcement to be compensated.

DESIGN PROCEDURE (The half apex angle  $\alpha \leq 30$  deg.)

1. Determine  $P/S_s E_f$  and read the value of  $\Delta$  from tables A and B.
2. Determine factor  $y$ , For reinforcing ring on shell,  $y = S_s E_s$   
For reinforcing ring on cone,  $y = S_c E_c$

TABLE A - VALUES OF  $\Delta$  FOR JUNCTIONS AT THE LARGE END

$P/S_s E_f$	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009*
$\Delta$ , deg.	11	15	18	21	23	25	27	28.5	30

TABLE B - VALUES OF  $\Delta$  FOR JUNCTIONS AT THE LARGE END

$P/S_s E_f$	0.002	0.005	0.010	0.020	0.040	0.080	0.100	0.125*
$\Delta$ , deg.	4	6	9	12.5	17.5	24	27	30

\*  $\Delta = 30$  deg. for greater value of  $P/S_s E_f$

When the value of  $\Delta$  is less than  $\alpha$ , reinforcement shall be provided.

3. Determine factor  $k = y/S_s E_f$  (Use minimum 1.0 for  $k$  in formula).
4. Design size and location of reinforcing ring (see next page).

## NOTATION

$E$  = with subscripts  $s$ ,  $c$  or  $r$  modulus of elasticity of shell, cone or reinforcing ring material respectively, psi.  
See charts beginning on page 43 for modulus of elasticity.

$E$  = with subscripts 1 or 2 efficiency of welded joints in shell or cone respectively.  
For compression  $E=1.0$  for butt welds.

$f$  = axial load at large end due to wind, dead load, etc. excluding pressure, lb/in.

$f_s$  = axial load at small end due to wind, dead load, etc. excluding pressure, lb/in.

$P$  = Design pressure, psi

$Q_1$  = algebraic sum of  $PR_0/2$  and  $f_1$  lb/in.

$Q_2$  = algebraic sum of  $PR_0/2$  and  $f_2$  lb/in.

$R_c$  = inside radius of large cylinder at large end of cone, in.

$R_s$  = inside radius of small cylinder at small end of cone, in.

$S$  = with subscripts  $s$ ,  $c$  or  $r$  allowable stress of shell, cone or reinforcing material, psi.

$t$  = minimum required thickness of cylinder at the junction, in.

$t_s$  = actual thickness of cylinder at the junction, in.

$t_c$  = minimum required thickness of cone at the junction, in.

$t_r$  = actual thickness of cone at the junction, in.

$\alpha$  = half apex angle of cone or conical section, deg.

$\Delta$  = angle from table A or B, deg.

$y$  = factor:  $S_s E_s$  or  $S_c E_c$



## REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER

### FORMULAS

#### JUNCTION AT THE LARGE END

Required area of reinforcement,  $A$  sq. in. when tension governs (see notes)

$$A_{rt} = \frac{kQ_s R_c}{S E_f} \left(1 - \frac{\Delta}{\alpha}\right) \tan \alpha$$

Area of excess metal for reinforcement, sq. in.

$$A_{et} = (t_s - t) \sqrt{R_c t_s} + (t_c - t) \sqrt{R_c t_c} / \cos \alpha$$

The distance from the junction within which the additional reinforcement shall be situated, in.

$$\sqrt{R_c t_s}$$

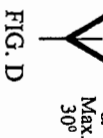


FIG. D

The distance from the junction within which the centroid of the reinforcement shall be situated, in.

$$0.25 \times \sqrt{R_c t_s}$$

#### JUNCTION AT THE SMALL END

Required area of reinforcement  $A$  sq. in. when tension governs (see notes)

$$A_{rs} = \frac{kQ_s R_c}{S E_f} \left(1 - \frac{\Delta}{\alpha}\right) \tan \alpha$$

Area of excess metal available for reinforcement  $A_s$ , sq. in.

$$A_{es} = (t_s / t) \cos (\alpha - \Delta) (t_s - t) \sqrt{R_c t_s} + (t_c / t_s) \times \cos (\alpha - \Delta) (t_c - t_s) \sqrt{R_c t_c} / \cos \alpha$$

The distance from the junction within which the centroid of the reinforcement shall be situated, in.

$$\sqrt{R_c t_s}$$

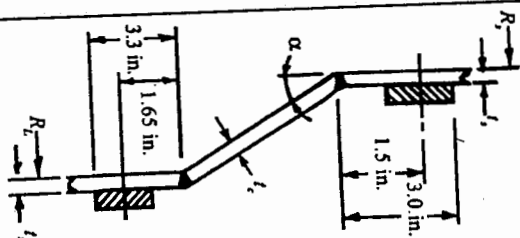
The distance from the junction within which the centroid of the reinforcement shall be situated, in.

$$0.25 \times \sqrt{R_c t_s}$$

**NOTES:** When at the junction compressive loads  $f_c$  or  $f_s$  exceed the tensional loads determined by  $P/R_c/2$  or  $P/R_s/2$  respectively, the design shall be in accordance with U2 (g): ("as safe as those provided by the rules of the Code, Section VIII, Division 1.")  
When the reducers made out of two or more conical sections of different apex angles without knuckle, and when the half apex angle,  $\alpha$  is greater than 30 deg., the design may be based on special analysis. (Code 1-5 (f) & (g).)

## REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER EXAMPLE

### DESIGN DATA:



$\alpha$  = 30 deg., half apex angle of cone.  
 $E_1 E_2$  = 30 x 10<sup>6</sup>, modulus of elasticity, psi.  
 $E_1/E_2$  = 1.0, joint efficiency in shell and cone  
 $E_3$  = 0.55, joint efficiency in reinforcing ring  
 $f_1$  = 800 lb/in., axial load at large end  
 $f_2$  = 952 lb/in., axial load at small end  
 $P$  = 50 psi., internal design pressure  
 $R_c$  = 100 in., inside radius of large cylinder  
 $R_s$  = 84 in., inside radius of small cylinder  
 $R_c$  = 15,700 psi., allowable stress of shell material  
 $S_c$  = 15,700 psi., allowable stress of cone material  
 $S_r$  = 17,100 psi., allowable stress of ring material  
 $t_c$  = 0.429 in., required min. thickness for large cylinder  
 $t_s$  = 0.360 in., required min. thickness for small cylinder  
 $t_r$  = 0.500 in., actual thickness of cone.  
 $t_{cl}$  = 0.4375 in., actual thickness of large cylinder  
 $t_{cs}$  = 0.375 in., actual thickness of small cylinder  
 $t_{cr}$  = 0.41 in., required thickness of cone at small cylinder  
 $t_{rl}$  = 0.49 in., required thickness of cone at large cylinder

Using the same material for shell and cone.

$$1. \quad P/S E_f = \frac{50}{15,700 \times 1} = 0.0032 \text{ from table A. } \Delta = 18.6$$

Since  $\Delta$  is less than  $\alpha$ , reinforcements is required.

2. Using reinforcement ring on the shell

$$y = S E_f = 15,700 \times 30 \times 10^6$$

$$3. \quad \text{Factor } k = y/S E_r = 15,700 \times 30 \times 10^6 / 17,100 \times 30 \times 10^6 = 0.92$$

Use  $k = 1$

$$4. \quad Q_c = P R_c / 2 f_1, \text{ lb/in.} = \frac{50 \times 100}{2} + 800 = 3,300 \text{ lb/in.}$$

$$5. \quad \text{The required cross-sectional area of compression ring:}$$

$$A_{rt} = \frac{k Q_s R_c}{S E_f} \left(1 - \frac{\Delta}{\alpha}\right) \tan \alpha = \frac{1 \times 3,300 \times 100}{15,700 \times 1} \left(1 - \frac{18.6}{30}\right) \tan 30^\circ = 4.62 \text{ sq in.}$$

The area of excess in shell available for reinforcement:

$$A_{et} = (t_{cl} - t_s) \sqrt{R_c t_{cl}} + (t_c - t_{cl}) \sqrt{R_c t_c} / \cos \alpha$$

$$= (0.4375 - 0.429) \times \sqrt{100 \times 0.4375} + (0.5 - 0.49) \times \sqrt{100 \times 0.5} / \cos 30^\circ$$

$$= 0.132 \text{ sq. in.}$$

$A_{et} - A_{rt} = 4.62 - 0.132 = 4.49 \text{ sq. in.}$  the required cross sectional area of compression ring  
 Using 1 in. thick bar, the width of ring:  $4.55/1 = 4.55 \text{ in.}$

Location of compression ring:

$$\text{Maximum distance from the junction} = \sqrt{R_c t_s} = \sqrt{100 \times 0.4375} = 6.60 \text{ in.}$$

$$\text{Maximum distance from the junction} = 0.25 \sqrt{R_c t_s} =$$

$$0.25 \sqrt{100 \times 0.4375} = 1.65 \text{ in.}$$



## REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER EXAMPLE (continued)

### JUNCTION AT SMALL CYLINDER

1.  $P/S_2 E_f = 0.0032$ ; from table B  $\Delta = 4.8^\circ$   
Since  $\Delta$  is less than  $\alpha$ , reinforcement is required.
2. Factor  $\gamma = S_2 E_f = 15,700 \times 30 \times 10^6$
3. Factor  $k = 1$

$$4. Q_2 = PR_2/2 + f_2 \text{ lb./in.} = \frac{50 \times 84}{2} + 952 = 3,052 \text{ lb./in.}$$

5. The required cross-sectional area of compression ring:

$$A_{r2} = \frac{kQ_2 R_2}{S_2 E_f} \left(1 - \frac{\Delta}{\alpha}\right) \tan \alpha = \frac{1 \times 3,052 \times 84}{15,700 \times 1} \left(1 - \frac{4.8}{30}\right) \tan 30^\circ = 7.92 \text{ sq. in.}$$

The area of excess in shell available for reinforcement:

$$A_{r2} = (t_{c2}/t_{s2}) \cos(\alpha - \Delta) (t_{c2} - t_{s2}) \sqrt{R_2 t_{s2}} + (t_{c2}/t_{s2}) \times \cos(\alpha - \Delta) (t_{c2} - t_{s2}) \sqrt{R_2 t_{c2}} / \cos \alpha$$

$$(0.375/0.36) \times \cos(3-4.8) \times (0.375 - 0.36) \times \sqrt{84 \times 0.375} + (0.5/0.41) \cos(30-4.8) \times (0.5-0.41) \times \sqrt{84 \times 0.5/\cos 30^\circ} = 0.77 \text{ sq. in.}$$

$A_{r2} - A_{r2} = 7.92 - 0.77 = 7.15 \text{ sq. in.}$ , the required cross sectional area of compression ring.

Using  $1\frac{1}{2}$  thick bar, the required width of the bar:  $7.15/1.5 = 4.8 \text{ in.}$

Location of the compression ring:

Maximum distance from the junction:  $\sqrt{R_2 t_{s2}} = \sqrt{84 \times 0.375} = 5.6 \text{ in.}$

Maximum distance of centroid from the junction:  $0.25 \sqrt{R_2 t_{s2}} = \sqrt{84 \times 0.375} = 1.4 \text{ in.}$

Insulation ring may be utilized as compression ring provided it is continuous and the ends of it are joined together.

Since the moment of inertia of the ring is not factor, the use of flat bar rolled easy-way is more economical than the use of structural shapes.

To eliminate the necessity of additional reinforcement by using thicker plate for the cylinders at the junction in some cases may be more advantageous than the application of compression rings.

## REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER UNDER EXTERNAL PRESSURE

Reinforcement shall be provided at the junction of cone to cylinder, or at the junction of the large end of conical section to cylinder when cone, or conical section doesn't have knuckles and the value of  $\Delta_1$  obtained from table E, is less than  $\alpha$ .

TABLE E - VALUES OF  $\Delta$

P/SE	0	0.002	0.005	0.010	0.02	0.04	0.08	0.10
$\Delta_1$ , deg	0	5	7	10	15	21	29	33
P/SE	0.125	0.15	0.20	0.25	0.30	0.35		
$\Delta_1$ , deg	37	40	47	52	57	60		

Note: Interpolation may be made for intermediate values.

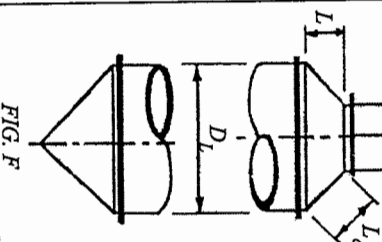


FIG. F

The required moment of inertia and cross-sectional area of reinforcing (stiffening) ring - when the half apex angle  $\alpha$  is equal to or less than 60 degrees - shall be determined by the following formulas and procedure.

1. Determine P/SE, and read the value of  $\Delta$  from table E.
2. Determine the equivalent area of cylinder, cone and stiffening ring,  $A_{TL}$ , sq. in. (See page 48 for construction of stiffening ring.)  
Make subscripts more visible

$$A_{TL} = \frac{L_L t_s}{2} + \frac{L_c t_c}{2} + A_s \quad \text{Calculate factor } B, B = \frac{3}{4} \left( \frac{F_L D_L}{A_{TL}} \right)$$

where

$$F_L = PM + f_1 \tan \alpha \quad M = \frac{-R_L \tan \alpha}{2} + \frac{L_L}{2} + \frac{R_L^2 - R_s^2}{3R_L \tan \alpha}$$

If  $F_L$  is a negative number, the design shall be in accordance with U-2 (b).

3. From the applicable chart (pages 43 thru 47) read the value of  $\Delta$  entering at the value of  $B$ , moving to the left to the material/temperature line and from the intersecting point moving vertically to the bottom of the chart.

For values of  $B$  falling below the left end of the material/temperature line for the design temperature, the value of  $\Delta = 2B/E$ .

If the value of  $B$  is falling above the material/temperature line for the design temperature: the cone or cylinder configuration shall be changed, and/or the stiffening ring relocated, the axial compression stress reduced.

For values of  $B$ , having multiple values of  $\Delta$ , such as when  $B$  falls on a horizontal portion of the curve, the smallest value of  $\Delta$  shall be used.

4. Compute the value of the required moment of inertia

For the stiffening ring only:

$$I_s = \frac{AD_L^2}{14.0} \frac{A_{TL}}{A_{TL}}$$

For the ring-shell-cone section:

$$I_s = \frac{AD_L^2}{10.9} \frac{A_{TL}}{A_{TL}}$$

5. Select the type of stiffening ring and determine the available moment of inertia (see page 95) of the ring only  $I_r$ , or the shell-cone or the ring-shell-cone section  $I'$ .



## REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER

(continued)

If  $I$  or  $I'$  is less than  $I_s$  or  $I'_s$  respectively, select stiffening ring with larger moment of inertia.

6. Determine the required cross-sectional area of reinforcement,  $A_{rL}$ , sq. in. (when compression governs):

$$A_{rL} = \frac{kQ_L R_L \tan \alpha}{SE} \left[ 1 - \frac{1}{4} \left( \frac{P R_L - Q_L}{Q_L} \right) \frac{\Delta}{\alpha} \right]$$

Area of excess metal available for reinforcement:  $A_{eL}$ , sq. in.:

$$A_{eL} = 0.55 \sqrt{D_L t_s} (t_s + t_c / \cos \alpha)$$

The distance from the junction within which the additional reinforcement shall be situated, in.

$$\sqrt{R_L t_s}$$

The distance from the junction within which the centroid of the reinforcement shall be situated, in.

$$0.25 \sqrt{R_L t_s}$$

Reinforcing shall be provided at the junction of small end of conical section without flare to cylinder.

The required moment of inertia and cross-sectional area of reinforcing (stiffening) ring shall be determined by the following formulas and procedure.

1. Determine the equivalent area of cylinder, cone and stiffening ring,  $A_{rS}$ , sq. in.

$$A_{rS} = \frac{L_s t_s}{2} + \frac{L_c t_c}{2} + A_s$$

2. Calculate factor  $B$

$$B = \frac{3}{4} \left( \frac{F_s D_s}{A_{rS}} \right)$$

where

$$F_s = PN + f_j \tan \alpha$$

$$N = \frac{R_s \tan \alpha}{2} + \frac{L_s}{2} + \frac{L_L^2 - R_s^2}{6 R_s \tan \alpha}$$

If  $F_s$  is a negative number, the design shall be in accordance with U-2 (g).

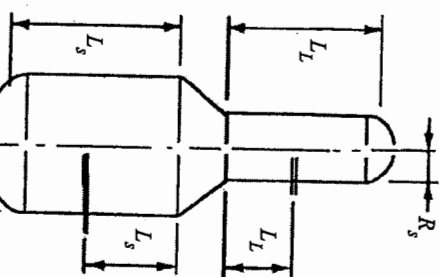


FIG. G

## REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER

(continued)

3. From the applicable chart (pages 43 thru 47) read the value of  $A$  entering at the value of  $B$ , moving to the left to the material/temperature line and from the intersecting point moving vertically to the bottom of the chart.

For values of  $B$  falling below the left end of the material/temperature line for the design temperature, the value of  $A = 2B/E$ .

If the value of  $B$  is falling above the material/temperature line for the design temperature: the cone or cylinder configuration shall be changed, and/or the stiffening ring relocated, the axial compression stress reduced.

For values of  $B$  having multiple values of  $A$ , such as when  $B$  falls on a horizontal portion of the curve, the smallest value of  $A$  shall be used.

4. Compute the value of the required moment of inertia:

For the ring-shell-cone section:

$$I'_s = \frac{A D_s^2 A_{rS}}{10.9}$$

For the stiffening ring only:

$$I_s = \frac{A D_s^2 A_{rS}}{14.0}$$

5. Select the type of stiffening ring and determine the available moment of inertia (see page 95) of the ring only,  $I$  and of the ring-shell-cone section,  $I'$ . If  $I$  or  $I'$  is less than  $I_s$  or  $I'_s$  respectively, select stiffening ring with larger moment of inertia.

6. Determine the required cross-sectional area of reinforcement,  $A_{rS}$ , sq. in.:

$$A_{rS} = \frac{kQ_s R_s \tan \alpha}{SE}$$

Area of excess metal available for reinforcement,  $A_{eS}$ , sq. in.

$$A_{eS} = 0.55 \sqrt{D_s t_s} [(t_s - t) + (t_c - t_r) / \cos \alpha]$$

The distance from the junction within which the additional reinforcement shall be situated, in.

$$\sqrt{R_s t_s}$$

The distance from the junction within which the centroid of the reinforcement shall be situated, in.

$$0.25 \sqrt{R_s t_s}$$

NOTE: When the reducers made out of two or more conical sections of different apex angles without knuckle, and when the half apex angle is greater than 60 degrees, the design may be based on special analysis. (Code 1-8 (d) and (e).)

### NOTATION

$A_e$  = area of excess metal available for reinforcement, sq. in.

$A_s$  = cross-sectional area of the stiffening ring, sq. in.

$A_{rL}$  = required area of reinforcement when  $Q_L$  is in compression, sq. in.

$A_r$  = equivalent area of cylinder, cone and stiffening ring, sq. in.

$B$  = factor

$A_{rS}$  = required area of reinforcement when  $Q_L$  is in compression, sq. in.

$D_L$  = outside diameter of cone or large end of conical section, in.

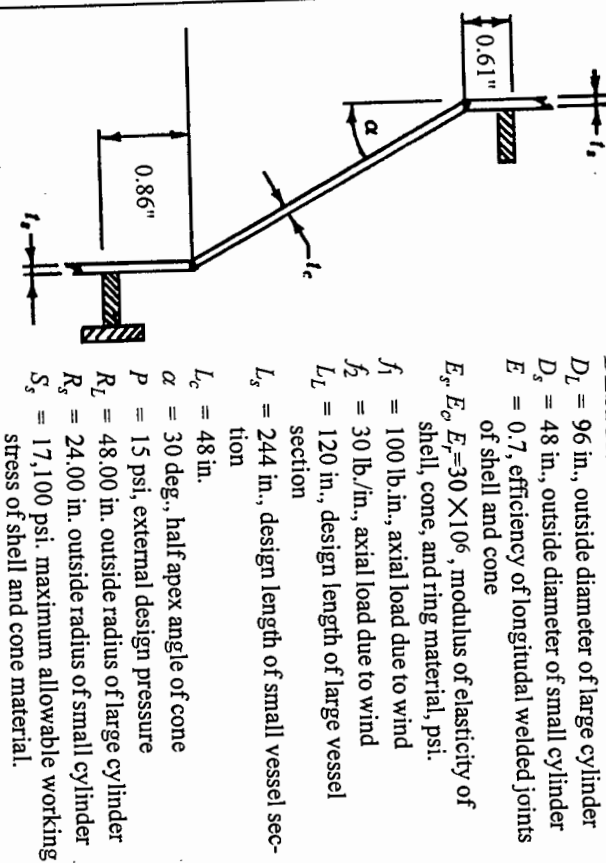


## REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER (continued)

$D_o$	= outside diameter of cylindrical shell, in.	shell junction and one-third the depth of head on the other end of the large shell.
$D_s$	= outside diameter at small end of conical section, in.	
$E$	= lowest efficiency of the longitudinal joint in the shell, head or cone; $E = 1$ for butt welds in compression.	$L_s$ = design length of a vessel section, in. for stiffened vessel section: distance between the cone-to-small-shell junction and an adjacent stiffening ring on the small shell.
$E$	= with subscripts $c$ , $r$ or $s$ modulus of elasticity of cone, reinforcement or shell material respectively, psi.	for unstiffened vessel section: distance between the cone-to-small-shell junction and one third the depth of head on the other end of the small shell.
$k$	= $S_s E_s / S_r E_r$ but not less than 1.0.	
$f_1$	= axial load at large end due to wind etc., lb./in. The value of $f_1$ shall be taken as positive in all calculations.	$P$ = external design pressure, psi.
$f_2$	= axial load at small end due to wind, etc. lb./in. The value of $f_2$ shall be taken as positive in all calculations.	$Q_c = \frac{P R_L}{2} + f_1$ $Q_s = \frac{P R_s}{2} + f_2$
$I$	= available moment of inertia of the stiffening ring, in <sup>4</sup>	$R_L$ = outside radius of large cylinder, in.
$I'$	= available moment of inertia of combined ring-shell cross-section, in <sup>4</sup> . The width of the shell which is taken as contributing to the moment of inertia of the combined section:	$R_s$ = outside radius of small cylinder, in.
	$1.10 \sqrt{D_o t}$	$S$ = allowable working stress, psi. of cone material.
$I_s$	= required moment of inertia of the stiffening ring, in <sup>4</sup> .	$S_r$ = allowable stress of reinforcing material, psi.
$I_s'$	= required moment of inertia of the combined ring-shell-cone cross-section, in <sup>4</sup> .	$S_s$ = allowable stress of shell material, psi.
$L$	= axial length of cone, in.	$t$ = minimum required thickness of cylinder without allowance for corrosion, in.
$L_c$	= length of cone along surface of cone, or distance between stiffening rings of cone, in.	$t_c$ = actual thickness of cone without corrosion allowance, in.
$L_L$	= design length of a vessel section, in. for stiffened vessel section: the distance between the cone-to-large shell junction and an adjacent stiffening ring on the large shell.	$t_r$ = minimum required thickness of cone without corrosion allowance, in.
	for unstiffened vessel section: the distance between the cone-to-large-	$t_s$ = actual thickness of shell without allowance for corrosion, in.
		$\alpha$ = half apex angle, deg.
		$\Delta$ = value to indicate need for reinforcement, from table E, deg.

## REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER EXAMPLE

### DESIGN DATA



Design temperature = 500°F

$S_r$  = 15700 psi, maximum allowable working stress of reinforcement material.

- $t_{rL}$  = 0.25 in. minimum required thickness of large cylinder.
- $t_{rs}$  = 0.1875 in. minimum required thickness of small cylinder.
- $t_c$  = 0.25 in. actual thickness of cone.
- $t_r$  = 0.25 in. minimum required thickness of cone.
- $t_s$  = 0.25 in. actual thickness of cylinder.

### JUNCTION AT THE LARGE END

- $P/SE = 15/17100 = 0.00088$ ; from table E  $\Delta = 2.2$  since  $\Delta$  is less than  $\alpha$ , reinforcement is required.
- Assuming  $A_s = 0$ ,  $A_{rL} = L_L t_s / 2 + L_c t_c / 2 + A_s =$   
 $= 120 \times 0.125 + 48 \times 0.125 + 0 = 21 \text{ in}^2$   
 $M = \frac{R_L \tan \alpha}{2} + \frac{L_c}{2} + \frac{R_c^2 - R_s^2}{2} + \frac{48 \times 0.5774}{2} + \frac{120}{2} + \frac{48^2 - 24^2}{3 \times 48 \times 0.5774} = 66.9$   
 $F_L = PM + f_1 \tan \alpha = 15 \times 66.9 + 100 \times 0.5774 = 1061$



### REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER EXAMPLE (continued)

$$B = \frac{3}{4} \left( \frac{F_r D}{A_{rs}} \right) = 0.75 \times 1061 \times 96/21 = 3636$$

3.  $A = 0.0003$  from chart on page 42.

4. Required moment of inertia of the combined ring-shell-cone cross section:

$$I_r = \frac{AD_r A_{rs}}{10.9} = \frac{0.0003 \times 96^2 \times 21}{10.9} = 5.32 \text{ in.}^4$$

5. Using two  $2\frac{1}{2} \times \frac{1}{2}$  flat bars as shown, and the effective width of the shell:

$$1.10 \times \sqrt{D_{st}} = 1.1 \sqrt{96 \times .025} = 5.389 \text{ in.},$$

The available moment of inertia:  $5.365 \text{ in.}^4$  (see page 95)

It is larger than the required moment of inertia. The stiffening is satisfactory.

6. The required cross-sectional area of reinforcing:

$$k = \frac{S_r E_r}{S_r E_r} = \frac{17100 \times 30 \times 10^6}{15700 \times 30 \times 10^6} = 1.09$$

$$Q_L = \frac{P R_L}{2} + f_1 = \frac{15 \times 48}{2} + 100 = 460$$

$$A_{rs} = \frac{k Q_L R_L \tan \alpha}{S_r E_r} \left[ 1 - \frac{1}{\alpha} \left( \frac{P R_L - Q_L}{Q_L} \right) \frac{\Delta}{\alpha} \right]$$

$$= \frac{1.09 \times 460 \times 48 \times 0.5774}{17100 \times 0.7} \left[ 1 - 0.25 \left( \frac{15 \times 48 - 460}{460} \right) \frac{2.2}{30} \right] = 1.15 \text{ in.}^2$$

The cross-sectional area of the stiffening ring is  $2.5 \text{ in.}^2$ . It is larger than the area required.

The reinforcing shall be situated within a distance from the junction:

$$\sqrt{R_L t_s} = \sqrt{48 \times 0.25} = 3.46 \text{ in.}$$

The centroid of the ring shall be within a distance from the junction:

$$0.25 \sqrt{R_L t_s} = 0.25 \sqrt{48 \times 0.25} = 0.86 \text{ in.}$$

#### JUNCTION AT THE SMALL END

1. The conical section having no flare, reinforcement shall be provided.

2. Assuming  $A_s = 0$ ,  $A_{rs} = L_{st}/2 + L_{cd}/2 + A_s =$

$$244 \times 0.25/2 + 48 \times 0.25/2 + 0 = 36.5 \text{ in.}^2$$

$$N = \frac{R_g \tan \alpha}{2} + \frac{L_s}{2} + \frac{R_L^2 - R_s^2}{6 R_s \tan \alpha} = \frac{24 \times 0.5774}{2} + \frac{244}{2} + \frac{48^2 - 24^2}{6 \times 24 \times 0.5774} = 149.7 \text{ in.}$$

### REINFORCEMENT AT THE JUNCTION OF CONE TO CYLINDER EXAMPLE (continued)

$$F_r = P N + f_2 \tan \alpha = 15 \times 149.7 + 30 \times 0.5774 = 2263$$

$$B = \frac{3}{4} \frac{F_r D_s}{A_{rs}} = 3/4 \left( \frac{2263 \times 48}{36.5} \right) = 2232$$

3. Since value of  $B$  falls below the left end of material/temperature line:  
 $A = 2 B/E = 2 \times 2232 / 30 \times 10^6 = 0.00014$

4. Required moment of inertia of the combined ring-shell-cone cross section:

$$I_r = \frac{AD_r^2 A_{rs}}{10.9} = \frac{0.00014 \times 48^2 \times 36.5}{10.9} = 1.08 \text{ in.}^4$$

5. Using  $2\frac{1}{2} \times \frac{1}{2}$  flat bar, and the effective shell width:

$$1.1 \sqrt{48 \times 0.25} = 3.81 \text{ in.}$$

The available moment of inertia  $1.67 \text{ in.}^4$  (see page 95)

It is larger than the required moment of inertia; the stiffening is satisfactory.

6. The required area of reinforcing:

$$k = 1.09 \quad Q_s = \frac{P R_s}{2} + f_2 = \frac{15 \times 24}{2} + 30 = 210 \text{ lb./in.}$$

$$A_{rs} = \frac{k Q_s R_s \tan \alpha}{S_r E_r} = \frac{1.09 \times 210 \times 24 \times 0.5774}{17100 \times 0.7} = 0.265 \text{ in.}^2$$

Area of excess metal available for reinforcement:

$$A_e = \sqrt{\frac{R_s t_c}{\cos \alpha}} (t_c - t_s) + \sqrt{R_s t_s} (t_s - t_{rs})$$

$$= \sqrt{\frac{24 \times 0.25}{0.866}} (0.25 - 0.25) + \sqrt{24 \times 0.25} (0.25 - 0.1875) = 0.153 \text{ in.}^2$$

$$A_{rs} - A_e = 0.265 - 0.153 = 0.112 \text{ in.}^2$$

The area of ring used for stiffening  $1.25 \text{ in.}^2$ . It is larger than the required area for reinforcement.

The reinforcing shall be situated within a distance from the junction:

$$\sqrt{R_s t_s} = \sqrt{24 \times 0.25} = 2.44 \text{ in.}$$

and the centroid of the ring shall be within a distance from the junction:

$$0.25 \sqrt{R_s t_s} = 0.25 \sqrt{24 \times 0.25} = 0.61 \text{ in.}$$



# WELDING OF PRESSURE VESSELS

There are several methods to make welded joints. In a particular case the choice of a type from the numerous alternatives depend on:

1. The circumstances of welding
2. The requirements of the Code
3. The aspect of economy

## 1. THE CIRCUMSTANCES OF WELDING.

In many cases the accessibility of the joint determines the type of welding. In a small diameter vessel (under 18 - 24 inches) from the inside, no manual welding can be applied. Using backing strip it must remain in place. In larger diameter vessels if a manway is not used, the last (closing) joint can be welded from outside only. The type of welding may be determined also by the equipment of the manufacturer.

## 2. CODE REQUIREMENTS.

Regarding the type of joint the Code establishes requirements based on service, material and location of the welding. The welding processes that may be used in the construction of vessels are also restricted by the Code as described in paragraph UW-27.

The Code-regulations are tabulated on the following pages under the titles:

- a. **Types of Welded Joints**  
(Joints permitted by the Code, their efficiency and limitations of their applications.) Table UW-12

- b. **Design of Welded Joints**  
(Types of Joints to be used for vessels in various services and under certain design conditions.) UW-2, UW-3

- c. **Examination of Welded Joints**  
The efficiency of joints depends only on the type of joint and on the degree of examination and does not depend on the degree of examination of any other joint. (Except as required by UW-11(a)(5)  
This rule of the 1989 edition of the Code eliminates the concept of collective qualification of butt joints, the requirement of stress reduction.

## 3. THE ECONOMY OF WELDING.

If the two preceding factors allow free choice, then the aspect of economy must be the deciding factor.







Some considerations concerning the economy of weldings:

V-edge preparation, which can be made by torch cutting, is always more economical than the use of J or U preparation.

Double V preparation requires only half the deposited weld metal required for single V preparation.  
Increasing the size of a fillet weld, its strength increases in direct proportion, while the deposited weld metal increases with the square of its size.  
Lower quality welding makes necessary the use of thicker plate for the vessel. Whether using stronger welding and thinner plate or the opposite is more economical, depends on the size of vessel, welding equipment, etc. This must be decided in each particular case.



## TYPES OF WELDED JOINTS

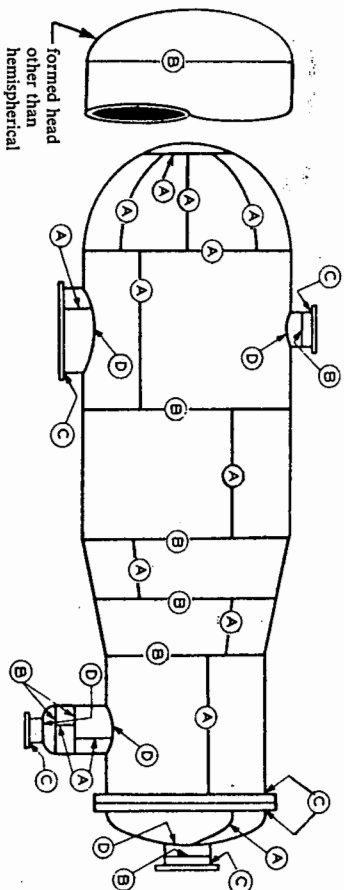
TYPES CODE UW-12		JOINT EFFICIENCY, E When the Joint:			
		a. Fully Radio- graphed	b. Spot Examined	c. Not Examined	
1		Butt joints as attained by double-welding or by other means which will obtain the same quality of deposited weld metal on the inside and outside weld surface. Backing strip if used shall be removed after completion of weld.	1.00	0.85	0.70
2	 For circumferential joint only	Single-welded butt joint with backing strip which remains in place after welding	0.90	0.80	0.65
3		Single-welded butt joint without use of backing strip	—	—	0.60
4		Double-full fillet lap joint	—	—	0.55
5		Single-full fillet lap joint with plug welds	—	—	0.50
6		Single full fillet lap joint without plug welds	—	—	0.45

## TYPES OF WELDED JOINTS

LIMITATIONS IN APPLYING VARIOUS WELD TYPES	NOTES
<p><b>FOR TYPE 1: NONE</b> Joint Category: A, B, C, D</p> <p><b>FOR TYPE 2: NONE</b> Joint Category: A, B, C, D Except butt weld with one plate offset — for circumferential joints only.</p> <p><b>FOR TYPE 3:</b> Joint Category: A, B, C Circumferential joints only, not over 5/8 in. thick and not over 24 in. outside diameter.</p> <p><b>FOR TYPE 4:</b> Longitudinal joints not over 3/8 in. thick. Joint Category: A</p> <p>(b) Circumferential joints not over 5/8 in. thick. Joint Category B, C For C joints these limitations not applicable for bolted flange connections.</p> <p><b>FOR TYPE 5:</b> (a) Circumferential joints for attachment of heads not over 24 in. outside diameter to shells not over 1/2 in. thick. Joints attaching hemispherical heads to shells are excluded. Joint Category B:</p> <p>(b) Circumferential joints for the attachment to shells of jackets not over 5/8 in. in nominal thickness where the distance from the center of the plug weld to the edge of the plate is not less than 1 1/2 times the diameter of the hole for the plug. Joint Category: C</p> <p><b>FOR TYPE 6:</b> (a) For the attachment of heads convex to pressure to shells not over 5/8 in. required thickness, only with use of fillet weld on inside of shell. Joint Category: A, B</p> <p>(b) For attachment of heads having pressure on either side, to shells not over 24 in. inside diameter and not over 1/4 required thickness with fillet weld on outside of flange only. Joint Category: A, B</p>	<p>1. In this table are shown the types of welded joints which are permitted by the Code in arc and gas welding processes.</p> <p>2. The shape of the edges to be joined by butt-weld shall be such as to permit complete fusion and penetration.</p> <p>3. Butt joints shall be free from undercuts, overlaps and abrupt ridges and valleys. To assure that the weld-grooves are completely filled, weld metal may be built up as reinforcement. The thickness of the reinforcement shall not exceed the following thicknesses. Plate thickness in. Maximum reinf. in. up to 1/2 incl. 3/32 1/8 over 1/2 to 1 incl. 1/8 over 1 3/16</p> <p>4. Before welding the second side of a double welded butt joint, the impurities of the first side welding shall be removed by chipping, grinding or melting out to secure sound metal for complete penetration and fusion. For submerged arc welding, chipping out a groove in the crater is recommended.</p> <p>5. The maximum allowable joint efficiencies given in this table are to be used in formulas, when the joints made by arc or gas welding processes.</p> <p>6. Joint efficiency, E = 1 for butt joints in compression.</p>



## DESIGN OF WELDED JOINTS



## WELDED JOINT LOCATIONS

To the joints under certain condition special requirements apply, which are the same for joints designated by identical letters.

These special requirements, which are based on service, material, thickness and other design conditions, are tabulated below.

DESIGN CONDITION	JOINT TYPE AND CATEGORY	RADIOGRAPHIC EXAMINATION	JOINT EFFICIENCY	POST WELD HEAT TREATMENT
1. The design is based on joint efficiency 1.0 or 0.9 (See design conditions listed below when full radiography is mandatory.) UW-11 UW-12(d)	All category A and D butt welds in vessel sections and heads	Full		
	All category B or C butt welds (but not including those in nozzles or communicating chambers) which intersects the category A welds in vessel sections or heads or connect seamless vessel sections or heads	Spot	Type (1) Type (2) 1.0 0.9	Per Code UCS-56
	Category A and B butt welds in vessel sections and heads shall be of Type (1) or Type (2)	None	0.85 0.80	
2. Full radiographic examination is not mandatory UW-11(b)	Type (1) or Type (2) butt welded joints	Spot	Type (1) Type (2) 0.85 0.80	Per Code UCS-56

## DESIGN OF WELDED JOINTS (CONT.)

DESIGN CONDITION	JOINT TYPE AND CATEGORY	RADIOGRAPHIC EXAMINATION	JOINT EFFICIENCY	POST WELD HEAT TREATMENT
3. Full radiographic examination is not mandatory. The vessel is designed for external pressure only. UW-11(c)	Any type of welded joints.	None	Type (1) 0.70 Type (2) 0.65 Type (3) 0.60 Type (4) 0.55 Type (5) 0.50 Type (6) 0.45	Per Code USC-56
	Joints A shall be Type No. (1) UW-2(a)(1)(a)	Full	1.0	Vessels fabricated of carbon or low alloy steel shall be post weld heat treated UW-2(a)
4. Vessels containing lethal substances. UW-2(a) UW-2(a)(1)(b)	Joints B and C shall be Type No. (1) or Type No. (2) UW-2(a)(1)(b)		1.0 Type (1) 0.9 Type (2)	
	Joints D shall be full penetration welds extending through the entire thickness of the vessel or nozzle wall UW-2(a)(1)(d).	All butt welded joints in shell and heads shall be fully radiographed except exchanger tubes and exchangers UW-2(a)(2) and per UW-11(a)(4)		
5. Vessels operated below -20°F or impact test is required for the material or weld metal UW-2(b)	Joints A shall be Type No. (1) (except for austenitic chromium nickel stainless steel). Joints B shall be Type No. (1) or No. (2). UW-2(b)(1) and (2).	Full Spot No	Type (1) Type (2) 1.0 0.90 0.85 0.80 0.70 0.65	Per Code UCS-56
	Joints C full penetration welds extending through the entire section of the joint UW-2(b)(3).			
6. Unfired steam boilers with design pressure exceeding 50 psi. See note above in this column at design condition 4.	Joints A shall be Type No. (1). Joints B shall be Type No. (1) or No. (2) UW-2(c)	All butt welded joints in shell heads shall be fully radiographed except under the provisions of UW-11(a)(4) UW-2(c)	1.0 1.0 Type (1) 0.9 Type (2)	Vessels fabricated of carbon or low alloy steel shall be post weld heat treated UW-2(c)



## DESIGN OF WELDED JOINTS (CONT.)

DESIGN CONDITION	JOINT TYPE AND CATEGORY	RADIOGRAPHIC EXAMINATION	JOINT EFFICIENCY	POST WELD HEAT TREATMENT
7. Pressure vessels subject to direct firing	Joints A shall be type No. (1) Joints B shall be type No. (1) or No. (2) when the thickness exceeds 5/8 in. No welded joints of type (3) are permitted for either A or B joints in any thickness UW-2(d)	Full Spot No	Type (1) Type (2) 1.0 0.90 0.85 0.80 0.70 0.65	When the thickness at welded joints of carbon steels (P-No. 1) exceeds 5/8 in. and all thicknesses for low alloy steels (other than P-No. 1) post weld heat treatment is mandatory
8. Electroslag welding	All butt welds UW-11(a) (6)	Full	1.0 Type (1) 0.9 Type (2)	Per Code UCS-56
9. Final closure of vessels	Any welds UW-11(a) (7)	Ultrasonic examination when the construction does not permit radiographs	1.0 Type (1) 0.9 Type (2)	Per Code UCS-56
10. Seamless vessel sections or heads UW-11(a) (5) (b) UW-12(d)	Joints connecting vessel sections and heads	Spot None or when A or B welds are type 3, 4, 5, 6	1.0* 0.85*	Per Code UCS-56
11. Joints completed by pressure UW-12(f)	Any Welds		Not greater than .80	

## EFFICIENCY (E) TO BE USED IN CALCULATIONS OF SEAMLESS HEAD THICKNESS ASME Code UW-12(d)

TYPE OF HEAD	TYPE OF JOINT	DEGREE OF EXAMINATION OF HEAD TO SHELL JOINT		
		FULL	SPOT	NO
Hemi spherical	No1	1.00	0.85	0.70
	No2	0.90	0.80	0.65
Others	ANY	1.00		0.85

\*For calculation involving circumferential stress or for thickness of seamless head

## EXAMINATION OF WELDED JOINTS

## RADIOGRAPHIC EXAMINATION

Full radiography is mandatory of joints: (Code UW-11)

1. All butt welds in shells, heads, nozzles, communicating chambers of unfired steam boilers having design pressures exceeding 50 psi and vessels containing lethal substances.

2. All butt welds in vessels in which the least nominal thickness at the welded joint exceeds:

1 1/4 in. of carbon steel and 1 1/2 in. of SA-240 stainless steel.

Exemption: Categories B and C butt welds in nozzles and communicating chambers that neither exceed 10 in pipe size nor 1 1/8 in. wall thickness do not require radiographic examination in any of the above cases.

3. All category A and D butt welds in vessel sections and heads where the design of the joint or part is based on joint efficiency: 1.0, or 0.9. (see preceding pages: Design of Welding Joints).

4. All butt welds joined by electroslag welding and all electrogas welding with any single pass greater than 1 1/2 in.

Spot radiography, as a minimum, is mandatory of

1. Category B or C welds which intersect the Category A butt welds in vessel sections (including nozzles and communicating chambers above 10 in. pipe size and 1 in. wall thickness) or connect seamless vessel sections or heads when the design of Category A and D butt welds in vessel sections and heads based on a joint efficiency of 1.0 or 0.9.

2. Spot radiography is optional of butt welded joints (Type 1 or 2) which are not required to be fully radiographed. If spot radiography specified for the entire vessel, radiographic examination is not required of Category B and C butt welds in nozzles and communicating chambers.

No Radiography. No radiographic examination of welded joints is required when the vessel or vessel part is designed for external pressure only, or when the design of joints based on no radiographic examination.

## ULTRASONIC EXAMINATION

1. In ferritic materials electroslag welds and electrogas welds with any single pass greater than 1 1/2 in. shall be ultrasonically examined throughout their entire length.

2. In addition to the requirements of radiographic examination, all welds made by the electron beam process or by the inertia and continuous drive friction welding process shall be ultrasonically examined for their entire length.

3. Ultrasonic examination may be substituted for radiography for the final closure seam if the construction of the vessel does not permit interpretable radiograph.



## APPLICATION OF WELDING SYMBOLS


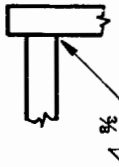

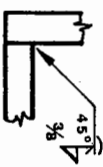

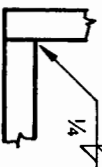




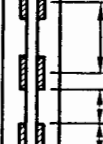


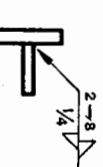


THE LENGTH OF THE TAPERED TRANSITION SHALL BE MINIMUM 3 TIMES THE OFFSET BETWEEN THE ADJACENT SURFACES. THE WELD MAY BE PARTLY OR ENTIRELY IN THE TAPERED SECTION OR ADJACENT TO IT.

	$l \geq 3y$
	$l \geq 3y$ Taper either inside or outside of vessel
	HEADS TO SHELLS ATTACHMENT $l \geq 3y \quad Z \geq 1/2(t_s - t_h)$ The shell plate centerline may be on either side of the head plate centerline.
	HEADS TO SHELLS ATTACHMENT $l \geq 3y \quad Z \geq 1/2(t_h - t_s)$ When $t_h$ exceeds $t_s$ , the minimum length of straight flange is $3t_h$ , but need not exceed 1-1/2 in. except when necessary to provide required length of taper. When $t_h$ is equal to or less than 1.25 $t_s$ , the length of straight flange shall be sufficient for any required taper. The shell plate centerline may be on either side of the head plate centerline.

APPLICATION OF WELDING SYMBOLS		
WELD	SYMBOL	MEANING OF SYMBOL
		SYMBOL INDICATES SQUARE GROOVE WELD ON ARROW SIDE. ROOT GAP 1/8 IN.
		SYMBOL INDICATES V-GROOVE WELD WITH AN ANGLE OF 60 DEGREES ON ARROW SIDE AND BEAD-TYPE BACK WELD ON THE OTHER SIDE
		SYMBOL INDICATES 1/2 IN. V-GROOVE WELD
		SYMBOL INDICATES V-GROOVE WELD ON ARROW SIDE AND ON OTHER SIDE WITH AN ANGLE OF 60 DEGREE
		SYMBOL INDICATES V-GROOVE WELD ON ARROW SIDE AND ON OTHER SIDE WITH A ROOT OPENING OF 1/8 IN.
		SYMBOL INDICATES PLUG WELD OF 1/2 IN. DIAMETER AND WITH AN ANGLE OF 60 DEGREES
		SYMBOL INDICATES 1/4 IN. FILLET WELD



## APPLICATION OF WELDING SYMBOLS

WELD	SYMBOL	MEANING OF SYMBOL
		SYMBOL INDICATES 3/8 IN. FILLET WELD ON ARROW SIDE AND 1/4 IN. FILLET WELD ON THE OTHER SIDE
		SYMBOL INDICATES BEVEL GROOVE WITH AN ANGLE OF 45 DEGREES, 3/8 FILLET WELD ON ARROW SIDE AND BEAD TYPE BACK WELD ON OTHER SIDE
		SYMBOL INDICATES 1/4 IN. FILLET WELD ON ARROW SIDE AND BEVEL GROOVE GRIND FLUSH ON OTHER SIDE
		SYMBOL INDICATES BEVEL GROOVE WELD AND 3/8 FILLET WELD ON ARROW SIDE, BEVEL GROOVE AND 1/4 FILLET WELD ON OTHER SIDE
		SYMBOL INDICATES WELD ALL AROUND 1/4 IN. FILLET WELD
		SYMBOL INDICATES 1/4 IN. INTERMITTENT FILLET WELDS EACH 3 IN. LONG AND SPACED ON 6 IN. CENTERS, FIELD WELDED
		SYMBOL INDICATES 1/4 IN. INTERMITTENT FILLET WELD, EACH 2 IN. LONG AND SPACED ON 8 IN. CENTERS, THE WELDS ARE STAGGERED.
		SYMBOL INDICATES 1/4 IN. FILLET WELD ON ARROW SIDE AND 3/8 FILLET WELD ON OTHER SIDE

## CODE RULES RELATED TO VARIOUS SERVICES

Service	Brief extracts of Code requirements	Code Paragraph
Air	All pressure vessels for use with compressed air, except as permitted otherwise in this paragraph shall be provided with suitable inspection opening. Min. thickness $\frac{3}{32}$ in.	UG-46(a) UG-16(b)(4)
Flammable and or noxious gases and liquids	Expanded connections shall not be used.	UG-43(b)(f)
Lethal substances	Butt welded joints in vessels to contain lethal substances shall be fully radiographed. When fabricated of carbon or low alloy steel shall be post weld heat treated. The joints of various categories shall conform to paragraph UW-2. Steel plates conforming to specifications SA-36, SA-283 shall not be used.	UW-2(a) UW-2(a) USC-6(b)(1)
Steam	Min. thickness $\frac{3}{32}$ in. shells and heads	UG-16(b)(4)
Unfired steam boilers (1)	With design pressures exceeding 50 psi., the joints of various categories shall conform to paragraph UW-2. Steel plates conforming to specifications SA-36, and SA-283 shall not be used. Min. thickness $\frac{1}{4}$ in. shells and heads.	USC-6(b)(2) UG-16(b)(3)
Water (2)	Minimum thickness $\frac{3}{32}$ in. shells and heads.	UG-16(b)(4)

## NOTES:

- Unfired steam boilers may also be constructed in accordance with the rules of Code Section I, (Code U-1(g))
- Vessels in water service excluded from the jurisdiction of the Code are listed in U-1(c)(6) and (7).



## CODE RULES RELATED TO VARIOUS WALL THICKNESSES OF VESSEL

Wall Thick- ness, in.	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
Applicable Notes	2, 4, 15 5, 6, 8, 9, 11, 12, 14	2, 4, 15 5, 6, 8, 9, 11, 12, 14	2, 3, 4, 5, 6, 8, 9, 11 12, 14, 15	2, 4, 5, 6, 8, 9, 11, 12, 14	4, 6, 8, 9 11, 12, 14 15	4, 6, 8, 9 11, 12, 14 15	7, 8, 9, 11, 12, 14, 15	7, 8, 9, 11, 12, 14, 15
Wall thick- ness, in.	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$	1
Applicable Notes	7, 10, 11, 12, 14, 15	7, 10, 11, 12, 14, 15	7, 10, 13, 16, 20	7, 10, 13, 16, 20	7, 10, 13, 16, 20	7, 10, 13, 16, 20	7, 10, 13, 16, 20	7, 10, 13, 16, 20
Wall Thick- ness, in.	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{3}{8}$	$\frac{1}{16}$	$\frac{1}{2}$ & over
Applicable Notes	7, 13, 16, 17, 20	7, 13, 16, 17, 20	7, 13, 16, 17, 20	7, 13, 16, 17, 20, 19, 22	7, 13, 16, 17, 18, 21 19, 20, 22	7, 13, 16, 17, 18, 21 19, 20, 22	7, 13, 16, 17, 18, 21 19, 20, 22	7, 13, 16, 17, 18, 19, 20, 21

### Notes (Brief Extracts of Code Requirements)

1. The minimum thickness of plate for welded construction shall be not less than  $\frac{1}{16}$ .  
The minimum thickness of shells and heads used in compressed air service, steam service and water service shall be  $\frac{3}{32}$  in.
2. Manufacturers' marking shall be other than deep die stamping.
3. In compressed air, steam and water service corrosion allowance not less than  $\frac{1}{16}$  of the calculated plate thickness shall be provided.
4. Single, welded openings up to 3 in. pipe size do not require reinforcement.
5. The minimum thickness of shells and heads of unfired steam boilers shall not be less than  $\frac{1}{4}$  in.
6. Double full fillet lap joint for longitudinal welded joints is acceptable.
7. Single, welded openings up to 2 in. pipe size do not require reinforcement.
8. Single full fillet lap joint with plug weld for attachment of heads not over 24 in. outside diameter to shells, acceptable.
9. Maximum thickness of reinforcement for butt weld  $\frac{3}{32}$  in.
10. Maximum thickness of reinforcement for butt weld  $\frac{1}{8}$  in.
11. Single full fillet lap joint with plug welds for circumferential joint acceptable.

## CODE RULES RELATED TO VARIOUS WALL THICKNESSES OF VESSEL (Continued)

### Notes (Brief Extracts of Code Requirements)

12. Single full fillet lap joints without plug welds acceptable for attachment of heads convex to pressure to shells.
13. Welded joints of pressure vessels subject to direct firing in category B shall be type (1) or (2). Post weld heat treatment required.
14. Single welded butt joint without use of backing strip acceptable for circumferential joints not over 24 in. outside diameter.
15. Double full fillet lap joints for circumferential joint acceptable.
16. Steel plates conforming to SA-36 and SA-283 shall not be used.
17. The maximum thickness of reinforcement for butt weld  $\frac{3}{16}$  in.
18. Butt welded joints in materials classified P-1 shall be fully radiographed.
19. Post weld heat treatment of P-1 materials is mandatory for all welded connections and attachments.
20. Double welded butt joint or single welded butt joint with backing strip shall be used for circumferential or longitudinal joints.
21. Full radiographic examination of butt welded joints of P-1 Grade 1, 2, and 3 materials is mandatory.
22. Post weld heat treatment of P-1 materials is not mandatory provided that the material is pre-heated.

The governing thickness of pressure vessels and parts joined by welding shall be determined by:

- UW-11, UCS-57 for radiographing,
- UCS-66 for impact testing
- UW-10, UW40(f), UCS-56,
- UHA-32 for post weld heat treatment.

See page 185 for low temperature operation.



## TANKS AND VESSELS CONTAINING FLAMMABLE AND COMBUSTIBLE LIQUIDS

Except from the Department of Labor Occupational Safety and Health Standards (OSHA), Chapter XVII, Part 1910.106, (Federal Register, July 1, 1985)

CLASSIFICATION	REGULATION
<b>ATMOSPHERIC TANKS</b> Storage tank which has been designed to operate at pressures from atmospheric through 0.5 psig.	Atmospheric tanks shall be built in accordance with acceptable good standards of design. Atmospheric tanks may be built in accordance with: 1. Underwriters' Laboratories, Inc. Standards 2. American Petroleum Institute Standards No. 12A, No. 650, No. 12B, No. 12D, & No. 12F.
<b>LOW PRESSURE TANKS</b> Storage tank which has been designed to operate at pressures above 0.5 psig. but not more than 15 psig.	Low-Pressure tanks shall be built in accordance with acceptable standards of design. Low-Pressure tanks may be built in accordance with: 1. American Petroleum Institute Standard No. 620. 2. ASME Code for Pressure Vessels, Section VIII. (These tanks are not within the jurisdiction of the ASME Code Section VIII (U-1d) but may be stamped with the Code U Symbol U-1g)
<b>PRESSURE VESSEL</b> Storage tank or vessel which has been designed to operate at pressures above 15 psig.	Pressure Vessels shall be built in accordance with the ASME Code for Pressure Vessels, Section VIII.

In addition to the regulations of the above mentioned standards and code, the occupational safety and health standards contain rules concerning tanks and vessels as follows:

1. Definition of combustible and flammable liquids
2. Material of storage tanks
3. Location of tanks
4. Venting for tanks
5. Emergency relief venting
6. Drainage
7. Installation of tanks

## LOW TEMPERATURE OPERATION

If a minimum design metal temperature and thickness-combination of carbon and low alloy steels is below the curves in FIG UCS-66, impact testing is required.

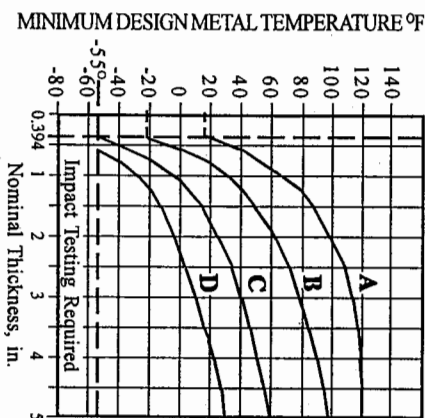


FIG. UCS-66 IMPACT TEST CURVES

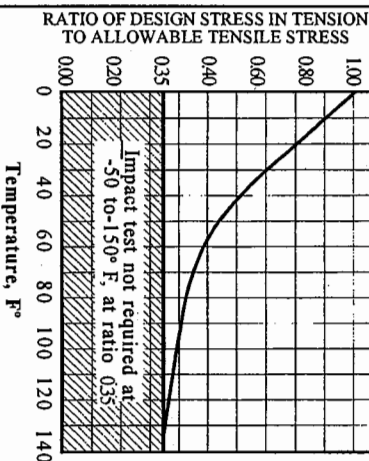


FIG. UCS-66.1 REDUCTION OF MINIMUM METAL TEMPERATURE

For stationary vessels, when the coincident ratio in Fig. UCS-66.1 is less than one, this Figure provides basis to use material without impact testing, UCS-66(b).

If the thickness at any welded joint exceeds 4 in. and the minimum design metal temperature is colder than 120°F, impact tested material shall be used, UCS-66(b).

NOTE: In the Handbook the most commonly used materials are listed. For others see ASME Code.

All carbon and alloy steels listed in the following pages and not shown below.

SA-515 Gr 60, SA-285 Gr A & B

SA-516 Gr 65 & 70 if not normalized

SA-516 Gr 55 & 60 if not normalized.

SA-516 all grades if normalized.

### NO IMPACT TEST IS REQUIRED :

For bolts: SA-193 B7 to -55°F

SA-307 B to -20°F

For nuts: SA-194 2H to -55°F

### REDUCTION OF MINIMUM METAL TEMPERATURE.

#### EXAMPLE:

For 1½ thick, SA-515 Gr 60 plate the minimum design temperature is from Fig. UCS-66 - 50°F.

If the actual stress in tension from internal pressure and other loads is 12,000 PSI, and the maximum allowable stress of the material is 17,100 psi, the ratio:  
 $12,000 / 17,100 = 0.7$

and from FIG. UCS 66.1 the reduction is 30°F. The minimum design temperature is: 50-30 = 20°F.

(Applicable joint efficiencies shall be included in the calculation of stresses.)

Impact test is not mandatory for materials which satisfy all of the following:

1. the thickness of material listed in curve A does not exceed ½ in.
2. the thickness of material listed in curves B, C and D does not exceed 1 in.
3. The vessel is hydrostatically tested.
4. the design temperature is not lower than -20°F and not higher than 650°F.
5. thermal, mechanical shock loading or cylindrical loading is not controlling design requirement.



# PROPERTIES OF MATERIALS CARBON & ALLOW STEEL\*

Form	Nominal Composition	Specifications		APPLICATION
		Number	Number	
C	SA-283	C	C	Structural quality. For pressure vessel may be used with limitations see note: 1
C	SA-285	C	C	Boilers for stationary service and other pressure vessels.
C-Si	SA-515	60	60	For intermediate and higher temperature
C-Si	SA-515	65	65	For intermediate and higher temperature
C-Si	SA-515	70	70	For intermediate and higher temperature
C-Si	SA-516	55	55	For moderate and lower temperature service
C-Si	SA-516	60	60	For moderate and lower temperature service
C-Mn-Si	SA-516	65	65	For moderate and lower temperature service
C-Mn-Si	SA-516	70	70	For moderate and lower temperature service
C-Si	SA-234	WPB	WPB	For moderate and elevated temperature
C-Mn-Si	SA-105	—	—	For ambient and higher temperature
C-Si	SA-181	—	—	For general service
C-Mn-Si	SA-350	LF1	LF1	For low temperature service
C-Mn	SA-350	LF2	LF2	For low temperature service
C-Mn	SA-53	B	B	For general service
C-Mn	SA-106	B	B	For high temperature service
1Cr-1/5 Mo	SA-193	B7	B7	For high temperature service Bolt 2½ in. diam or less
C	SA-194	2H	2H	For high temperature service nut
C	SA-307	B	B	Machine bolt for general use
C	SA-36	—	—	For general structural purposes
C	SA-36	—	—	For general structural purposes

\* Data of the most frequently used materials from ASME Code Section II and VIII

# PROPERTIES OF MATERIALS CARBON & ALLOW STEEL\* (continued)

Form	Specification		P Number	Tensile Strength 1,000 psi	Yield Point 1,000 psi	See Notes
	Number	Grade				
	SA-283	C	1	55.0	30.0	2
	SA-285	C	1	55.0	30.0	1,4
	SA-515	60	1	60.0	32.0	1,4
	SA-515	65	1	65.0	35.0	1,4
	SA-515	70	1	70.0	38.0	1,4
	SA-516	55	1	55.0	30.0	1,4
	SA-516	60	1	60.0	32.0	1,4
	SA-516	65	1	65.0	35.0	1,4
	SA-516	70	1	70.0	38.0	1,4
	SA-234	WPB	1	60.0	35.0	1,3
	SA-105	1	1	70.0	36.0	1,4
	SA-181	1	1	60.0	30.0	1,4
	SA-350	LF1	1	60.0	30.0	1,4
	SA-350	LF2	1	70.0	36.0	1,3
	SA-53	B	1	60.0	35.0	1,3
	SA-106	B	1	60.0	35.0	1,3
	SA-193	B7	—	125.0	105.0	5
	SA-194	2H	—	55.0	—	—
	SA-307	B	—	60.0	—	—
	SA-36	1	1	58.0	—	1
	SA-36	1	1	36.0	—	1,3



## PROPERTIES OF MATERIALS CARBON & LOW ALLOY STEEL

(continued)

### NOTES

1. Upon prolonged exposure to temperatures above 800° F, the carbide phase of carbon steel may be converted to graphite.
2. SA-36 and SA-283 ABCD plate may be used for pressure parts in pressure vessels provided all of the following requirements are met: UCS-6 (b)
  - (1) The vessels are not used to contain lethal substances, either liquid or gaseous;
  - (2) The material is not used in the construction of unfired steam boilers (see Code U-1 (g));
  - (3) With the exception of flanges, flat bolted covers, and stiffening rings the thickness of plates on which strength welding is applies does not exceed 5/8 in.
3. Allowable stresses for temperatures of 700° F and above are values obtained from time-dependent properties.
4. Allowable stresses for temperatures of 750° F and above are values obtained from time-dependent properties.
5. Stress values in bearing shall be 1.60 times the values in tables.

### MODULI OF ELASTICITY FOR FERROUS MATERIALS

Materials	Million psi, for Temperature °F. of:										
	-100	70	200	300	400	500	600	700	800	900	1000
Carbon steels with C ≤ 0.30%.	30.2	29.5	28.8	28.3	27.7	27.3	26.7	25.5	24.2	22.4	20.4
Carbon steels with C > 0.30%	30.0	29.3	28.6	28.1	27.5	27.1	26.5	25.3	24.0	22.3	20.2

The values in the External Pressure Charts are intended for external pressure calculations only.

## PROPERTIES OF MATERIALS CARBON & LOW ALLOY STEEL

Maximum Allowable Stress Values in Tension 1000 psi.\*

Specification		For Metal Temperature Not Exceeding Deg. F.											
Number	Grade	-20 to 650	700	750	800	850	900	950	1050	1100	1150	1200	
SA-283	C	13.8	—	—	—	—	—	—	—	—	—	—	
SA-285	C	13.8	13.3	12.1	10.2	8.4	6.5	—	—	—	—	—	
SA-515	55	13.8	13.3	12.1	10.2	8.4	6.5	4.5	2.5	—	—	—	
SA-515	60	15.0	14.4	13.0	10.8	8.7	6.5	4.5	2.5	—	—	—	
SA-515	65	16.3	15.5	13.9	11.4	9.0	6.5	4.5	2.5	—	—	—	
SA-515	70	17.5	16.6	14.8	12.0	9.3	6.5	4.5	2.5	—	—	—	
SA-516	55	13.8	13.3	12.1	10.2	8.4	6.5	4.5	2.5	—	—	—	
SA-516	60	15.0	14.4	13.0	10.8	8.7	6.5	4.5	2.5	—	—	—	
SA-516	65	16.3	15.5	13.9	11.4	9.0	6.5	4.5	2.5	—	—	—	
SA-516	70	17.5	16.6	14.8	12.0	9.3	6.5	4.5	2.5	—	—	—	
SA-105		17.5	16.6	14.8	12.0	9.3	6.5	4.5	2.5	—	—	—	
SA-181	I	15.0	14.4	13.0	10.8	8.7	6.5	4.5	2.5	—	—	—	
SA-350	LF1	15.0	14.4	13.0	10.8	7.8	5.0	3.0	1.5	—	—	—	
	LF2	17.5	16.6	14.8	12.0	7.8	5.0	3.0	1.5	—	—	—	
SA-53	B	15.0	14.4	13.0	10.8	8.7	6.5	—	—	—	—	—	
SA-106	B	15.0	14.4	13.0	10.8	8.7	6.5	4.5	2.5	—	—	—	
SA-193	B7≤2½"	25.0	25.0	23.6	21.0	17.0	12.5	8.5	4.5	—	—	—	
SA-194	2H	—	—	—	—	—	—	—	—	—	—	—	
SA-307	B	—	—	—	—	—	—	—	—	—	—	—	

See page 185 for low temperature operation.

\* The Stress Values in this table may be interpolated to determine values for intermediate temperatures.



# PROPERTIES OF MATERIALS STAINLESS STEEL

P-No. 8 Group No. 1

TABLE 1

TABLE 3

NOMINAL COMPOSITION 18 Cr - 8 Ni				NOMINAL COMPOSITION 16 Cr - 12 Ni - 2 Mo			
Product	Spec. No.	Grade	Notes	Product	Spec. No.	Grade	Notes
Plate	SA-240	304	2 3	Plate	SA-240	316	2 3
Smls. Tb.	SA-213	TP304	2	Smls. Tb.	SA-213	TP316	2
Smls. Tb.	SA-213	TP304H	-	Smls. Tb.	SA-213	TP316H	-
Smls. Pp.	SA-312	TP304	2	Smls. Pp.	SA-312	TP316	2
Smls. Pp.	SA-312	TP304H	-	Smls. Pp.	SA-312	TP316H	-
Smls. Pp.	SA-376	TP304	2	Smls. Pp.	SA-376	TP316	2
Smls. Pp.	SA-376	TP304H	-	Smls. Pp.	SA-376	TP316H	-
Forg.	SA-182	F304	2	Forg.	SA-182	F316	2
Forg.	SA-182	F304H	-	Forg.	SA-182	F316H	-
Bar	SA-479	304	2 3	Bar	SA-479	316	2 3

TABLE 2

TABLE 4

## MAXIMUM ALLOWABLE STRESS VALUES, 1,000 psi.

FOR METAL TEMPERATURES NOT EXCEEDING DEG. F.											
IN TABLE	200	300	400	500	600	650	700	750	800	850	900
1	20.0	18.9	18.3	17.5	16.6	16.2	15.8	15.5	15.2	14.9	14.6
2	16.7	15.0	13.8	12.9	12.3	12.0	11.7	11.5	11.2	11.0	10.8
3	16.7	16.7	15.8	14.7	14.0	13.7	13.5	13.3	13.0	-	-
4	16.7	14.3	12.8	11.7	10.9	10.4	10.2	10.0	9.8	9.7	-
5	20.0	20.0	19.3	18.0	17.0	16.6	16.3	16.1	15.9	15.7	15.6
6	16.7	16.7	16.7	15.1	14.8	14.0	13.7	13.5	13.2	12.9	12.7
7	16.7	14.2	12.7	11.7	10.9	10.4	10.2	10.0	9.8	9.6	9.4

### NOTES:

1. These higher stress values exceed 2/3 but do not exceed 90% of the yield strength at temperature. Use of these stress values may result in dimensional changes due to permanent strain. These stress values are not recommended for flanges or gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.
2. At temperatures above 1,000° F, these stress values apply only when the carbon is 0.04% or higher.
3. For temperatures above 1,000° F, these stress values may be used only if the material is heat treated by heating it to a minimum temperature of 1,900° F and quenching in water or rapidly cooling by other means.

## THERMAL EXPANSION

Linear Thermal Expansion between 70F and Indicated Temperature, Inches/100 Feet










THE DATA OF THIS TABLE ARE TAKEN FROM THE AMERICAN STANDARD CODE FOR PRESSURE PIPING. IT IS NOT TO BE IMPLIED THAT MATERIALS ARE SUITABLE FOR ALL THE TEMPERATURES SHOWN IN THE TABLE.

MATERIAL										
Temp. deg F	Carbon Steel Low-Chrome (thru 3 Cr Mo)	5 Cr Mo thru 9 Cr Mo	Austenitic Stainless 18 Cr 8 Ni	12 Cr 27 Cr	25 Cr 20 Ni	Monel 67 Ni 30 Cu	3% Nickel	Aluminum	Gray Cast Iron	Bronze
-325	-2.37	-2.22	-3.85	-2.04		-2.62	-2.25	-4.68		-3.98
-300	-2.24	-2.10	-3.63	-1.92		-2.50	-2.17	-4.46		-3.74
-275	-2.11	-1.98	-3.41	-1.80		-2.38	-2.07	-4.21		-3.50
-250	-1.98	-1.86	-3.19	-1.67		-2.16	-1.96	-3.97		-3.26
-225	-1.85	-1.74	-2.96	-1.58		-2.14	-1.86	-3.71		-3.02
-200	-1.71	-1.62	-2.73	-1.46		-2.02	-1.76	-3.44		-2.78
-175	-1.58	-1.50	-2.50	-1.35		-1.90	-1.62	-3.16		-2.54
-150	-1.45	-1.37	-2.27	-1.24		-1.79	-1.48	-2.88		-2.31
-125	-1.30	-1.23	-2.01	-1.11		-1.59	-1.33	-2.57		-2.06
-100	-1.15	-1.08	-1.75	-0.98		-1.38	-1.17	-2.27		-1.81
-75	-1.00	-0.94	-1.50	-0.85		-1.18	-1.01	-1.97		-1.56
-50	-0.84	-0.79	-1.24	-0.72		-0.98	-0.84	-1.67		-1.32
-25	-0.68	-0.63	-0.98	-0.57		-0.77	-0.67	-1.32		-1.05
0	-0.49	-0.46	-0.72	-0.42		-0.57	-0.50	-0.97		-0.77
25	-0.32	-0.30	-0.46	-0.27		-0.37	-0.32	-0.63		-0.49
50	-0.14	-0.13	-0.21	-0.12	0	-0.20	-0.15	-0.28	0	-0.22
70	0	0	0	0	0.32	0	0	0	0.21	0.36
100	0.23	0.22	0.34	0.20	0.58	0.28	0.23	0.46	0.38	0.66
125	0.42	0.40	0.62	0.36	0.84	0.52	0.42	0.85	0.55	0.96
150	0.61	0.58	0.90	0.53	1.10	0.75	0.61	1.23	0.83	1.26
175	0.80	0.76	1.18	0.69	1.37	0.99	0.81	1.62	1.03	1.56
200	0.99	0.94	1.46	0.86	1.64	1.22	1.06	2.00	1.27	1.86
225	1.21	1.13	1.75	1.03	1.91	1.46	1.21	2.41	1.58	2.17
250	1.40	1.33	2.03	1.21	2.18	1.71	1.42	2.83	1.87	2.48
275	1.61	1.52	2.32	1.38	2.45	1.96	1.63	3.24	2.17	2.79
300	1.82	1.71	2.61	1.56	2.72	2.21	1.84	3.67	2.48	3.11
325	2.04	1.90	2.90	1.74	2.99	2.44	2.05	4.09	2.79	3.42
350	2.26	2.10	3.20	1.93	3.26	2.68	2.26	4.52	3.03	3.74
375	2.48	2.30	3.50	2.11	3.53	2.91	2.47	4.95	3.24	4.05
400	2.70	2.50	3.80	2.30	3.80	3.25	2.69	5.39	3.53	4.37
425	2.93	2.72	4.10	2.50	4.07	3.52	2.91	5.83	3.82	4.69
450	3.16	2.93	4.41	2.69	4.34	3.79	3.13	6.28	4.11	5.01
475	3.39	3.14	4.71	2.89	4.59	4.06	3.35	6.72	4.34	5.33
500	3.62	3.35	5.01	3.08	4.88	4.33	3.58	7.17	4.57	5.65
525	3.86	3.58	5.31	3.28	5.15	4.61	3.81	7.63	4.80	5.98
550	4.11	3.80	5.62	3.49	5.42	4.90	4.04	8.10	5.03	6.31
575	4.35	4.02	5.93	3.69	5.69	5.18	4.27	8.56	5.26	6.64
600	4.60	4.24	6.24	3.90	5.96	5.46	4.50	9.03	5.50	6.96
625	4.86	4.47	6.55	4.10	6.23	5.75	4.74	9.50	5.74	7.29
650	5.11	4.69	6.87	4.31	6.50	6.05	4.98	9.97	5.98	7.62
675	5.37	4.92	7.18	4.52	6.77	6.34	5.22	10.44	6.22	7.95
700	5.63	5.14	7.50	4.73	7.04	6.64	5.46	10.91	6.47	8.28
725	5.90	5.38	7.82	4.94	7.31	6.94	5.70	11.38	6.72	8.62
750	6.16	5.62	8.15	5.16	7.58	7.25	5.94	11.85	6.97	8.96
775	6.43	5.86	8.47	5.38	7.85	7.55	6.18	12.32	7.23	9.30
800	6.70	6.10	8.80	5.60	8.12	7.85	6.43	12.79	7.49	9.64
825	6.97	6.34	9.13	5.82	8.39	8.16	6.68	13.26	7.75	9.99
850	7.25	6.59	9.46	6.05	8.66	8.48	6.93	13.73	8.02	10.33
875	7.53	6.83	9.79	6.27	8.93	8.80	7.18	14.20	8.25	10.68
900	7.81	7.07	10.12	6.49	9.20	9.12	7.43	14.67	8.50	11.03
925	8.08	7.31	10.45	6.71	9.47	9.44	7.68	15.14	8.75	11.37
950	8.36	7.56	10.78	6.94	9.74	9.77	7.93	15.61	9.00	11.72
975	8.64	7.81	11.11	7.17	10.01	10.09	8.17	16.08	9.25	12.07
1000	8.92	8.06	11.44	7.40	10.25	10.42	8.41	16.55	9.50	12.40
1025	9.19	8.30	11.77	7.62	10.55	10.75				
1050	9.46	8.55	12.10	7.85	10.82	11.09				
1075	9.75	8.80	12.43	8.08	11.05	11.43				
1100	10.04	9.05	12.76	8.31	11.28	11.77				
1125	10.31	9.28	13.18	8.53	11.51	12.11				
1150	10.57	9.52	13.52	8.76	12.11	12.47				
1175	10.83	9.76	13.86	8.98	12.44	12.81				
1200	11.10	10.00	14.20	9.20	12.77	13.15				
1225	11.38	10.24	14.50	9.43	13.10	13.45				
1250	11.66	10.48	14.88	9.65	13.43	13.82				
1275	11.94	10.73	15.22	9.88	13.76	14.22				
1300	12.22	11.06	15.56	10.11	14.09	14.58				
1325	12.50	11.29	15.90	10.35	14.42	14.98				
1350	12.78	11.50	16.28	10.58	14.75	15.36				
1400	13.34	12.05	16.92	11.01	15.29	16.02				
1425			17.30							
1450			17.69							
1475			18.07							
1500			18.47							









## DESCRIPTION OF MATERIALS

When describing various vessel components and parts on drawings and in bill of materials, it is advisable that a standard method be followed. For this purpose it is recommended the use of the widely accepted abbreviations in the sequences exemplified below. For ordering material the requirements of manufacturers should be observed.

PART	DESCRIPTION	MATERIAL SPECIFICATION
 BAR	Bar 2 x 1/4 x 3'-6 Bar 3/4 $\phi$ x 2'-0 Bar 1 $\phi$ x 3'-0	SA-7
 BOLT	3/4 $\phi$ x 2-1/2 H. Hd. M. B. w/ (1) sq. nut 1 $\phi$ x 5-1/2 stud w/ (2) h. nuts	SA-193 B7 bolt SA-194 2H nut
 CAP	8" Std. Cap	
 Screwed COUPLING	1" - 6000 # Cplg. 2" - 3000 # Cplg. 1" - 6000 # Half Cplg. 1" - 6000 # 4-1/2 Lg. Cplg.	SA-105
 Welding ELBOW	6" - Std. 90° L. R. El. 4" - X Stg. 45° S. R. El. 6" x 4" Std. L. R. Red. El	SA-234 WPB
 FLANGE	4" - 300 # R.F. So. Flg. 6" - 150 # R.F. Wn. Flg. Std. Bore 6" - 600 # RTJ. Wn. Flg. X Stg. Bore 3" - 150 # FF. So. Flg. 8" - 150 # R.F. Bld. Flg.	SA-181 1
 Screwed Socket Welding FORGED FITTING	1" - 6000 # 90° Scr'd. El. 1" - 3000 # 90° Scr'd. Street El. 2" - 3000 # S.W. Cplg. 1" - 3000 # Sq. Hd. Plug 2" - 6000 # Scr'd. Tee 2" - 3000 # 45° S. W. El.	SA-105
 GASKET	18 - 150 # 1/16" Serv. Sht. Gasket 18 - 300 # Spiral Wound ASB. Filled	ASB.
 HEAD	48" ID x 0.375 min. 2:1 ellip. head 2" S.F. 48" OD x 0.500" min. ASME F & D Head 2 S.F. L = 48" r = 3" 54" ID x 0.375" min. Hemis. Head	SA-285 C SA-515-70 SA-516-70

## DESCRIPTION OF MATERIALS (cont.)

 Long Welding Neck	18" - 300 RF. LWN	SA-181 1
 PIPE	6" - Std. Pipe x 2'-1 8" - X Stg. Pipe x 1' - 6-1/2 4" - S. 160 Pipe x 2'-4 24" - 0.438" Wall Pipe x 1' - 0	SA-53 B
 PLATE	H 96" x 3/8 x 12' - 6 H 24" OD x 1/2 x 18" ID H 18" OD x 1-1/2	SA-285 C
 Welding REDUCER	6" x 4" Std. Conc. Reducer 8" x 6" X Stg. Ecc. Reducer	SA-234 WPB
 Welding RETURN	6" - Std. 180° L. R. Return 4" - X Stg. 180° S. R. Return	SA-234 WPB
 Welding TEE	4" - Std. Tee 6" x 6" x 4" X Stg. Red. Tee	SA-234 WPB



## EQUIVALENT &amp; COMPARABLE MATERIALS OF FOREIGN COUNTRIES

U.S.A.	European Standard	Germany	United Kingdom	Japan
SA 285 Gr. B	P 235 GH	H I	161 Gr 400	SB 410
SA 515 Gr 60	P 265 GH	H II	161 Gr 430	SB 480
SA 515 Gr 70	P 295 GH	17 Mn 4	224 Gr 340	SPV 315
SA 299	P 355 GH	19 Mn 6	225 Gr 490	SPV 356
SA 204 Gr A	16 Mo 3	15 Mo 3	—	SB 480 M
SA 387 Gr 12 Class 2	13 Cr Mo 4-5	13 Cr Mo 44	630 Gr 27	SCMV2 Div. 2
SA 387 Gr 22 Class 2	10 Cr Mo 9-10	10 Cr Mo 910	620 Gr 31	SCMV4 Div. 4
SA 516 Gr 60	P 275 NH	WStE 285	164 Gr 400, Lt 20	SGV 450
SA 516 Gr 70	P 355 NH	WStE 355	225 Gr 490, Lt. 20	—
SA 572 Gr 65	P 460 NH	WStE 460	—	—
SA 240 - 410 S	X6 Cr 13	1.4000	403 S 17	410 S
SA 240 - 405	X6 Cr Al 13	1.4002	405 S 17	405
SA 240 - 304	X5 Cr Ni 18-10	1.4301	304 S 31	304
SA 240 - 304 L	X2 Cr Ni 19-11	1.4306	304 S 11	304 L
SA 240 - 316	X5 Cr Ni Mo 17-12-2	1.4401	316 S 31	316
SA 240 - 316 L	X2 Cr Ni Mo 17-12-2	1.4404	316 S 11	316 L
SA 240 - 317 L	X2 Cr Ni Mo 18-15-4	1.4438	—	317 L

## CODES, STANDARDS, SPECIFICATIONS

ASME Code II.	EN 10028-2,	DIN 17 102,	BS 1501, 4360,	JIS G 3103, 3115, 4109,
	10028-3, 10088	17155, 17440	970, 1449	3118, 4304 sus

## SPECIFICATION

## FOR THE DESIGN AND FABRICATION OF PRESSURE VESSELS

## NOTES:

Pressure vessel users and manufacturers have developed certain standard practices which have proven advantageous in the design and construction of pressure vessels. This specification includes those practices which have become the most widely accepted and followed.

These standards are partly references to the selected alternatives permitted by the ASME Code, and partly described design and construction methods not covered by the Code. The regulations of the Code are not quoted in this Specification.

## A. GENERAL

1. This Specification, together with the purchase order and drawings, covers the requirements for the design and fabrication of pressure vessels.
2. In case of conflicts, the purchase order and drawings take precedence over this Specification.
3. Pressure vessels shall be designed, fabricated, inspected and stamped in accordance with the latest edition of the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, and its subsequent addenda.
4. Vessels and vessel appurtenances shall comply with the regulations of the Occupational Safety and Health Act (OSHA).
5. Vessel Manufacturers are invited to quote prices on alternate materials and construction methods if economics or other aspects make it reasonable to do so.
6. All deviations from this Specification, the purchase order, or the drawings shall have the written approval of the purchaser.
7. Vessel fabricator, after receipt of purchase order, shall furnish to purchaser checked shop drawings for approval.

## B. DESIGN

1. Pressure Vessels shall be designed to withstand the loadings exerted by internal or external pressure, weight of the vessel, wind, earthquake, reaction of supports, impact, and temperature.
2. The maximum allowable working pressure shall be limited by the shell or head, not by minor parts.
3. Wind load and earthquake. All vessels shall be designed to be free-standing. To determine the magnitude of wind pressure, the probability of earthquakes and seismic coefficients in various areas of the United States, Standard ANSI/ASCE 7-95 (Minimum Design Loads in Buildings and Other Structures) shall be applied.  
It is assumed that wind and earthquake loads do not occur simultaneously, thus the vessel should be designed for either wind or earthquake loading, whichever is greater.
4. Horizontal vessels supported by saddles shall be designed according to the method of L. P. Zick (Stresses in Large Horizontal Pressure Vessels on Two Saddle Supports).
5. The deflection of vertical vessels under normal operating conditions shall not exceed 6 inches per 100 feet of length.



### Specification for the Design and Fabrication of Pressure Vessels (continued)

6. Stresses in skirts, saddles, or other supports and their attachment welds may exceed the maximum allowable stress values of materials given in Part UCS of the ASME Code by 33-1/3 percent.
7. Vessel manufacturers shall submit designs for approval when purchaser does not furnish a design or does not specify the required plate thickness.

### C. FABRICATION

1. Materials shall be specified by purchaser and their designation indicated on the shop drawings. Materials shall not be substituted for those specified without prior written approval of purchaser.
2. The thickness of plate used for shell and heads shall be 1/4-inch minimum.
3. Manufacturer's welding procedure and qualification records shall be submitted for approval upon receipt of purchase order. Welding shall not be performed prior to purchaser's approval of welding procedure and qualification.  
All welding shall be done by the metallic shielded arc or the submerged arc welding process.  
Permanently installed backing strips shall not be used without written approval of purchaser. When used, backing strips shall be the same composition steel as that which they are attached to.
4. Longitudinal seams in cylindrical or conical shells, all seams in spherical shells and built-up heads shall be located to clear openings, their reinforcing pads, and saddle-wear plates. Circumferential seams of shell shall be located to clear openings, their reinforcing pads, tray and insulation support rings, and saddle wear plates. When the covering of circumferential seam by reinforcing pad is unavoidable, the seam shall be ground flush and examined prior to welding the reinforcing pad in place.  
No longitudinal joints shall be allowed within the downcomer area or at any other place where proper visual inspection of the weld is impossible.  
The minimum size of fillet weld serving as strength weld for internals shall be 1/4 inch.
5. Skirt. Vertical vessels shall be provided with a skirt which shall have an outside diameter equal to the outside diameter of the supported vessel. The minimum thickness for a skirt shall be 1/4 inch.  
Skirts shall be provided with a minimum of two 2-inch vent holes located as high as possible 180 degrees apart.  
Skirts 4 feet in diameter and less shall have one access opening; larger than 4-foot diameter skirts shall have two 18-inch O.D. access openings reinforced with sleeves.
6. Base rings shall be designed for an allowable bearing pressure on concrete of 625 psi.
7. Anchor bolt chairs or lug rings shall be used where required and in all cases where vessel height exceeds 60 feet. The number of anchor bolts shall be in multiples of 4; a minimum of 8 is preferred.
8. Saddle. Horizontal vessels shall be supported by saddles, preferably by only two whenever possible.  
Saddles shall be welded to the vessel, except when specifically ordered to be shipped loose. Saddles to be shipped loose shall be fitted to the vessel and match-marked for field installation. The shop drawing shall bear detailed instruction concerning this.

### Specification for the Design and Fabrication of Pressure Vessels (continued)

When temperature expansion will cause more than 3/8 inch change in the distance between the saddles, a slide bearing plate shall be used. Where the vessel is supported by concrete saddles 1/4 inch thick, corrosion plate 2 inches wider than the concrete saddle shall be welded to the shell with a continuous weld. The corrosion plate shall be provided with a 1/4 inch vent hole plugged with plastic sealant after the vessel has been pressure tested.

9. Openings of 2 inches and smaller shall be 6000 lb forged steel full or half coupling.  
Openings 2-1/2 inches and larger shall be flanged.  
Flanges shall conform to Standard ANSI B16.5-1973.  
Flange faces shall be as follows:  

Raised face . . . . .	below rating 600 lb ANSI
Raised face . . . . .	rating 600 lb ANSI, pipe size 3 inches and smaller
Ring type joint . . . . .	rating 600 lb ANSI, pipe size 4 inches and larger
Ring type joint . . . . .	above rating 600 lb ANSI

 Flange-bolt-holes shall straddle the principal centerlines of the vessel. Openings shall be flush with inside of vessel when used as drains or when located so that there would be interference with vessel internals. Internal edges of openings shall be rounded to a minimum radius of 1/8 inch or to a radius equal to one-half of the pipe wall thickness when it is less than 1/4 inch.  
When the inside diameter of the nozzle neck and the welding neck flange or welding fitting differ by 1/16 inch or more, the part of smaller diameter shall be tapered at a ratio 1:4.  
Openings shall be reinforced for new and cold, as well as for corroded condition. The plate used for reinforcing pad shall be the same composition steel as that used for the shell or head to which it is connected.  
Reinforcing pads shall be provided with a 1/4 inch tapped tell-tale hole located at 90° off the longitudinal axis of vessel.  
The minimum outside diameter of the reinforcing pad shall be 4 inches plus the outside diameter of the opening's neck.  
When covers are to be provided for openings according to the purchaser's requisition, manufacturer shall furnish the required gaskets and studs; these shall not be used for testing the vessel.  
Manway covers shall be provided with davits.  
Coupling threads must be clean and free from defects after installation.
10. Internals. Trays shall be furnished by tray fabricator and installed by vessel manufacturer. Tray support rings and downcomer bolting bars shall be furnished and installed by vessel manufacturer. The tray fabricator shall submit complete shop details, including installation instructions and packing list, to purchaser for approval and transmittal to vessel fabricator.  
Trays shall be designed for a uniform live load of 10 psf or the weight of water setting, whichever is greater, and for a concentrated live load of 250 lb.  
At the design loading the maximum deflection of trays shall not exceed  

up to 10-foot diameter - 1/8 inch
larger than 10-foot diameter - 3/16 inch



### Specification for the Design and Fabrication of Pressure Vessels (continued)

The minimum thickness of internal plateworks and support rings shall not be less than 1/4 inch.

Internal carbon steel piping shall be standard weight.

Internal flanges shall be ANSI 150-lb slip-on type or fabricated from plate.

Carbon steel internal flanges shall be fastened with carbon steel square-head machine bolts and square nuts tack-welded to the flanges to avoid loosening. Removable internals shall be made in sections which can be removed through the manways.

Removable internals shall not be provided with corrosion allowance. For openings connected to pump suction, a vortex breaker shall be provided.

11. Appurtenances. Vessels provided with manways, liquid level controls or relief valves 12 feet above grade, shall be equipped with caged ladders and platforms. Ladder and platform lugs shall be shop-welded to the vessel. Where vertical vessels require insulation, fabricator shall furnish and install support rings. Reinforcing rings may also be utilized in supporting insulation.

Insulation support rings shall be 1/2 inch less in width than the thickness of insulation and spaced 12 foot-1/2 inch clear starting at the top tangent line. The top ring shall be continuously welded to the head; all other rings may be attached by a 1-inch long fillet weld on 12-inch centers. The bottom head of insulated vertical vessel shall be equipped with 1/2-inch square nuts welded with their edges to the outside of the head on approximately 12-inch square centers.

12. Fabrication tolerances shall not exceed the limits indicated in the table beginning on page 200.

### D. INSPECTION

1. Purchaser reserves the right to inspect the vessel at any time during fabrication to assure that the vessel materials and the workmanship are in accordance with this specification.
2. The approval of any work by the purchaser's representative and his release of a vessel shall not relieve the manufacturer of any responsibility for carrying out the provisions of this specification.

### E. MISCELLANEOUS

1. Radiographic examination shall be performed when required by the ASME Code or when determined by the economics of design.
2. The completed vessel shall be provided with a name plate securely attached to the vessel by welding.
3. If the vessel is post-weld heat-treated, no welding is permitted after stress relieving.
4. Removable internals shall be installed after stress relieving.
5. The location of all vessel components openings, seams, internals, etc., of the vessel shall be indicated on the shop drawings by the distance to a common reference line. The reference line shall be permanently marked on the shell.
6. The hydrostatic test pressure shall be maintained for an adequate time to permit a thorough inspection, in any case not less than 30 minutes.
7. Vessels shall not be painted unless specifically stated on order.

### Specification for the Design and Fabrication of Pressure Vessels (continued)

### F. PREPARATION FOR SHIPMENT

1. After final hydrostatic test, vessel shall be dried and cleaned thoroughly inside and outside to remove grease, loose scale, rust and dirt.
2. All finished surfaces which are not protected by blind flanges shall be coated with rust preventative.
3. All flanged openings which are not provided with covers shall be protected by suitable steel plates.
4. Threaded openings shall be plugged.
5. For internal parts, suitable supports shall be provided to avoid damage during shipment.
6. Bolts and nuts shall be coated with waterproof lubricant.
7. Vessels shall be clearly identified by painting the order and item number in conspicuous location on the vessel.
8. Small parts which are to be shipped loose shall be bagged or boxed and marked with the order and item number of the vessel.
9. Vessel fabricator shall take all necessary precautions in loading by blocking and bracing the vessel and furnishing all necessary material to prevent damages.

### G. FINAL REPORTS

1. Before the vessel is ready for shipment the manufacturer shall furnish purchase copies or reproducible transparency each of the following reports:
  - a. Manufacturer's data report.
  - b. Shop drawings showing the vessel and dimensions "as built".
  - c. Photostatic copies of recording charts showing pressure during hydrostatic test.
  - d. Photostatic copies of recording charts showing temperature during post-weld heat treatment.
  - e. Rubbing of name plate.

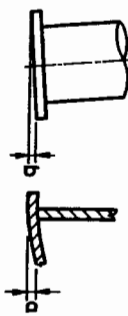
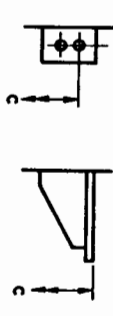

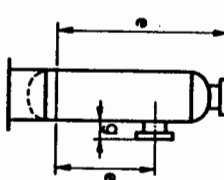
### H. GUARANTEE

Manufacturer guarantees that the vessel fulfills all conditions as stated in the Specification and that it is free from fault in design, workmanship and material. Should any defect develop during the first year of operation, the manufacturer agrees to make all necessary alterations, repairs and replacements free of charge.

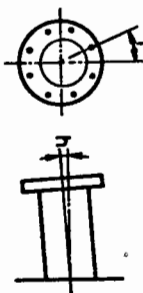
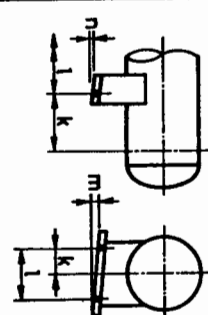
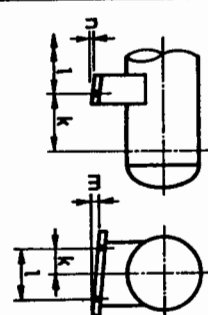






## VESSEL FABRICATION TOLERANCES

The dimensional tolerances in this table - unless otherwise noted - are based on practice widely followed by users and manufacturers of pressure vessels. All tolerances are inches, unless otherwise indicated. Tolerances not listed in this table shall be held within a practical limit.

	
<b>Base Ring</b>	
a. Flatness . . . . .	$\pm 1/16$
b. Out of level . . . . .	$\pm 1/8$
	
<b>Clips, Brackets</b>	
c. Distance to the reference line . . . . .	$\pm 1/4$
d. Deviation circumferentially measured at the joint of structure . . . . .	$\pm 1/4$
e. Distance between two adjacent clips . . . . .	$\pm 1/16$
	
<b>Manway</b>	
e. Distance from the face of flange or centerline of manway to reference line, vessel support lug, bottom of saddle, centerline of vessel, whichever is applicable . . . . .	$\pm 1/2$
f. Deviation circumferentially measured on the outer surface of vessel . . . . .	$\pm 1/2$
g. Projection; shortest distance from outside surface of vessel to the face of manway . . . . .	$\pm 1/2$
h. Deviation from horizontal, vertical or the intended position in any direction . . . . .	$\pm 1^{\circ}$
i. Deviation of bolt holes in any direction . . . . .	$\pm 1/4$
	
<b>Nozzle, Coupling which are not to be connected to piping.</b>	
The tolerances for manways shall be applied.	
<b>Nozzle, Coupling which are to be connected to piping.</b>	
Distance from the face of flange or centerline of opening to reference line, vessel support lug, bottom of saddle, centerline of vessel, whichever is applicable . . . . .	
f. Deviation circumferentially measured on the outer surface of vessel . . . . .	$\pm 1/4$
g. Projection; shortest distance from outside surface of vessel to the face of opening . . . . .	$\pm 1/4$

## VESSEL FABRICATION TOLERANCES (continued)

	
<b>Nozzles, (continued)</b>	
h. Deviation from horizontal, vertical or the intended position in any direction . . . . .	$\pm 1/2^{\circ}$
i. Deviation of bolt holes in any direction . . . . .	$\pm 1/8$
	
<b>Nozzles, Couplings used for level gage, level control, etc.</b>	
Distance between centerline of openings . . . . .	$\pm 1/16$
	
<b>Saddle</b>	
k. Distance centerline of bolt holes to reference line . . . . .	$\pm 1/8$
k. Distance centerline of bolt holes to centerline of shell . . . . .	$\pm 1/8$
l. Distance between bolt holes in base plate or between bolt holes or slots of two saddles . . . . .	$\pm 1/8$
m. Transverse tilt of base plate . . . . .	$\pm 1/32$ per Ft.
n. Longitudinal tilt of base plate . . . . .	$\pm 1/8$
	
<b>Shell</b>	
o. Deviation from verticality for vessels of up to 30 ft overall length . . . . .	$\pm 1/2$
for vessels of over 30 ft overall length . . . . .	$\pm 1/8$ per 10 ft. max. 1-1/2
	
<b>Vessels for internal pressure. The difference between the maximum and minimum inside diameters at any cross section shall not exceed one percent of the nominal diameter at the cross section . . . . .</b>	$\pm 1\%$
Deviation from nominal inside diameter as determined by strapping . . . . .	
Out of roundness Code UG-80	$\pm 1/32$ per Ft.
External pressure. See Code UG-80	
Formed Heads, Code UG-81	
	
<b>Tray Installation</b>	
r. Out of level in any direction . . . . .	$\pm 1/32$ per Ft.
	
<b>Tray Support</b>	
r. Out of level in any direction . . . . .	$\pm 1/32$ per Ft.



## VESSEL FABRICATION TOLERANCES (continued)

### Tray Support (continued)

s. Distance between adjacent tray supports . . . . .	± 1/8
t. Distance to reference line . . . . .	± 1/4
s. Distance to seal pan . . . . .	± 1/8
v. Distance to downcomer support . . . . .	± 1/8
w. Tilt for any width of support ring . . . . .	± 1/16
<b>Weir Plate</b>	
x. Out of level . . . . .	± 1/16
y. Height . . . . .	± 1/8
z. Distance to inside of vessel wall . . . . .	± 1/4

## API Specification for SHOP WELDED TANKS

Summary of Major Requirements of API Standard 12F, Eleventh Edition 1994

**SCOPE** - This Specification covers material, design, fabrication and testing requirements for vertical, cylindrical, above-ground, shop fabricated, welded, steel storage tanks for oilfield service in standard sizes as tabulated below.

### MATERIAL

Plates shall conform to the following ASTM Standards:  
A26, A283, C or D, and A285 C.

### MINIMUM PLATE THICKNESS

Shell and deck:  $\frac{3}{16}$  in., Bottom:  $\frac{1}{4}$  in., Sump:  $\frac{3}{8}$  in.  
15-6 diam Deck:  $\frac{1}{4}$  in.

### CONSTRUCTION

The bottom of the tank shall be flat or conical; the latter may be skirted or unskirted, Fig. A, B, C. The deck shall be conical. The slope of the bottom and deck cone = 1:12.

### WELDING

Bottom shell and deck plate joints shall be double-welded butt joints with complete penetration, Fig. D. The bottom and the deck shall be attached to the shell by double-welded butt joint or  $\frac{3}{16}$  in fillet welds, both inside and outside, Fig. E through K.

### OPENINGS

Tanks shall be furnished with 24 in.  $\times$  36 in. extended neck cleanout, API Std. 12F Fig. 4.

### TESTING

The tank will be tested with air  $1\frac{1}{2}$  times the maximum design pressure.

### PAINTING

One coat Primer.

### TANK DIMENSIONS

Nominal Capacity bbl.	Working Capacity bbl.	Outside Diameter ft. in.	Height ft.
90	72	7-11	10
100	79	9-6	8
150	129	9-6	12
200	166	12-0	10
210	200	10-0	15
250	224	11-0	15
300	266	12-0	15
400	366	12-0	20
500	466	12-0	25
500	479	15-6	16
750	746	15-6	24
Tolerance	—	$\pm \frac{1}{8}$ in.	$\pm \frac{3}{8}$ in.



## WELDED STEEL TANKS FOR OIL STORAGE

API Standard 650, Ninth Edition, 1993

### APPENDIX A—OPTIONAL DESIGN BASIS FOR SMALL TANKS (Summary of major requirements)

#### SCOPE

This appendix provides rules for relatively small capacity, field-erected tanks in which the stressed components are limited to a maximum of  $\frac{1}{2}$  inch nominal thickness, including any corrosion allowance specified by the purchaser.

#### MATERIALS

The most commonly used plate materials of those permitted by this standard: A 283 C, A 285 C, A 36, A 516-55, A 516-60  
The plate materials shall be limited to  $\frac{1}{2}$  thickness.

#### WELDED JOINTS

The type of joints at various locations shall be:

##### Vertical Joints in Shell

Butt joints with complete penetration and complete fusion as attained by double welding or by other means, which will obtain the same quality of joint.

##### Horizontal Joints in Shell

Complete penetration and complete fusion butt weld.

##### Bottom Plates

Single-welded, full-fillet lap joint, or single-welded butt joint with backing strip.

##### Roof Plates

Single-welded, full-fillet lap joint. Roof plates shall be welded to the top angle of the tank with continuous fillet weld on the top side only.

##### Shell to Bottom Plate Joint

Continuous fillet weld laid on each side of the shell plate. The size of each weld shall be the thickness of the thinner plate.

The bottom plates shall project at least 1 inch width beyond the outside edge of the weld attaching the bottom to shell plate.

#### INSPECTION

##### Butt Welds

Inspection for quality of welds shall be made by the radiographic method. By agreement between purchaser and manufacturer, the spot radiography may be deleted.

##### Fillet Welds

Inspection of fillet welds shall be made by visual inspection.

## WELDED STEEL TANKS FOR OIL STORAGE

API Standard 650, Ninth Edition, 1993

#### TESTING

##### Bottom Welds

1. Air pressure or vacuum shall be applied using soapsuds, linseed oil, or other suitable material for detection of leaks, or
2. After attachment of at least the lowest shell course, water shall be pumped underneath the bottom and a head of 6 inches shall be maintained inside a temporary dam.

##### Tank Shell

1. The tank shall be filled with water, or
2. Painting all joints on the inside with highly penetrating oil, and examining outside for leakage.
3. Applying vacuum.

Appendix A — Optional Design Basis for Small Tanks

Appendix B — Recommendations for Design and Construction of Foundations for Above Ground Oil Storage Tanks

Appendix C — External Floating Roofs

Appendix D — Technical Inquiries

Appendix E — Seismic Design of Storage Tanks

Appendix F — Design of Tanks for Small Internal Pressures

Appendix G — Structurally Supported Aluminum Dome Roofs

Appendix H — Internal Floating Roofs

Appendix I — Undertank Leak Detection and Subgrade Protection

Appendix J — Shop-Assembled Storage Tanks

Appendix K — Sample Application of the Variable-Design-Point Method to Determine Shell-Plate Thickness

Appendix L — API Standard 650 Storage Tank Data Sheets

Appendix M — Requirements for Tanks Operating at Elevated Temperatures

Appendix N — Use of New Materials That Are Not Identified

Appendix O — Recommendations for Under-Bottom Connections

Appendix P — Allowable External Loads on Tank Shell Openings

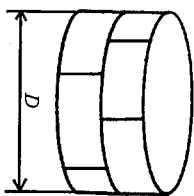
Appendix S — Austenitic Stainless Steel Storage Tanks



## WELDED STEEL TANKS APL Standard 650—APPENDIX A FORMULAS

### NOTATION

$C.A.$ = corrosion allowance, in.	$H$ = design liquid level, ft.
$D$ = nominal diameter of tank, ft.	$t$ = minimum required plate thickness, in.
$E$ = joint efficiency, 0.85 when spot radiographed 0.70 when not radiographed	$R$ = radius of curvature of roof, ft.
$G$ = specific gravity of liquid to be stored, but in no case less than 1.0	$\theta$ = angle of cone elements with horizontal, deg.

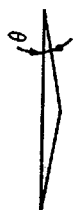


SHELL

$$t = \frac{(2.6)(D)(H-1)(G)}{(E)(21,000)} + C.A.$$

but in no case less than the following:

Mean diameter of tank feet	Plate thickness inches
Smaller than 50	3/16
50 to 120, excl.	1/4
120 to 200, incl.	5/16
Over 200	3/8

SELF-SUPPORTING  
CONE ROOF

$$t = \frac{D}{400 \sin \theta} \text{ but not less than } 3/16 \text{ in.}$$

Maximum $t$ = 1/2 in.	9:12 slope
Maximum $\theta$ = 37 deg.	2:12 slope
Minimum $\theta$ = 9 deg.	

SELF-SUPPORTING  
DOME AND  
UMBRELLA ROOF

Maximum $t$ = 1/2 in.	
$R$ = radius of curvature of roof, in feet	
Maximum $R$ = 0.8 $D$ (unless otherwise specified by the purchaser.	
Maximum $R$ = 1.2 $D$	

The cross-sectional area of the top angle plus the participating area of the shell and roof plate shall be equal or exceed the following:

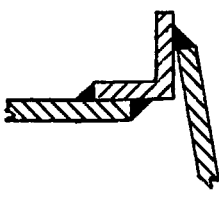
For Self-Supporting  
Cone Roofs:

$$\frac{D^2}{3,000 \sin \theta}$$

For Self-Supporting  
Dome and Umbrella Roofs:

$$\frac{DR}{1,500}$$

TOP RING



BOTTOM

All bottom plates shall have a minimum nominal thickness of 1/4 in.

## WELDED STEEL TANKS FOR OIL STORAGE

APL Standard 650, Ninth Edition 1993

### APPENDIX J—SHOP-ASSEMBLED STORAGE TANKS (Summary of major requirements)

#### SCOPE

This appendix provides design and fabrication requirements for vertical storage tanks in sizes that permit complete shop assembly and delivery to the installation site in one piece. Storage tanks designed on this basis are not to exceed 20 feet in diameter.

#### MATERIALS

The most commonly used plate materials of those permitted by this standard: A 36, A 283 C, A 285 C, A 516-55, A 516-60

#### WELDED JOINTS

As described in Appendix A (see preceeding page) with the following modifications:

Lap-welded joints in bottoms are not permissible.

All shell joints shall be full penetration, butt-welded without the use of backup bars.

Top angles shall not be required for flanged roof tanks.

Joints in bottom plates shall be full penetrations butt-welded.

Flat bottoms shall be attached to the shell by continuous fillet weld laid on each side of the shell plate.

#### BOTTOM DESIGN

All bottom plate shall have a minimum thickness of 1/4 inch.

Bottoms may be flat or flat-flanged.

Flat bottoms shall project at least 1 inch beyond the outside diameter of weld attaching the bottom shell.

#### SHELL DESIGN

Shell plate thickness shall be designed with the formula:

(for notations see Appendix A on the preceeding page.)

$$t = \frac{(2.6)(D)(H-1)(G)}{(E)(21,000)} + C.A.$$

but in no case shall the nominal thickness be less than:

Nominal Tank Diameter (feet)	Nominal Plate Thickness (inches)
Up to 10.5, incl	3/16
Over 10.5	1/4

#### ROOF DESIGN

Roofs shall be self supporting cone or dome and umbrella roofs. See Appendix A for design formulas.

#### TESTING

Apply 2 to 3 pounds per square inch internal pressure. For tanks with a diameter of 12 feet or less, a maximum pressure of 5 psig shall be used.



# Summary of Major Requirements of PIPING CODES

## PIPE WALL THICKNESS AND ALLOWABLE PRESSURE

### CODE & SCOPE

### FORMULAS

#### Straight Pipe Under Internal Pressure

$$t = \frac{PD_o}{2(SE + P_y)} + A$$

$$t = \frac{Pd + 2SE(A + 2vPA)}{2(SE + P_y - P)}$$

$$P = \frac{2SE(t_m - A)}{D_o - 2y(t_m - A)}$$

$$P = \frac{2SE(t_m - A)}{d - 2y(t_m - A) + 2t_m}$$

#### VALUES OF S, 1000 psi.

For materials ASTM A53B and A106B  
-20 to 650 700 750 800

For metal temperatures not exceeding Deg. F.  
15.0 14.4 13.0 10.8

#### External Pressure

For determining wall thickness and stiffening requirements, the procedures outlined in Paras. UG-28, 29 and 30, Section VIII, Division 2 of the ASME Boiler and Pressure Vessel Code shall be followed.

#### Internal Pressure

$$t_m = t + A \quad P = \frac{2SEt}{D} \quad t = \frac{PD}{2SE}$$

#### VALUES OF S, 1000 psi.

For materials ASTM A53B and A106B  
-20 to 100 200 300 400 450

For metal temperatures not exceeding Deg. F.  
20.00 19.10 18.15 17.25 16.80

#### Internal Pressure

$$t_m = t + c \quad t = \frac{PD}{2(SE - P(1 - \gamma))}$$

$$t = \frac{PD}{2(SE + P_y)}$$

#### VALUES OF S, 1000 psi.

For materials ASTM A53B and A106B  
-20 to 100 200 300 400 500

For metal temperatures not exceeding Deg. F.  
A53B 20.00 20.0 20.0 20.0 18.9

#### External Pressure

For determining wall thickness and stiffening requirements the procedures outlined in Paras. UG-28, 29 and 30, Section VIII, Div. 1 of the ASME Boiler and Pressure Vessel Code shall be followed.

# Summary of Major Requirements of PIPING CODES

(Continued from facing page)

### NOTATION

### NOTES

$A$  = an additional thickness in inches to compensate for material removed in threading, grooving, etc., and to provide for mechanical strength, corrosion and erosion.

Centrifugally cast 0.14 in.  
Statically cast 0.18 in.

$c$  = the sum in inches of the mechanical allowances (thread or groove depth) plus corrosion and erosion allowance.

$d$  = inside diameter of the pipe in corroded conditions, inches.

$D$  &  $D_o$  = outside diameter of the pipe, inches

$E$  = efficiency factor of welded joint in pipe (see applicable code) For seamless pipe  $E = 2.0$ .

$F$  = for cast iron pipe casting quality factor  $F$  shall be used in place of  $E$ .

$P$  = internal design pressure, or maximum allowable working pressure, psig.

$S$  = maximum allowable stress in material due to internal pressure and the design temperature, psig.

$t$  = thickness of pipe required for pressure, inches

$t_m$  = minimum thickness of pipe in inches required for pressure and to compensate for material removed for threading, grooving, etc., and to provide for mechanical strength, corrosion and erosion.

$y$  &  $Y$  = coefficients as tabulated below

#### VALUES OF $y$ & $Y$

Temperature F	900° and below	950	1000	1050	1100	1250 and above
Ferritic Steels	0.4	0.5	0.7	0.7	0.7	0.7
Austenitic Steels	0.4	0.4	0.4	0.4	0.5	0.7

Note: For intermediate temperatures the values may be interpolated. For nonferrous materials and cast iron,  $y$  equals 0.4.

For pipe with a  $D_o/t_m$  ratio less than 6, the value of  $y$  for ferritic and austenitic steels designed for temperatures of 900°F and below shall be taken as:

$$y = \frac{d}{d + D_o}$$

1. The minimum thickness for the pipe selected, considering manufacturer's minus tolerance, shall not be less than  $t_m$ . The minus tolerance for seamless steel pipe is 12.5% of the nominal pipe wall thickness.

2. Where steel pipe is threaded and used for steam service at pressure above 250 psi, or for water service above 100 psi with water temperature above 200°F, the pipe shall be seamless, having the minimum ultimate tensile strength of 48,000 psi and weight at least equal to sch. 80 of ANSI B36.20. (Code ANSI B31.1, Para. 104.1.2C.1)

3. Piping systems installed in open easements which are accessible to the general public or to individuals other than the owner of the piping system or his employee or agent, shall be designed in accordance with ANSI B31.8. (Code ANSI B31.02, Para. 201.1)

4. When not specifically required by a gas using process or equipment, the maximum working pressure for piping systems installed in buildings intended for human use and occupancy shall not exceed 20 psig. (Code ANSI B31.2, Para. 201.2.1)

5. Every piping system, regardless of anticipated service conditions, shall have a design pressure of at least 10 psig between the temperatures of minus 20°F and 250°F. (Code ANSI B31.2, Para. 201.2.2.b)

6. Where the minimum wall thickness is in excess of 0.10 of the nominal diameter, the piping system shall meet the requirements of ANSI B31.3. (Code ANSI B31.2, Para. 203)

7. Pipe with  $t$  equal to or greater than  $D/6$ , or  $P/SE$  greater than 0.385, requires special consideration, taking into account design and material factors such as theory of failure, fatigue and thermal stresses.

8. Pipe bends shall meet the flattening limitations of the applicable Code.



# Summary of Major Requirements of PIPING CODES

## PIPE WALL THICKNESS AND ALLOWABLE PRESSURE

### CODE & SCOPE

### FORMULAS

#### ANSI B31.4-1998 LIQUID TRANSPORTATION SYSTEMS

This Code prescribes requirements for the design, materials, construction, assembly, inspection, and testing of piping transporting liquids such as crude oil, condensate, natural gasoline, natural gas liquids, liquefied petroleum gas, liquid alcohol, liquid anhydrous ammonia, and liquid petroleum products between producers' lease facilities, tank farms, natural gas processing plants, refineries, stations, terminals, and other delivery and receiving points.

**Straight Pipe Under Internal Pressure**

$$t_n = t + A$$

$$t = \frac{PD}{2S}, \text{ where}$$

$S$  = allowable stress value, psi. For pipe materials ASTM A 53 B and A 106 B,  $S = 25,200$  psi. at  $-20^\circ\text{F}$  to  $250^\circ\text{F}$ .

$t$  = pressure design wall thickness inches (See notes 1, 2).

#### ANSI B31.5-2000 REFRIGERATION PIPING

This Code provides minimum requirements for the materials, design, fabrication, assembly, erection, test, and inspection of refrigerant and secondary coolant piping for temperatures as low as  $320^\circ\text{F}$  (whether erected on the premises or factory assembled) except as specifically excluded in the following paragraphs.

Users are advised that other piping Code Sections may provide requirements for refrigeration piping in their respective jurisdictions.

This Code shall not apply to:

(a) any self-contained or unit systems subject to the requirements of Underwriters' Laboratories or other nationally recognized testing laboratory;

(b) water piping;

(c) piping designed for external or internal gage pressure not exceeding 15 psi (103 kPa) regardless of size.

### Internal Pressure

$$t_m = t + c$$

$$t = \frac{PD_o}{2(S + Py)} \text{ or } t = \frac{Pd}{2(S + Py - P)}$$

$$P = \frac{2St}{D_o - 2yt}, \text{ where}$$

$S$  = maximum allowable stress, psi. For pipe materials ASTM A 53 B and A 106 B,  $S = 15,000$  psi. at  $100^\circ\text{F}$  to  $400^\circ\text{F}$ .

$t$  = pressure design wall thickness, inches. (See notes 1, 2).

### External Pressure

The pressure design thickness,  $t$ , shall be determined in accordance with Code, Para. 504.1.3.

#### ANSI B31.8-1999 GAS TRANSMISSION AND DISTRIBUTING PIPING SYSTEMS

This Code covers the design, fabrication, installation, inspection, testing, and the safety aspects of operation and maintenance of gas transmission and distribution systems, including gas pipelines, gas compressor stations, gas metering, and regulating stations, gas mains, and service lines up to the outlet of customer's meter set assembly. Included within the scope of this Code are gas storage equipment of the closed type, fabricated or forged from pipe or fabricated from pipe and fittings and gas storage lines.

### Steel Pipe Design Formula

### Internal Pressure

$$P = \frac{2St}{D} \times F \times E \times T, \text{ where}$$

$S$  = specified minimum yield strength, psi. For pipe materials ASTM A 53 B and A 106 B,  $S = 35,000$  psi.

$t$  = nominal wall thickness, inches (See notes 1, 2, 3, 4 & 5).

# Summary of Major Requirements of PIPING CODES

(Continued from facing page)

### NOTATION:

$A$  = Sum of allowance, inches for threading and grooving as required under Code, Para. 402.4.2, corrosion as required under Code, Para 402.4.2, and increase in wall thickness if used as protective measure under Code Para. 402.1.

$c$  = For internal pressure, the sum of allowances in inches thread and groove depth, manufacturers' minus tolerance, plus corrosion and erosion allowance.

For external pressure, the sum in inches of corrosion and erosion allowances, plus manufacturers' minus tolerance.

$d$  = Inside diameter of pipe, inches.

$D_o$  = Outside diameter of pipe, inches.

$E$  = Longitudinal joint factor obtained from Code, table 841.12. For seamless pipe,  $E = 1.0$ .

$F$  = Values of Design Factor  $F$

### Construction Type Design Factor $F$

(See Code 841.114A)

Type - A	0.72
Type - B	0.60
Type - C	0.50
Type - D	0.40

$P_i$  &  $P$  = Internal design pressure, psig.

$S$  = As described at the formulas, and in applicable Code, psi.

$t_i$  = As described at the formulas, inches.

$t_n$  = Nominal wall thickness of straight part of steel pipe satisfying requirements for pressure and allowances.

$t_m$  = Minimum required thickness, inches, satisfying requirements for design pressure and mechanical, corrosion and erosion allowances.

$T$  = Temperature Derating Factor for Steel Pipe.

Temperature Degrees Fahrenheit	Factor $T$
250 F or less	1.000
300 F	0.967
350 F	0.933
400 F	0.900
450 F	0.867

Note: Interpolate for intermediate values.

$y$  = Coefficient for materials indicated:

For nonferrous materials, ferritic steels and austenitic steels  $y = 0.4$ .

If  $\frac{D_o}{t}$  in range of 4-6, use

$$y = \frac{d}{d + D_o}$$

for ductile materials.

For brittle materials use  $y = 0.0$ .

### NOTES:

1. In selection of pipe the manufacturers' minus tolerance shall be taken into consideration. The minus tolerance for seamless steel pipes is 12.5% of the nominal wall thickness. This tolerance may be used also when specification is not available.

2. Pipe bends shall meet the flattening limitations of the applicable Code.

3. Classification of Locations. In Code B31.8, Para. 840.2, four classes are described as a basis for prescribing the types of construction.

4. Limitation by Pipe Design Factors, Code B31.8, Para. 841.111-114.

5. Least Nominal Wall Thickness, Code B31.8, Table 841.141.

The formulas and regulations are extracted from the American National Standard Code for Pressure Piping with the permission of the publisher, The American Society of Mechanical Engineers.



## NOTES

## RECTANGULAR TANKS

### UNDER HYDROSTATIC PRESSURE

Flat-walled tanks due to their mechanically disadvantageous shape are used for low hydrostatic pressure only. The quantity of material required for rectangular tanks is higher than for cylindrical vessels of the same capacity. However, sometimes the application of rectangular tanks is preferable because of their easy fabrication and the good utilization of space.

#### MAXIMUM SIZE

Unstiffened tanks may be not larger than 30 cu. ft. and tanks with stiffenings, 140 cubic feet capacity.

For larger tanks, the use of stay rods is advisable for economic reasons.

#### RATIO OF SIDES

If all sides are equal, the length of one side:  $B = \sqrt[3]{V}$ ; where  $V$  = volume cu. ft.

Preferable ratio: Longer side: 1.5 B; Shorter side: 0.667 B

#### DESIGN

The formulas on the following pages are based on maximum allowable deflection;  $\Delta = t_s/2$ , where  $t_s$  denotes the thickness of side-plate.

#### Values of $\alpha$ and $\beta$

Ratio, $\frac{H}{L}$ or $\frac{H}{l}$	0.25	0.286	0.333	0.4	0.5	0.667
Constant, $\beta$	0.024	0.031	0.041	0.056	0.080	0.116
Constant, $\alpha$	0.00027	0.00046	0.00083	0.0016	0.0035	0.0083

Ratio, $\frac{H}{L}$ or $\frac{H}{l}$	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Constant, $\beta$	0.16	0.26	0.34	0.38	0.43	0.47	0.49
Constant, $\alpha$	0.022	0.043	0.060	0.070	0.078	0.086	0.091

$H$  = height of tank  $L$  = length of tank  $l$  = maximum distance between supports

#### WELDING OF PLATE EDGES

Some preferable welded joints of plate edges:



The stiffenings may be attached to the tank wall either by intermittent or continuous welding and may be placed inside or outside.

#### BIBLIOGRAPHY

Other design methods are offered in the following papers:

Vojtaszak, I. A.: Stress and Deflection of Rectangular Plates, ASME Paper A-71, Journal Appl. Mech., Vol. 3 No. 2, 1936.

Timoshenko, S. and S. Woinowsky-Krieger: "Theory of Plates and Shells". 2nd edition. McGraw-



# RECTANGULAR TANKS UNDER HYDROSTATIC PRESSURE WITH TOP-EDGE STIFFENING

## NOTATION

$\alpha$  = factor depending on ratio of length and height of tank,  $H/L$  (See Table)  
 $E$  = modulus of elasticity, psi; 30,000,000 for carbon steel  
 $G$  = specific gravity of liquid  
 $H$  = height of tank, in  
 $I$  = moment of inertia, in<sup>4</sup>  
 $l$  = maximum distance between supports, inches  
 $L$  = length of tank, inches  
 $R$  = reaction with subscripts indicating the location, lb./in.  
 $S$  = stress value of plate, psi, as tabulated in Code, Tables UCS - 23  
 $t$  = required plate thickness, inches  
 $t_a$  = actual plate thickness, inches  
 $t_b$  = required plate thickness for bottom, inches  
 $t_b$  = actual thickness of bottom, inches  
 $w$  = load per unit of length lb./in.  
 $y$  = deflection of plate, inches

## REQUIRED PLATE THICKNESS

$$t = L \sqrt{\frac{\beta H 0.036 G}{S}}$$

Thickness,  $t$  may be used also for the bottom plate if its entire surface is supported.

Thickness,  $t$  shall be increased in corrosive service.

Maximum deflection of plate:

$$\max = \frac{\alpha 0.036 G H L^4}{E t_a^3}$$

## STIFFENING FRAME

$$w = \frac{0.036 G H^2}{2} \quad R_1 = 0.3w \quad R_2 = 0.7w$$

Minimum required moment of inertia for top-edge stiffening:

$$I_{\min} = \frac{R_1 L^4}{192 E t_a}$$

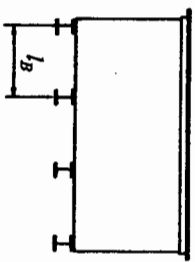
## BOTTOM PLATE

## WHEN SUPPORTED BY BEAMS

$$l_b = \frac{I_b}{1.254 \sqrt{\frac{S}{0.036 G H}}}$$

Maximum spacing of supports for a given thickness of bottom:

$$l_b = 1.254 t_b \sqrt{\frac{S}{0.036 G H}}$$



# RECTANGULAR TANKS EXAMPLES

## DESIGN DATA

Capacity of the tank: 600 gallon = 80 cu. ft. approximately  
 Content: water;  $G = 1$

The side of a cube-shaped tank for the designed capacity:  $\sqrt[3]{80} = 4.31$  ft.  
 Preferred proportion of sides:

$$L = 4.31 \times 1.5 = 6.47 \text{ ft.} = 78 \text{ inches}$$

$$H = 4.31 \times .667 = 2.87 \text{ ft.} = 34 \text{ inches}$$

$$\text{Width of the tank } 4.31 \text{ ft.} = 52 \text{ inches}$$

$$S = 15,700, \text{ using SA 285 C material}$$

$$\text{Corrosion allowance: } 1/16 \text{ in.}$$

$$H/L = 34/78 = 0.43; \beta = 0.063$$

## REQUIRED PLATE THICKNESS

$$t = 78 \sqrt{\frac{0.063 \times 34 \times 10.036 \times 1}{15,700}} = 0.1729 \text{ in.}$$

$$+ 0.0625 \text{ corr. allow} = 1/4 \text{ in.}$$

## STIFFENING FRAME

$$w = \frac{0.036 \times 1 \times 34^2}{2} = 20.808 \text{ lb/in} \quad R_1 = 0.3 \times 20.808 = 6.24 \text{ lb/in} \quad R_2 = 0.6 \times 20.808 = 14.57 \text{ lb/in}$$

$$I_{\min} = \frac{6.24 \times 78^4}{192 \times 30,000,000 \times 0.1875} = 0.214 \text{ in}^4$$

1-3/4 × 1-3/4 × 3/16 (.18 in<sup>4</sup>) satisfactory for stiffening at the top of the tank

## BOTTOM PLATE WHEN SUPPORTED BY BEAMS

if number of beams = 3;  $l = 39$  inches

$$l_b = \frac{39}{1.254 \sqrt{\frac{15,700}{0.036 \times 1 \times 34}}} = 0.275 \text{ in.}$$

Or using the plate thickness 0.1875 as calculated above, the maximum spacing for supports:

$$l = 1.254 \times 0.1875 \sqrt{\frac{15,700}{0.036 \times 1 \times 34}} = 26.63 \text{ in.}$$

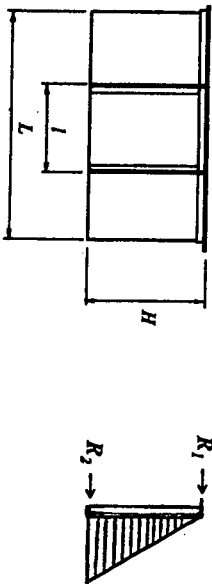
Using 4 beams,  $l = 26$  in.



## RECTANGULAR TANKS WITH VERTICAL STIFFENINGS

### NOTATION

- $\beta$  = Factor depending on ratio of length and height,  $H/l$   
 (See Table on page 213)  
 $E$  = modulus of elasticity, psi.  
 $H$  = height of tank inches  
 $I$  = moment of inertia, in<sup>4</sup>  
 $G$  = specific gravity of liquid  
 $l$  = the maximum distance between stiffenings on the longer or shorter side of the tank, inches.  
 $L$  = length of tank, inches  
 $S$  = stress value of plate, psi.  
 $t$  = required plate thickness, inches     $t_a$  = actual plate thickness, inches  
 $w$  = load, lbs.  
 $Z$  = section modulus, in<sup>3</sup>



### REQUIRED PLATE THICKNESS

$$t = l \sqrt{\frac{\beta H 0.036 G}{S}}$$

### LOADS, lb/in

$$W = \frac{0.036 G H^2}{2} \quad R_1 = 0.3_w \quad R_2 = 0.7_w$$

### STIFFENING FRAME

Required section modulus of vertical stiffening

$$Z = \frac{0.0642 \cdot 0.036 G H^3 l}{S}$$

Minimum required moment of inertia for top-edge stiffening:

$$I_{min} = \frac{R_1 L^4}{192 E t_a}$$

## RECTANGULAR TANKS WITH VERTICAL STIFFENINGS EXAMPLES

### DESIGN DATA

- $E = 30,000,000$  psi  
 $L = 78$  in.  
 $H = 34$  in.  
 $B = 52$  in.  
 $S = 15,700$  psi  
 $l = 26$  in.  
 Content: Water  
 $G = 1$   
 $H/l = \frac{34}{26} = 1.31$ ;  $\beta = 0.22$

### REQUIRED PLATE THICKNESS

$$t = 26 \times \sqrt{\frac{0.22 \times 34 \times 0.036 \times 1}{15,700}} = 0.1077 \text{ in.}$$

+ corr. allow  $\frac{0.0625}{0.1702}$  in.

+ use  $3/16$  in. plate

### STIFFENING FRAME

$$Z_{min} = \frac{0.0642 \times 0.036 \times 1 \times 34^3 \times 26}{15,700} = 0.1504 \text{ in.}^3$$

$2 \times 2 \times 3/16$  (.19 in.<sup>3</sup>) satisfactory for vertical stiffening

$$w = \frac{0.036 \times 1 \times 34^2}{2} = 20.8 \text{ lb./in.} \quad R_1 = 0.3 \times 20.8 = 6.24 \text{ lb./in.}$$

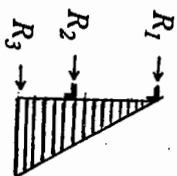
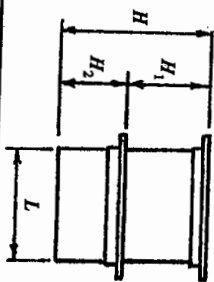
$$I_{min} = \frac{6.24 \times 78 \text{ in.}^4}{192 \times 30,000,000 \times 0.125} = 0.32 \text{ in.}^4$$



### RECTANGULAR TANKS Under Hydrostatic Pressure WITH HORIZONTAL STIFFENINGS

#### NOTATION

$E$  = modulus of elasticity, psi.; 30,000,000 for carbon steel  
 $G$  = specific gravity of liquid  
 $H$  = height of tank, in.  
 $I$  = moment of inertia, in.<sup>4</sup>  
 $L$  = length of tank, inches  
 $P$  = pressure of liquid, psi.  
 $R$  = reaction with subscripts indicating the location, lb./in.  
 $S$  = stress value of plate, psi.  
 $t$  = required plate thickness, inches  
 $t_a$  = actual plate thickness, inches  
 $w$  = load per unit of length lb./in.



#### SPACING OF STIFFENINGS

$$H_1 = 0.6H$$

$$H_2 = 0.4H$$

#### REQUIRED PLATE THICKNESS

$$t = 0.3H \sqrt{\frac{0.036 GH}{S}}$$

#### LOAD lb./in.

$$w = \frac{0.036 GH^2}{2}$$

$$R_1 = 0.06 w \quad R_2 = 0.3 w \quad R_3 = 0.64 w$$

#### MINIMUM MOMENT OF INERTIA FOR STIFFENING

Minimum required moment of inertia  
for top-edge stiffening

$$I_1 = \frac{R_1 L^4}{192 E t_a}$$

Minimum required moment of inertia  
for intermediate stiffening

$$I_2 = \frac{R_2 L^4}{192 E t_a}$$

### RECTANGULAR TANKS WITH INTERMEDIATE HORIZONTAL STIFFENINGS EXAMPLES

#### DESIGN DATA:

Designed capacity = 1,000 gallon = 134 cu. ft. (approx.)

Content: water

$S = 15,700$  psi, using SA 285 C material

Corrosion allowance =  $1/16$  in.

The side of a cube-shaped tank for the designed capacity:  $\sqrt[3]{134} = 5.12$  ft.

Preferred proportion of sides:

width =  $0.667 \times 5.12 = 3.41$  ft; approx. 42 inches

length =  $1.500 \times 5.12 = 7.68$  ft; approx. 92 inches

height = 5.12 ft; approx. 60 inches

For height 60 inches, intermediate stiffening is required.

#### SPACING OF STIFFENINGS:

$$H_1 = 0.6 \quad H = 36 \text{ in.}$$

$$H_2 = 0.4H = 24 \text{ in.}$$

#### REQUIRED PLATE THICKNESS:

$$t = 0.3 \times 60 \sqrt{\frac{0.036 \times 1 \times 5.60}{15,700}} = 0.2111 \text{ in.}$$

$$+ \text{corr. allow} \quad 0.0625 \text{ in.}$$

use  $5/16$ " plate

#### LOADS:

$$w = \frac{0.036 \times 1 \times 60^2}{2} = 64.8 \text{ lb./in.}$$

$$R_1 = 0.06w = 3.89 \text{ lb./in.}$$

$$R_2 = 0.3w = 19.44 \text{ lb./in.}$$

#### MINIMUM MOMENT OF INERTIA FOR STIFFENINGS:

$$I_1 = \frac{3.89 \times 92^4}{192 \times 30,000,000 \times 0.25} = 0.4690 \text{ in.}^4$$

$$I_2 = \frac{19.44 \times 92^4}{192 \times 30,000,000 \times 0.25} = 0.967 \text{ in.}^4$$

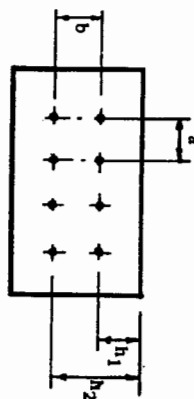


### TIE ROD SUPPORT FOR RECTANGULAR TANKS Under Hydrostatic Pressure

To avoid the use of heavy stiffenings, the sides of large tanks may be supported most economically by tie rods.

#### NOTATIONS

$A$  = Required cross sectional area of tie rod, sq. in.  
 $a$  = horizontal pitch, in.  
 $b$  = vertical pitch, in.  
 $G$  = specific gravity of liquid  
 $P$  = pressure of liquid, lb.  
 $S$  = stress value of rod material, psi.  
 $t$  = required plate thickness, in.  
 $S_p$  = stress value of plate material, psi.



REQUIRED  
PLATE  
THICKNESS

$$\text{when } a \approx b \quad t = 0.7b \sqrt{\frac{0.036 G h}{S_p}}$$

LOAD ON  
TIE ROD

$$P = ab \, 0.036 G h$$

REQUIRED CROSS  
SECTIONAL AREA  
OF TIE ROD

$$A = \frac{P}{S}$$

#### DESIGN DATA

Length=30 ft., width=12 ft., height=15 ft.

$a = 60$  in.

$b = 60$  in.

$G = 1$

$S = 20,000$  psi.

$S_p = 20,000$  psi.

$S_p = 20,000$  psi.

$$t = 0.7 \times 60 \sqrt{\frac{0.036 \times 1 \times 120}{20,000}}$$

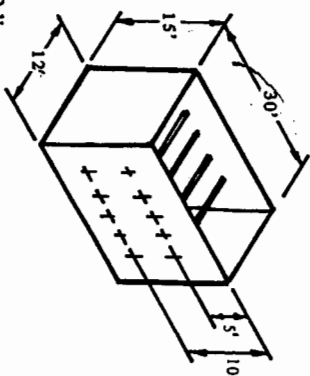
$$= 0.625 \approx 5/8 \text{ in. plate}$$

$$P_2 = ab \, 0.036 G h_2 = 60 \times 60 \times 0.036 \times 1 \times 20 = 15,552 \text{ lb.}$$

$$A_2 = \frac{15,552}{20,000} = 0.778 \text{ sq. in.} = 1 \phi \text{ rods}$$

$$P_1 = ab \, 0.036 G h_1 = 60 \times 60 \times 0.036 \times 60 = 7,776 \text{ lb.}$$

$$A_1 = \frac{7,776}{20,000} = 0.389 \text{ sq. in.} = 3/4 \phi \text{ rods}$$



#### EXAMPLE

## CORROSION

Vessels or parts of vessels subject to thinning by corrosion, erosion or mechanical abrasion shall have provision made for the desired life of the vessel by suitable increase in the thickness of the material over that determined by the design formulas, or by using some other suitable method for protection (Code UG-25b).

The Code does not prescribe the magnitude of corrosion allowance except for vessels with a required minimum thickness of less than 0.25 in. that are to be used in steam, water or compressed air service, shall be provided with corrosion allowance of not less than one-sixth of the required minimum thickness. The sum of the required minimum thickness and corrosion allowance need not exceed 1/4 in. This requirement does not apply to vessel parts designed with no x-ray examination or seamless vessel parts designed with 0.85 joint efficiency. (Code UCS-25).

For other vessels when the rate of corrosion is predictable, the desired life of the vessel will determine the corrosion allowance and if the effect of the corrosion is indeterminated, the judgment of the designer. A corrosion rate of 5 mils per year (1/16 in. = 12 years) is usually satisfactory for vessels and piping.

The desired life time of a vessel is an economical question. Major vessels are usually designed for longer (15-20 years) operating life time, while minor vessels for shorter time (8-10 years).

The corrosion allowance need not be the same thickness for all parts of the vessel if different rates of attack are expected for the various parts (Code UG-25 c).

There are several different methods for measuring corrosion. The simplest way is the use of tetraite holes (Code UG-25 e) or corrosion gauges.

Vessels subject to corrosion shall be supplied with drain-opening (Code UG-25 f).

All pressure vessels subject to internal corrosion, erosion, or mechanical abrasion shall be provided with inspection opening (Code UG-46).

To eliminate corrosion, corrosion resistant materials are used as lining only, or for the entire thickness of the vessel wall.

The rules of lining are outlined in the Code in Part UCL, Appendix F and Par. UG-26. The vessel can be protected against mechanical abrasion by plate pads which are welded or fastened by other means to the exposed area of the vessel.

In vessels where corrosion occurs, all gaps and narrow pockets shall be avoided by joining parts to the vessel wall with continuous weld.

Internal heads may be subject to corrosion, erosion or abrasion on both sides.



## SELECTION OF CORROSION RESISTANT MATERIALS

The tabular information on the following pages is an attempt to present a summarized analysis of existing test data. It is necessarily brief and, while the utmost precautions have been taken in its preparation, it should not be considered as infallible or applicable under all conditions. Rather, it should be looked upon as a convenient tool for use in determining the degree of safety which various materials are capable of providing and in narrowing down the field of investigation required for final selection. This particularly applies where failure due to corrosion may produce a hazardous situation or result in expensive down-time.

Footnotes have been generously used to explain and further clarify information contained in this table. It is most important that these notes be carefully read when using the table.

In rating materials, the letter "A" has been used to indicate materials which are generally recognized as satisfactory for use under the conditions given. The letter "F" signifies materials which are somewhat less desirable but which may be used where a low rate of corrosion is permissible or where cost considerations justify the use of a less resistant material. Materials rated under the letter "C" may be satisfactory under certain conditions. Caution should be exercised in the use of materials in this classification unless specific information is available on the corroding medium and previous experience justifies their use for the service intended. The letter "X" has been used to indicate materials generally recognized as not acceptable for the service.

Information on metals has been obtained from the International Nickel Company, the Dow Chemical Company, the Crane Company, the Haynes-Stellite Company, "Corrosion Resistance of Metals and Alloys" by McKay & Worthington, "Metals and Alloys Data Book" by Samuel L. White, "Chemical and Metallurgical Engineering" and "The Chemical Engineers' Handbook," Third Edition by McGraw-Hill.

### NOTES - GASKET MATERIALS

I. The generally accepted temperature limit for a good grade compressed asbestos sheet, also called asbestos composition sheet, is 750°F. However, some grades are successfully used at considerable higher temperatures. This type of sheet is used for smooth flanges. For rough flanges, gaskets cut from asbestos-metallic sheet or formed by folding asbestos-metallic cloth are preferred. The latter and gaskets cut from felted asbestos sheet, are indicated for flanges when bolt pressures are necessarily limited because of the type of flange material.

II. Data from the Pfaulder Company are given from the special point of view of the suitability of the gasket material for use with glass-lined steel equipment.

III. Data in this column apply specifically to Silastic 181, a special silicone rubber for use in gasketing produced by Dow-Corning Corporation.

IV. Fiberglass fabric filled with Silastic silicone rubber (polysiloxane elastomer) has a usable compressibility of about 20 per cent and shows the chemical resistance cited here over the temperature range from -85 to 392°F. For Fiberglass fabric filled with chemically resistant synthetic rubber, the temperature range is approximately -40 to 257°F. Both the silicone rubber and the ordinary synthetic rubber are available as gasket materials in which the reinforcing fabric is a metal cloth (brass, aluminum, iron, stainless steel). The chemical properties of these constructions are the same as those given here for the Fiberglass-reinforced material, with the properties of the metal in the cloth imposed upon them. The metal-cloth construction for increased mechanical strength and electrical conductivity.

V. Teflon is the DuPont trade-name for polymerized tetrafluorethylene. It is completely inert in the presence of all known chemicals. It is not affected by any known solvent or combination of solvents. It is chemically stable up to 617°F but, being a plastic, it is not recommended for gasket applications above 392°F or for high pressures unless confined in a tongue-and-groove or similar joint.

\* Sources of Data: A - Armstrong Cork Co.; C - Connecticut Hard Rubber Co.; D - Dow-Corning Corp.; E - E. I. DuPont de Nemours & Co.; J - Johns-Manville Corp.; P - The Pfaulder Co.; S - Stanco Distributors, Inc.; U - United States Rubber Co.

Information on gasket materials compiled by McGraw-Hill, "Chemical Engineers Handbook," Third Edition.



## CHEMICAL RESISTANCE OF METALS

**Caution:** Do not use table without reading footnotes and text.

Resistance Ratings: A = Good; F = Fair; C = Caution - depends on conditions; X = Not recommended.

Chemical	Iron and Steel	Red Brass	Commercial Bronze	Lead	Copper	Aluminum	Nickel	Inconel	Monel Metal	Type 304 S.S.	Type 316 S.S.	Type 347 S.S.	Carpenter "20" S.S.	Hastelloy "B" or "C"
Acetic acid, crude.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Pure.....	X	C	F	C	F	A	C	C	C	C	C	C	A	A
Vapors.....	X	C	F	C	F	A	C	C	C	C	C	C	A	A
150 lb./sq.in. @ 400°F.....	X	C	F	C	F	A	C	C	C	C	C	C	A	A
Acetic anhydride.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Acetone.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Acetylene.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Aluminum chloride.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Aluminum sulfate.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Alums.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Ammonia gas, dry.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Moist.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Ammonium chloride.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Ammonium hydroxide.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Ammonium nitrate.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Ammonium phosphate.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Ammonium sulfate.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Aniline, aniline oil.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Aniline dyes.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Barium chloride.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Barium hydroxide.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Barium sulfide.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Beer.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Beet sugar liquors.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Benzene, benzol.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Benzene, petroleum ether, naphtha	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Black sulfate liquor.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Boric acid.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A
Bromine.....	C	C	F	C	F	A	C	C	C	C	C	C	A	A

Notes continued on opposite page

1. In absence of oxygen.
2. 125° maximum.
3. All percents; 70°.
4. To boiling.
5. 50% room temperature.
6. To 122°.
7. Iron and steel may rust considerably in presence of water and air.
8. High copper alloys prohibited by Codes; yellow brass acceptable.
9. Hastelloy "C" recommended to 105°.
10. Where color is not important. Do not use with c.p. acid.
11. Room temperature to 212°. Moisture inhibits attack.
12. Gas; 70°.
13. To 500°.
14. Hastelloy "C" at room temperature.
15. Room temperature to 158°.
16. At room temperature.
17. Where discoloration is not objectionable.
18. 50% maximum; 150° maximum.
19. Satisfactory vapors to 212°.

## CHEMICAL RESISTANCE OF GASKETS

(SEE CHEMICALS ON OPPOSITE PAGE)

Resistance Ratings: Same as facing page

	Asbestos		Rubber		Miscellaneous	
	Comp. Rubber Bonded	Woven Rubber Frictioned				
White (comp. or woven) I	C	C	C	C	C	C
Blue (comp. or woven) I	A	A	A	A	A	A
Compressed sheet	C	C	C	C	C	C
White (Buna-S) II	A	A	A	A	A	A
White (Neoprene) II	A	A	A	A	A	A
Blue (Butyl) II	A	A	A	A	A	A
Blue (Neoprene) II	A	A	A	A	A	A
White (Neoprene) II	A	A	A	A	A	A
Blue (Butyl) II	A	A	A	A	A	A
GR-S	C	C	C	C	C	C
Neoprene	C	C	C	C	C	C
Buna-N	F	F	F	F	F	F
Butyl	F	F	F	F	F	F
Thiokol	F	F	F	F	F	F
Natural	C	C	C	C	C	C
Silicone III	D	D	D	D	D	D
Glass Fabric and Silicone Elastomer IV	A	A	A	A	A	A
Glass Fabric and Synthetic Rubber IV	A	A	A	A	A	A
Cork Composition	C	C	C	C	C	C
Plant-Fiber Sheet	X	X	X	X	X	X
Teflon II	P	P	P	P	P	P

See text at the front page of these tables.

20. Highly corrosive to nickel alloys at elevated temperatures. Recommendation applies to "dry" gas at ordinary temperatures.
21. 48% — boil at 330°.
22. Room temperature — over 80%.
23. Not for temperatures over 390°F.
24. Up to 140°F.
25. Up to 200°F.
26. Up to 176°F.
27. 100% maximum; boiling.
28. 50% ; 350°.
29. Do not use if iron contamination is not permissible.
30. 10% — room temperature.
31. Hot.
32. Unsatisfactory for hot gases.
33. Hastelloy "C" to 158°.
34. Room temperature to 158°. Corrosion increases with increase in concentration as well as temperature.
35. Dilute at room temperature.
36. Attack increases when only partially submerged; fumes very corrosive.
37. Hastelloy "C" to 212°.



## CHEMICAL RESISTANCE OF METALS

**Caution:** Do not use table without reading footnotes and text.

Resistance Ratings: A = Good; F = Fair; C = Caution - depends on conditions; X = Not recommended.

Chemical	Iron and Steel	Red Brass	Commercial Bronze	Lead	Copper	Aluminum	Nickel	Inconel	Monel Metal	Type 304 S.S.	Type 316 S.S.	Type 347 S.S.	Carpenter "20" S.S.	Hastelloy "B" or "C"
Butane.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A
Butyl alcohol, butanol.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A
Calcium chloride.....	F	F	F	-	A	C	-	A	A	C	C	C	C	A
Calcium hypochlorite.....	A	C	F	-	A	C	-	A	A	C	C	C	C	A
Carbolic acid, phenol.....	A	C	F	-	A	C	-	A	A	C	C	C	C	A
Carbon dioxide, dry.....	F	A	A	-	A	A	-	A	A	A	A	A	A	A
Carbon tetrachloride.....	C	A	A	-	A	A	-	A	A	A	A	A	A	A
Chlorine, dry.....	C	A	A	-	A	A	-	A	A	A	A	A	A	A
Chlorine, wet.....	C	A	A	-	A	A	-	A	A	A	A	A	A	A
Chromic acid.....	C	A	A	-	A	A	-	A	A	A	A	A	A	A
Citric acid.....	C	A	A	-	A	A	-	A	A	A	A	A	A	A
Ethers.....	C	A	A	-	A	A	-	A	A	A	A	A	A	A
Ethylene glycol.....	C	A	A	-	A	A	-	A	A	A	A	A	A	A
Ferric chloride.....	X	X	X	-	A	A	-	A	A	A	A	A	A	A
Ferric sulfate.....	X	X	X	-	A	A	-	A	A	A	A	A	A	A
Formaldehyde.....	F	A	A	-	A	A	-	A	A	A	A	A	A	A
Formic acid.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A
Freon, dry.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A
Furfural.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A
Gasoline, sour.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A
Gasoline, refined.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A
Glycerin, glycerol.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A
Hydrochloric acid, <150°F.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A
Hydrofluoric acid, cold, <65%.....	X	X	X	-	A	A	-	A	A	A	A	A	A	A
Hot <65%.....	X	X	X	-	A	A	-	A	A	A	A	A	A	A
>65%.....	X	X	X	-	A	A	-	A	A	A	A	A	A	A
Hydrogen gas, cold.....	A	A	A	-	A	A	-	A	A	A	A	A	A	A

Notes continued on opposite page

1. In absence of oxygen.
2. 125° maximum.
3. All percents; 70°.
4. To boiling.
5. 5% room temperature.
6. To 122°.
7. Iron and steel may rust considerably in presence of water and air.
8. High copper alloys prohibited by Codes; yellow brass acceptable.
9. Hastelloy "C" recommended to 105°.
10. Where color is not important. Do not use with c.p. acid.
11. Room temperature to 212°. Moisture inhibits attack.
12. Gas; 70°.
13. To 500°.
14. Hastelloy "C" at room temperature.
15. Room temperature to 158°.
16. At room temperature.
17. Where discoloration is not objectionable.
18. 5% maximum; 130° maximum.
19. Satisfactory vapors to 212°.

## CHEMICAL RESISTANCE OF GASKETS

(SEE CHEMICALS ON OPPOSITE PAGE)

Resistance Ratings: Same as facing page

	Asbestos		Rubber		Miscellaneous	
	Comp. Rubber Bonded	Woven Rubber Frictioned				
*J	White (comp. or woven) I					
J	Blue (comp. or woven) I					
U	Compressed sheet					
P	White (Buna-S) II					
P	White (Neoprene) II					
P	Blue (Butyl) II					
P	Blue (Neoprene) II					
P	White (Neoprene) II					
P	Blue (Butyl) II					
U	GR-S					
A	Neoprene					
U	Buna-N					
U	Butyl					
U	Thiokol					
U	Natural					
D	Silicone III					
C	Glass Fabric and Silicone Elastomer IV					
C	Glass Fabric and Synthetic Rubber IV					
A	Cork Composition					
A	Plant-Fiber Sheet					
P	Teflon II					

\*See text at the front page of these tables.

20. Highly corrosive to nickel alloys at elevated temperatures. Recommendation applies to "dry" gas at ordinary temperatures.
21. 48% - boil at 330°.
22. Room temperature - over 80%.
23. Not for temperatures over 390°F.
24. Up to 140°F.
25. Up to 200°F.
26. Up to 176°F.
27. 10% maximum; boiling.
28. 50% - 320°.
29. Do not use if iron contamination is not permissible.
30. 10% - room temperature.
31. Hot.
32. Unsatisfactory for hot gases.
33. Hastelloy "C" to 158°.
34. Room temperature to 158°. Corrosion increases with increase in concentration as well as temperature.
35. Dilute at room temperature.
36. Attack increases when only partially submerged; fumes very corrosive.
37. Hastelloy "C" to 212°.



## CHEMICAL RESISTANCE OF METALS

**Caution:** Do not use table without reading footnotes and text.

Resistance Ratings: A = Good; F = Fair; C = Caution - depends on conditions; X = Not recommended.

Chemical	Iron and Steel	Red Brass	Commercial Bronze	Lead	Copper	Aluminum	Nickel	Inconel	Monel Metal	Type 304 S.S.	Type 316 S.S.	Type 347 S.S.	Carpenter "20" S.S.	Hastelloy "B" or "C"
Hydrogen peroxide	C	C	F	C	C	C	C	C	C	A	A	A	A	A
Hydrogen sulfide, dry (20)	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Wet	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Lacquer (solvents)	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Lactic acid	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Lubricating oils, refined	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Magnesium chloride	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Magnesium hydroxide	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Magnesium sulfate	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Mercury	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Natural gas	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Nitric acid, crude	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Diluted	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Concentrated	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Oleic acid	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Oxalic acid	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Palmic acid	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Petroleum oils, <500°F-crude	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Phosphoric acid	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Potassium hydroxide	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Potassium sulfate	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Propane	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Sewage (gas)	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Soda ash, (sodium carbonate)	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Sodium bisulfate	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Sodium chloride	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Sodium cyanide	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Sodium hydroxide	C	C	C	C	C	C	C	C	C	A	A	A	A	A
Sodium hypochlorite	C	C	C	C	C	C	C	C	C	A	A	A	A	A

Notes continued on opposite page

1. In absence of oxygen.
2. 12% maximum.
3. All percents; 70°.
4. To boiling.
5. 50% room temperature.
6. To 122°.
7. Iron and steel may rust considerably in presence of water and air.
8. High copper alloys prohibited by Codes; yellow brass acceptable.
9. Hastelloy "C" recommended to 105°.
10. Where color is not important. Do not use with c.p. acid.
11. Room temperature to 212°. Moisture inhibits attack.
12. Gas; 70°.
13. To 500°.
14. Hastelloy "C" at room temperature.
15. Room temperature to 158°.
16. At room temperature.
17. Where discoloration is not objectionable.
18. 5% maximum; 150° maximum.
19. Satisfactory vapors to 212°.

## CHEMICAL RESISTANCE OF GASKETS

(SEE CHEMICALS ON OPPOSITE PAGE)

Resistance Ratings: Same as facing page

		Asbestos		Rubber		Miscellaneous	
		Comp., Rubber Bonded	Woven Rubber Frictioned				
*J	White (comp. or woven) I	C	C	C	C	C	C
J	Blue (comp. or woven) I	C	C	C	C	C	C
U	Compressed sheet	C	C	C	C	C	C
P	White (Buna-S) II	C	C	C	C	C	C
P	White (Neoprene) II	C	C	C	C	C	C
P	Blue (Butyl) II	C	C	C	C	C	C
P	Blue (Neoprene) II	C	C	C	C	C	C
P	White (Neoprene) II	C	C	C	C	C	C
P	Blue (Butyl) II	C	C	C	C	C	C
U	GR-S	C	C	C	C	C	C
A	Neoprene	C	C	C	C	C	C
U	Buna-N	C	C	C	C	C	C
U	Butyl	C	C	C	C	C	C
U	Thiokol	C	C	C	C	C	C
U	Natural	C	C	C	C	C	C
D	Silicone III	C	C	C	C	C	C
C	Glass Fabric and Silicone Elastomer IV	C	C	C	C	C	C
C	Glass Fabric and Synthetic Rubber IV	C	C	C	C	C	C
A	Cork Composition	C	C	C	C	C	C
A	Plant-Fiber Sheet	C	C	C	C	C	C
P	Teflon II	C	C	C	C	C	C

\*See text at the front page of these tables.

20. Highly corrosive to nickel alloys at elevated temperatures. Recommendation applies to "dry" gas at ordinary temperatures.
21. 48% - boil at 330°.
22. Room temperature - over 80%.
23. Not for temperatures over 390°F.
24. Up to 140°F.
25. Up to 200°F.
26. Up to 176°F.
27. 10% maximum; boiling.
28. 50% ; 320°.
29. Do not use if iron contamination is not permissible.
30. 10% - room temperature.
31. Hot.
32. Unsatisfactory for hot gases.
33. Hastelloy "C" to 158°.
34. Room temperature to 158°. Corrosion increases with increase in concentration as well as temperature.
35. Dilute at room temperature.
36. Attack increases when only partially submerged; fumes very corrosive.
37. Hastelloy "C" to 212°.



## CHEMICAL RESISTANCE OF METALS

**Caution:** Do not use table without reading footnotes and text.

Resistance Ratings: A = Good; F = Fair; C = Caution - depends on conditions; X = Not recommended.

Chemical	Iron and Steel	Red Brass	Commercial Bronze	Lead	Copper	Aluminum	Nickel	Inconel	Monel Metal	Type 304 S.S.	Type 316 S.S.	Type 347 S.S.	Carpenter "20" S.S.	Hastelloy "B" or "C"
Sodium nitrate.....	A	A	A	A	A	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A	A	A	A	A <sub>25</sub>
Sodium peroxide.....	C	C	C	A <sup>1</sup>	A	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A	A	A	A	A <sub>25</sub>
Sodium sulfate.....	A	A	A	A	A	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A	A	A	A	A <sub>25</sub>
Sodium sulfide.....	A	C	C	A	A	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A	A	A	A	A <sub>25</sub>
Sodium thiosulfate, "hypo".....	A <sub>25</sub>	A	A	A	A	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A <sub>25</sub>	A	A	A	A	A <sub>25</sub>
Stearic acid.....	F	A	A	A	A	A	A	A	A	A	A	A	A	A <sub>25</sub>
Sulfur.....	A	A	A	A	A	A	A	A	A	A	A	A	A	A <sub>25</sub>
Sulfur dioxide, dry.....	A	A	A	A	A	A	A	A	A	A	A	A	A	A <sub>25</sub>
Sulfur dioxide, wet.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A <sub>25</sub>
Sulfuric acid, <10%, cold.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A <sub>25</sub>
Hot.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A <sub>25</sub>
10-75%, cold.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A <sub>25</sub>
Hot.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A <sub>25</sub>
75-95%, cold.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A <sub>25</sub>
Hot.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A <sub>25</sub>
Fuming.....	A	A	A	A	A	A	A	A	A	A	A	A	A	A <sub>25</sub>
Sulfurous acid.....	A	A	A	A	A	A	A	A	A	A	A	A	A	A <sub>25</sub>
Tartaric acid.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A <sub>25</sub>
Toluene.....	A	A	A	A	A	A	A	A	A	A	A	A	A	A <sub>25</sub>
Trichloroethylene, dry.....	A	A	A	A	A	A	A	A	A	A	A	A	A	A <sub>25</sub>
Wet.....	A	A	A	A	A	A	A	A	A	A	A	A	A	A <sub>25</sub>
Turpentine.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A <sub>25</sub>
Water, fresh (tap), boiler feed, etc.).....	C	C	C	C	C	C	C	C	C	C	C	C	C	A
Water, sea water.....	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Whiskey and wines.....	C	C	C	C	C	C	C	C	C	C	C	C	C	A
Zinc chloride.....	X	X	X	X	X	X	X	X	X	X	X	X	X	A
Zinc sulfate.....	C	C	C	C	C	C	C	C	C	C	C	C	C	A

Notes continued on opposite page

1. In absence of oxygen.
2. 125° maximum.
3. All percents: 70°.
4. To boiling.
5. 5% room temperature.
6. To 125°.
7. Iron and steel may rust considerably in presence of water and air.
8. High copper alloys prohibited by Codes; yellow brass acceptable.
9. Hastelloy "C" recommended to 105°.
10. Where color is not important. Do not use with c.p. acid.
11. Room temperature to 212°. Moisture inhibits attack.
12. Gas; 70°.
13. To 500°.
14. Hastelloy "C" at room temperature.
15. Room temperature to 158°.
16. At room temperature.
17. Where discoloration is not objectionable.
18. 5% maximum; 150° maximum.
19. Satisfactory vapors to 212°.

CHEMICAL RESISTANCE OF GASKETS  
(SEE CHEMICALS ON OPPOSITE PAGE)  
Resistance Ratings: Same as facing page

	Asbestos		Rubber		Miscellaneous	
	Comp. Rubber Bonded	Woven Rubber Frictioned				
White (comp. or woven) I	J	J				
Blue (comp. or woven) I	U	U				
Compressed sheet	P	P				
White (Buna-S) II	P	P				
White (Neoprene) II	P	P				
Blue (Butyl) II	P	P				
Blue (Neoprene) II	P	P				
White (Neoprene) II	P	P				
Blue (Butyl) II	P	P				
GR-S	U	U				
Neoprene	A	A				
Buna-N	U	U				
Butyl	U	U				
Thiokol	U	U				
Natural	C	C				
Silicone III	D	D				
Glass Fabric and Silicone Elastomer IV	C	C				
Glass Fabric and Synthetic Rubber IV	C	C				
Cork Composition	A	A				
Plant-Fiber Sheet	A	A				
Teflon II	P	P				

\*See text at the front page of these tables.

20. Highly corrosive to nickel alloys at elevated temperatures. Recommendation applies to "dry" gas at ordinary temperatures.
21. 48% — boil at 330°.
22. Room temperature — over 80%.
23. Not for temperatures over 390°F.
24. Up to 140°F.
25. Up to 200°F.
26. Up to 176°F.
27. 10% maximum, boiling.
28. 50%, 320°.
29. Do not use if iron contamination is not permissible.
30. 10% — room temperature.
31. Hot.
32. Unsatisfactory for hot gases.
33. Hastelloy "C" to 158°.
34. Room temperature to 158°. Corrosion increases with increase in concentration as well as temperature.
35. Dilute at room temperature.
36. Attack increases when only partially submerged; James very corrosive.
37. Hastelloy "C" to 212°.



## FABRICATING CAPACITIES

THE TABLES BELOW ARE FOR DATA OF FABRICATING CAPACITIES OF THE SHOP WHICH HAVE TO BE KNOWN BY THE VESSEL DESIGNER. THE COLUMNS HAVE BEEN LEFT OPEN AND ARE TO BE FILLED IN BY THE USER OF THIS HANDBOOK ACCORDING TO THE FACILITIES OF THE SHOP CONSIDERED.

ROLLING PLATES TENSILE STRENGTH OF PLATE      psi.	MAXIMUM WIDTH in.	MAXIMUM THICKNESS in.	MINIMUM DIAMETER in.
NOTE: FOR MATERIAL OF HIGHER STRENGTH THE THICKNESS OR WIDTH OF THE PLATE MUST BE REDUCED IN DIRECT PROPORTION TO THE HIGHER STRENGTH			
ROLLING ANGLES	LEG IN	MAXIMUM SIZE	MINIMUM DIAMETER in.
	LEG OUT		
ROLLING BEAMS	LEG IN	MAXIMUM SIZE	MINIMUM DIAMETER in.
	LEG OUT		
ROLLING CHANNELS	ON FLANGES	MAXIMUM SIZE	MINIMUM DIAMETER in.
	IN FLANGES		
ROLLING FLAT BAR	ON EDGE	MAXIMUM SIZE	MINIMUM DIAMETER in.

## FABRICATING CAPACITIES

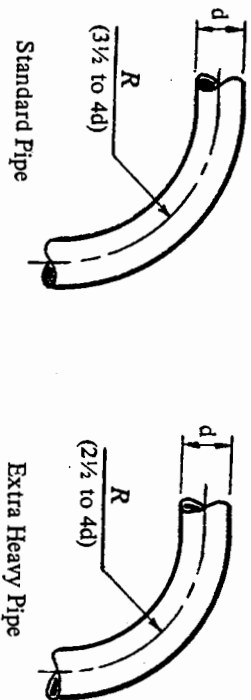
BENDING PIPES	NOMINAL PIPE SIZE	SCHEDULE	MINIMUM RADIUS in.	
BENDING PLATES WITH PRESS BRAKE	PLATE THICKNESS in.	MINIMUM INSIDE RADIUS in.	PLATE THICKNESS in.	MINIMUM INSIDE RADIUS in.
PUNCHING HOLES	PLATE THICKNESS in.	MAXIMUM DIAMETER OF HOLE in.	PLATE THICKNESS in.	MAXIMUM DIAMETER OF HOLE in.
MINIMUM INSIDE DIAMETER OF VESSEL ACCESSIBLE FOR INSIDE WELDING				
inches				
TYPES OF WELDINGS AVAILABLE				
FURNACES FOR STRESS RELIEVING	WIDTH MAX. TEMPERATURE	ft. HEIGHT F.	ft. LENGTH	ft.



## PIPE AND TUBE BENDING \*

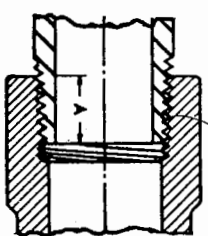
In bending a pipe or tube, the outer part of the bend is stretched and the inner section compressed, and as the result of opposite and unequal stresses, the pipe or tube tends to flatten or collapse. To prevent such distortion, the common practice is to support the wall of the pipe or tube in some manner during the bending operation. This support may be in the form of a filling material, or, when a bending machine or fixture is used, an internal mandrel or ball-shaped member may support the inner wall when required.

**MINIMUM RADIUS:** The safe minimum radius for a given diameter, material, and method of bending depends upon the thickness of the pipe wall, it being possible, for example, to bend extra heavy pipe to a smaller radius than pipe of standard weight. As a general rule, wrought iron or steel pipe of standard weight may readily be bent to a radius equal to five or six times the nominal pipe diameter. The minimum radius for standard weight pipe should, as a rule, be three and one-half to four times the diameter. It will be understood, however, that the minimum radius may vary considerably, depending upon the method of bending. Extra heavy pipe may be bent to radii varying from two and one-half times the diameter for smaller sizes to three and one-half to four times the diameter for larger sizes.



## MINIMUM RADIUS

\*From Machinery's Handbook, 1969 Industrial Press, Inc. - New York

PIPE ENGAGEMENT  
LENGTH OF THREAD ON PIPE TO MAKE A TIGHT JOINT


Nominal Pipe Size	Dimension A inches	Nominal Pipe Size	Dimension A inches
1/8	1/4	3-1/2	1-1/16
1/4	3/8	4	1-1/8
3/8	3/8	5	1-1/4
1/2	1/2	6	1-5/16
3/4	9/16	8	1-7/16
1	11/16	10	1-5/8
1-1/4	11/16	12	1-3/4
1-1/2	11/16		
2	3/4		
2-1/2	15/16		
3	1		

DIMENSIONS DO NOT ALLOW FOR VARIATION  
IN TAPPING OR THREADING

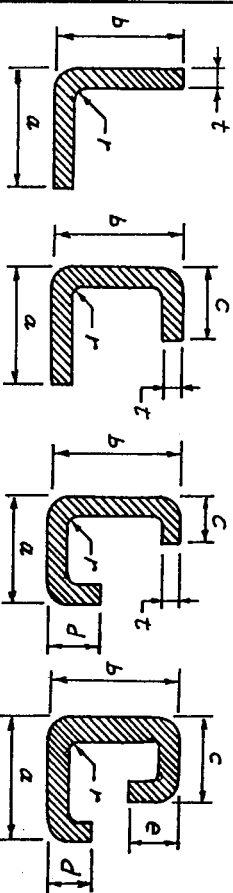
## DRILL SIZES FOR PIPE TAPS

Nominal Pipe Size	Tap Drill Size in.	Nominal Pipe Size	Tap Drill Size in.
1/8	11/32	2	2-3/16
1/4	7/16	2-1/2	2-9/16
3/8	19/32	3	3-3/16
1/2	23/32	3-1/2	3-11/16
3/4	15/16	4	4-3/16
1	1-5/32	5	5-5/16
1-1/4	1-1/2	6	6-5/16
1-1/2	1-23/32		



### BEND ALLOWANCES For 90° Bends in Low-Carbon Steel

Metal Thickness (t) in.	Bend Allowance Inches With Inside Radius (r) in.				
	1/32	1/16	3/32	1/8	1/4
0.032	0.059	0.066	0.079	0.093	0.146
0.050	0.087	0.101	0.114	0.129	0.254
0.062	0.105	0.118	0.132	0.145	0.276
0.078	0.128	0.142	0.155	0.169	0.290
0.090	0.146	0.160	0.173	0.187	0.310
0.125	0.198	0.211	0.224	0.243	0.324
0.188	0.289	0.302	0.316	0.329	0.367
0.250	0.382	0.395	0.409	0.424	0.443
0.313	0.474	0.488	0.501	0.515	0.519
0.375	0.566	0.580	0.593	0.607	0.676
0.437	0.658	0.672	0.685	0.699	0.768
0.500	0.750	0.764	0.777	0.791	0.860
					0.952



$w = a + b -$  bend allowance (2 x bend allowance)  $w = a + b + c + d -$  (3 x bend allowance)  $w = a + b + c + d + e -$  (4 x bend allowance)

Note:  $w$  = developed width (length) of blank,  $t$  = metal thickness,  $r$  = inside radius of bend.

EXAMPLE: Carbon steel bar bent at two places.

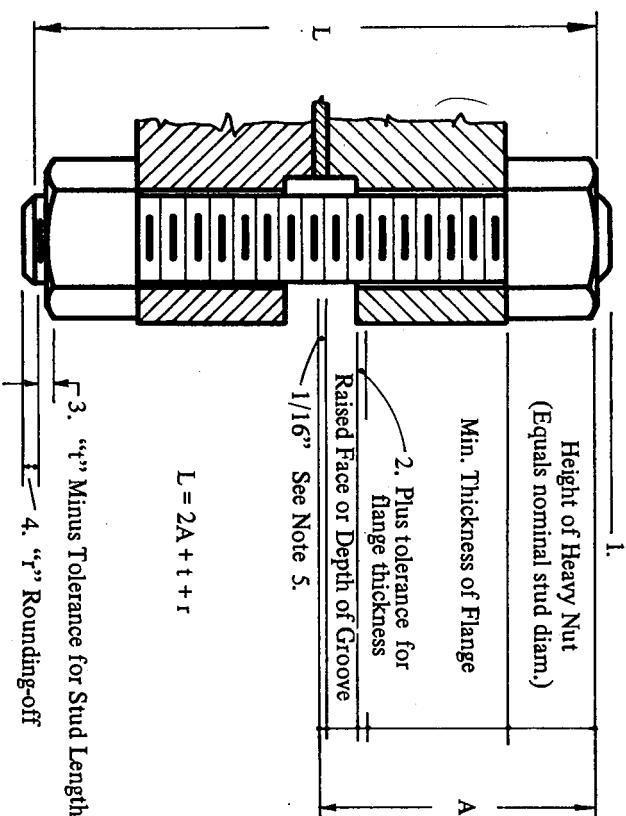
The required length of a 1/4 in. thick bar bent to 90 degrees with 1/4 in inside radius as shown above when the sum of dimensions  $a$ ,  $b$  and  $c$  equals 12 inches, is  $12 - (2 \times 0.476) = 11.048$  inches

MINIMUM RADIUS FOR COLD BENDING:

The minimum permissible inside radius of cold bending of metals when bend lines are transverse to the direction of the final rolling, varies in terms of the thickness,  $t$  from 1-1/2  $t$  up to 6  $t$  depending on thickness and ductility of material.

When bend lines are parallel to the direction of the final rolling the above values may have to be approximately doubled.

### LENGTH OF STUD BOLTS FOR FLANGES\*



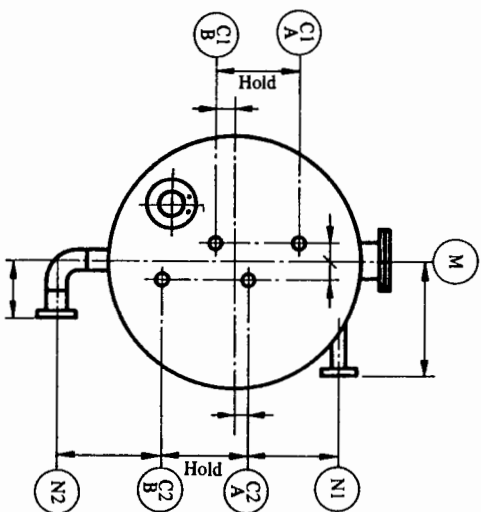
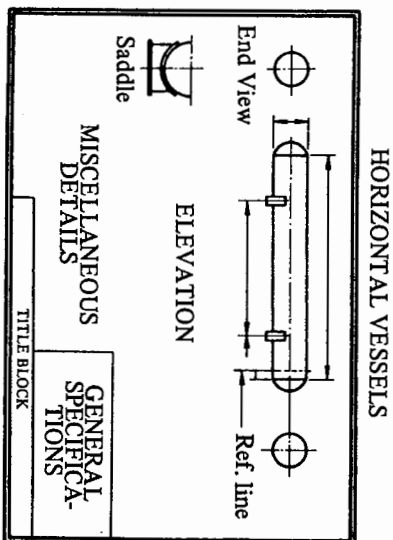
1. Length of the stud bolts do not include the heights of the point. (1.5 times thread pitch)
2. Plus tolerance of flg. thk's.  
Sizes 18 in. & smaller 0.12 in.  
Sizes 20 in. and larger 0.19 in.
3. Minus tolerance of stud length  
For lengths up to 12" incl. 0.06 in.  
For lengths over 12" to 18" incl. 0.12 in.  
For lengths over 18" 0.25 in.
4. Rounding-off to the next larger 0.25 in. increment.
5. Gasket thickness for raised face, M & F and T & G flanges 0.12 in. For ring type joint see table on page 356 and take half of the dimensions shown, since in dimension "A" only half of the gasket thickness is included.

\*Extracted from American National Standard :  
ANSI B16.5 - 1973 Steel Pipe Flanges and Flanged Fittings.



## PRESSURE VESSEL DETAILING

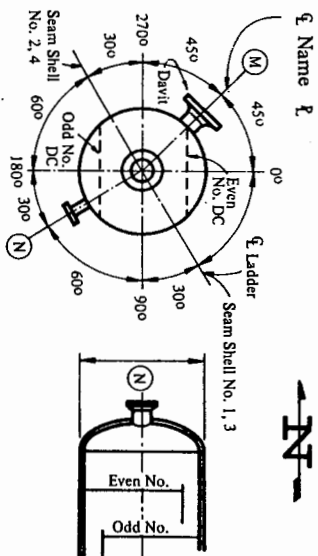
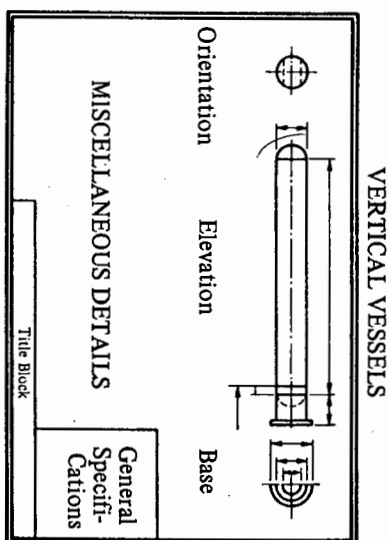
IN THE PRACTICE THERE ARE SEVERAL DIFFERENT WAYS OF DETAILING PRESSURE VESSELS. BY MAKING THE DRAWINGS ALWAYS WITH THE SAME METHOD, CONSIDERABLE TIME CAN BE SAVED AND ALSO THE POSSIBILITIES OF ERRORS ARE LESS. THE RECOMMENDED METHOD IN THE FOLLOWING PROVED PRACTICAL AND GENERALLY ACCEPTED.



END VIEW

- A. Select the scale so that all openings, seams, etc., can be shown without making the picture overcrowded or confusing.
- B. Show right-end view if necessary only for clarity because of numerous connections, etc., on heads. In this case it is not necessary to show on both views the connections etc., in shell.
- C. Show the saddles separately, if showing them on the end view would overcrowd the picture. On elevation show only a simple picture of saddle and the centerlines.
- D. Locate davit.
- E. Locate name plate.
- F. Locate seams, after everything is in place on elevation. The seams have to clear nozzles, lugs and saddles.
- G. Show on the elevation and end view a simple picture of openings, internals, etc., if a separate detail has to be made for these.
- H. Dimensioning on the elevation drawing. All locations shall be shown with tailed dimensions measured from the reference line. The distance from ref. line to be shown for one saddle only. The other saddle shall be located showing the dimension between the anchor bolt holes of the saddles.
- I. Two symbolic bolt holes shown in flanges make clear that the holes are straddling the parallel lines with the principal centerlines of vessel.

## PRESSURE VESSEL DETAILING (cont.)

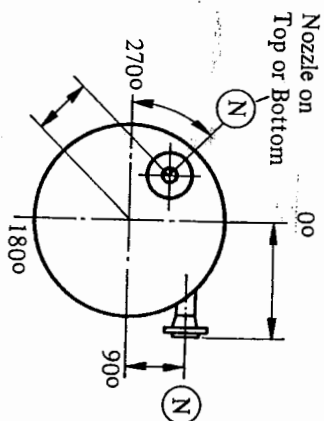


ORIENTATION PLAN

- A. Select the scale so that all openings, trays, seams, etc., can be shown without making the picture overcrowded or confusing.
- B. If the vessel diameter is unproportionally small to the length, draw the width of the vessel in a larger scale to have space enough for all details.
- C. The orientation is not a top view, but a schematic information about the location of nozzles, etc.
- D. Show the orientation so rotated that the down-corners on the elevation can be shown in their true position.
- E. Dimensioning. All locations on the elevation drawing shall be shown with tailed dimensions measured from the reference line.
- F. Locate long seams, after everything is in place on elevation.
- G. Mark vessel centerlines w/ degrees: 0°, 90°, 180°, 270° and use it in the same position on all other orientations.



## PRESSURE VESSEL DETAILING (cont.)



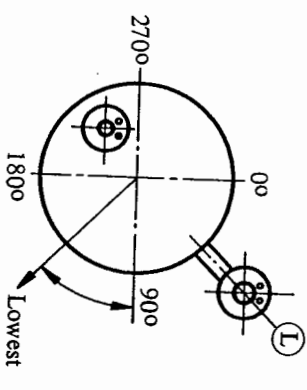
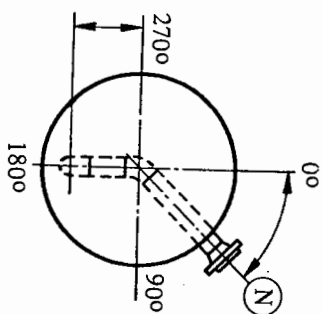
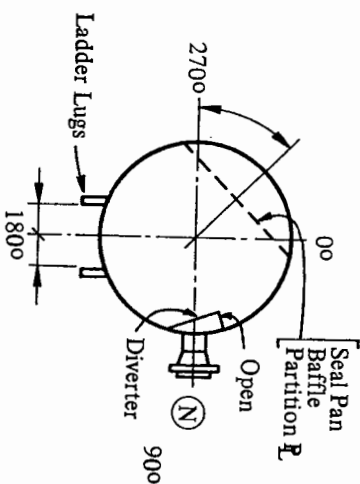
H. It is not necessary to show internals on vessel orientation if their position is clear from detail drawings or otherwise.

J. Draw separate orientations for showing different internals, lugs, etc. if there is not space enough to show everything on one.

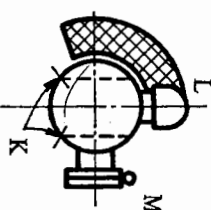
K. For vessels with conical sections, show 2 orientations if necessary, one for the upper section, one for the lower section.

L. Two, symbolic bolt holes shown in flanges make clear that the holes are straddling the lines parallel with the principal centerlines of vessel.

M. If there is a sloping tray, partition plate, coil, etc., in the vessel, show in the orientation the direction of slope.



## ORIENTATIONS

PREFERRED LOCATIONS  
Of Vessel Components and Apertures

A. Anchor bolts straddle principal centerlines of vessel.

B. Skirt access openings above base minimum to clear anchor lugs, maximum 3'-0".

C. Skirt vent holes as high as possible.

D. Name plate above manway or liquid level control, or level gauge. If there is no manway, 5'-0" above base.

E. Lifting lugs - if the weight of the vessel is uniform, "E" dimension is equal .207 times the overall length of vessel.

F. Manway 3'-0" above top of platform-floor plate.

G. Insulation ring must clear girth seam and shall be cut out to clear nozzles, etc.

H. Insulation ring spacing 8 - 12 feet (approx. length of metal jacket sheet).

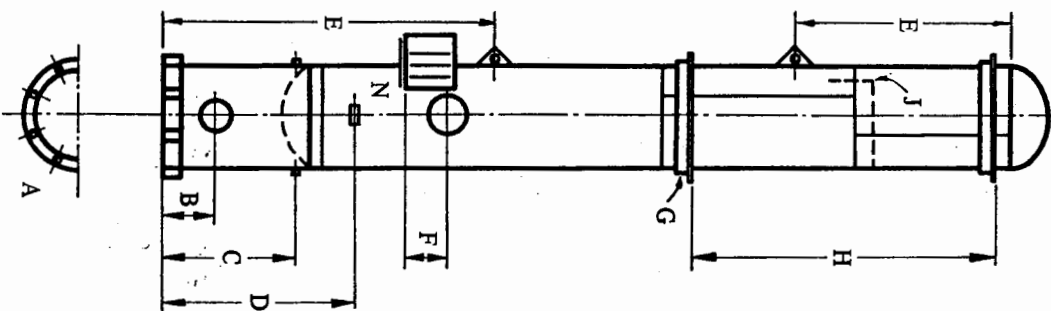
J. Girth seams shall clear trays, nozzles, lugs.

K. Long seams to clear nozzles, lugs, tray down-comers. Do not locate long seams behind down-comers. Seams shall be located so that visual inspection can be made with all internals in place. Longitudinal seams to be staggered 180° if possible.

L. Ladder and platform relation.

M. Davit and hinge to be located as the manway is most accessible, or right hand side.

N. Ladder rung level with top of platform floor plate. The height of first rung above base varies, minimum 6", maximum 1'-6".





### A. Interferences

1. When the location on the elevation and orientation is not checked. The practice of not showing openings etc. on the elevation in their true position, may increase the probability of this mistake.

2. The tail dimensions or the distances between openings on the orientation do not show interference, but it is disregarded, that the nozzles, lugs etc., have certain extension. Thus it can take place that:

- a. Skirt access opening does not clear the anchor lugs.
- b. Ladder lug interferes with nozzles.
- c. The reinforcing pads of two nozzles overlap each other.
- d. Reinforcing pad covers seam.
- e. Vessel-davit interferes with nozzles. This can be overlooked especially if the manufacturer does not furnish the vessel-davit itself, but the lugs only.
- f. Lugs, openings, etc. are on the vessel seam.
- g. There is no room on perimeter of the skirt for the required number of anchor lugs.

Particular care should be taken when ladder, platform, vessel-davit etc., are shown on separate drawings, or more than one orientations are used.

### B. Changes.

Certain changes are necessary on the drawing which are carried out on the elevation, but not shown on the orientation or reversed. Making changes, it is advisable to ask the question: "What does it affect?"

For example:

**The change of material affects:**

Bill of material  
Schedule of openings  
General specification  
Legend

**The change of location affects:**

Orientation  
Elevation  
Location of internals  
Location of other components

C. Showing O.D. (outside diameter) instead of I.D. (inside diameter) or reversed

D. Dimensions shown erroneously:

1'-0" instead of 10"  
2'-0" instead of 20" etc.

### E. Overlooking the requirement of special material

## PRESSURE VESSEL DETAILING (cont.)

## GENERAL SPECIFICATIONS

VESSEL TO BE CONSTRUCTED IN STRICT ACCORDANCE WITH THE LATEST EDITION OF THE ASME CODE SECTION VIII, DIV. I, FOR PRESSURE VESSELS AND IS TO BE SO STAMPED. INSPECTION BY COMMERCIAL UNION INSURANCE CO. OF AMERICA.

DESIGN DATA				
	DESIGN	MAX. A. WORKING.	MAX. A. N. & C.	HYDRO. TEST
PRESSURE PSIG. @				
TEMPERATURE OF.				
LIMITED BY				
WIND PRESS. LBS./SQ. FT.		CORROSION ALLOW. IN.		
SEISMIC COEFFICIENT		RADIOGRAPHIC EXAMINATION		
ERECTION (SHIPPING) WEIGHT LBS.		LONGITUDINAL JOINT EFFICIENCY		
WEIGHT FULL W/ WATER LBS.		POST WELD HEAT TREATMENT @ 1100°F		
OPERATING WEIGHT LBS.				

## DESIGN DATA

**DATA NOT SHOWN ARE NOT FACTOR OF DESIGN**

MATERIAL				
SHELL	SA.	HEAD	SA.	
	THK.		TYPE	
FLANGE		SKIRT		
NOZZLE NECK		BASE		
BOLTING		ANCH. BOLT		
COUPLING		SADDLES		
WELDED FITTING				
GASKET				

## MATERIAL

SHELL		SA.	HEAD		SA.
THK.			TYPE		
			THK		
FLANGE			SKIRT		
NOZZLE NECK			BASE		
BOLTING			ANCH. BOLT		
COUPLING			SADDLES		
WELDED FITTING					
GASKET					

## PAINT

[illegible]



## PRESSURE VESSEL DETAILING (cont.)



1. Drill and Tap  $\frac{1}{4}"$   $\varnothing$  Teltale hole in reinforcing pads.
2. Flange bolt holes to straddle principal centerlines of vessel.
3. Inside edges of Nozzle Necks shall be rounded. The radius of roundness  $\frac{1}{8}"$  min. or one-half the wall thickness if the pipe wall is less than  $\frac{1}{4}"$ .

Detailing openings as shown on the opposite page with data exemplified in the schedule of openings below, eliminates the necessity of detailing every single opening on the shop drawing.

## SCHEDULE OF OPENINGS



PRESSURE VESSEL HANDBOOK  
12th EDITION

ERRATA

Page 83:

Formula:  $F_{cb} = \frac{F_c}{(\frac{1}{4} + nt_s) r C_c}$

Revised to read:

$$F_{cb} = \frac{F_c}{(l_4 + nt_s) r C_c}$$

November, 2001

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Revised to read:

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November, 2001



## TRANSPORTATION OF VESSELS

### Shipping capabilities and limitations.

#### 1. TRANSPORTATION BY TRUCK.

The maximum size of loads which may be carried without special permits

- a. weight approximately 40,000 lbs.
- b. width of load 8 ft., 0 in.
- c. height above road 13 ft., 6 in. (height of truck 4 ft., 6 in. to 5 ft., 0 in.)
- d. length of load 40 ft., 0 in.

Truck shipments over 12 ft., 0 in. width require escort. It increases considerably the costs of transportation.

#### 2. TRANSPORTATION BY RAILROAD.

Maximum dimensions of load which may be carried without special routing.

- a. width of load 10 ft., 0 in.
- b. height above bed of car 10 ft., 0 in.

With special routing, loads up to 14 ft., 0 in. width and 14 ft., 0 in. height may be handled.

## PAINTING OF STEEL SURFACES

### PURPOSE

The main purpose of painting is the preservation of a steel surface. The paint retards the corrosion i., by preventing the contact of corrosive agents from the vessel surface and 2., by rust inhibitive, electro-chemical properties of the paint material.

The paints must be suitable to resist the effects of the environment, heat, impact, abrasion and action of chemicals.

### SURFACE PREPARATION

The primary requisite for a successful paint job is the removal of mill scale, rust, dirt, grease, oil and foreign matter. Mill scale is the bluish-gray, thick layer of iron oxides which forms on structural steel subsequent to the hot rolling operation. If the mill scale is intact and adheres tightly to the metal, it provides protection to the steel, however, due to the rolling and dishing of plates, completely intact mill scale is seldom encountered in practice.

If mill scale is not badly cracked, a shop primer will give long life in mild environments, provided that the loose mill scale, rust, oil, grease, etc. are removed.

### ECONOMIC CONSIDERATIONS

The selection of paint and surface preparation beyond the technical aspects is naturally a problem of economics.

The cost of paint is normally 25-30% or less of the cost of painting a structure, thus the advantage of using high quality paint is apparent. Sixty percent or more of the total expense of a paint job lies in the surface preparation and the cost of preparation to different degrees is varying in a proportion of 1 to 10-12. For example, the cost of sandblasting is about 10-12 times higher than that of the hand wire brushing. The cost of surface preparation should be balanced against the increased life of the vessel.

### SELECTION OF PAINT SYSTEMS

The tables on the following pages serve as guides to select the proper painting system and estimate the required quantity of paint for various service conditions. The data tabulated there have been taken from the Steel Structures Painting Council's specifications and recommendations.

Considering the several variables of painting problems, it is advisable to request the assistance of paint manufacturers.

### SPECIAL CONDITIONS

#### ABRASION

When the painting must resist abrasion, the good adhesion of the coating is particularly important. For maximum adhesion, blast cleaning is the best and also pickling is satisfactory. Pretreatments such as hot phosphate or wash primer are excellent for etching and roughening the surface.

Urethane coatings, epoxies and vinyl paints have very good abrasion resistance. Zinc-rich coating, and phenolic paints are also good. Oleoresinous paints may develop much greater resistance by incorporation of sand reinforcement.



**HIGH TEMPERATURE**

Below temperatures of 500-600°F to obtain a good surface for coating, hot phosphate treatment is satisfactory. Above 500-600°F a blast cleaned surface is desirable.

**Recommended Paints:**

Up to 200 - 250 F	Oil base paints limited period
200 - 300 F	An alkylid or phenolic vehicle
300 - 400 F	Specially modified alkylids
300 - 550 F	Colored silicones
700 - 800 F	Inorganic zinc coatings above 550 F
800 - 1200 F	Black or Aluminum silicones
	Aluminum silicones up to 1600-1800 F
	Silicone ceramic coatings

**CORROSIVE CHEMICALS**

See tables I and V for the selection of paint systems.

**THE REQUIRED QUANTITY OF PAINT**

Theoretically, one gallon of paint covers 1600 square feet surface with 1 mil (0.001 inch) thick coat when it is wet.

The dry thickness is determined by the solid (non volatile) content of the paint, which can be found in the specification on the label, or in the supplier's literature.

If the content of solids by volume is, for example, 60%, then the maximum dry coverage (spreading rate) theoretically will be  $1600 \times .60 = 960$  square feet.

**THE CONTENT OF SOLIDS OF PAINTS BY VOLUME %**

Spec. No.	Paint	%	Spec. No.	Paint	%
1	Red Lead and Raw linseed Oil Primer	96	12	Cold Applied Asphalt Mastic (Extra Thick Film)	50
2	Red Lead, Iron Oxide, Raw Linseed Oil and Alkyd Primer	82	13	Red or Brown One-Coat Shop Paint	60
3	Red Lead, Iron Oxide, and Fractionated Linseed Oil Primer	96	14	Red Lead, Iron Oxide & Linseed Oil Primer	96
4	Extended Red Lead, Raw and Bodied Linseed Oil Primer	70	15	Steel Joist Steel Shop Paint	70
5	Zinc Dust, Zinc Oxide, and Phenolic Varnish Paint	60	16	Coal Tar Epoxy-Polyamide Black (or Dark Red) Paint	75
6	Red Lead, Iron Oxide, and Phenolic Varnish Paint	47	101	Aluminum Alkyd Paint	40
8	Aluminum Vinyl Paint	14	102	Black Phenolic Paint	37
9	White (or Colored) Vinyl Paint	17	103	Black Phenolic Paint	57
11	Red Iron Oxide, Zinc Chromate, Raw Linseed Oil and Alkyd Primer	70	104	White or Tinted Alkyd Paint, Types I, II, III, IV	47 - 50
			106	Black Vinyl Paint	13
			107	Red Lead, Iron Oxide and Alkyd Intermediate Paint	60

In practice, especially with spray application, the paint never can be utilized at 100 percent. Losses due to overspray, complexity of surface (piping, etc.) may decrease the actual coverage to 40-60%, or even more.

**PAINTING**  
**TABLE I. PAINT SYSTEMS**

System Number SPC-PS	CONDITION	Surface Preparation Table II	Pretreatment Table III	Paint and Dry Thickness, mils See Table IV					Total Thickness
				1st Coat	2nd Coat	3rd Coat	4th Coat	5th Coat	
1.01	Condensation, chemical fumes, brine drippings and other extremely corrosive conditions are <u>not</u> present	2 or 3	Not Req'd	14 (1.7)	104 (1.3)	104 (1.0)	104	104	4.0
1.02				14 (1.7)	14	104	104	104	5.0
1.03				1 (1.7)	104 (1.7)	104 (1.0)	104	104	4.0
1.05				2 (1.7)	104	104	104	104	4.0
1.06				A (1.7)	104	104	104	104	4.0
2.01	Steel surfaces exposed to the weather, high humidity, infrequent immersion in fresh or salt water or to mild chemical atmospheres	6 or 8	Not Req'd	C (1.5)	C (1.5)	104 (1.5)	104 (1.0)	104	5.0
2.02				D (1.5)	104 (1.5)	104 (1.0)	104	104	4.0
2.03				B (1.5)	104 (1.5)	104 (1.0)	104	104	4.0
2.04				E (1.5)	104 (1.5)	104 (1.0)	104	104	3.5
3.00	Steel surfaces exposed to alternate immersion, high humidity and condensation or to the weather or moderately severe chemical atmospheres or immersed in fresh water	5, 6, 8, or 10	1, 2, 3, or 4	5, or 6 (1.5)	5, or 6 (1.5)	103 (1.0)	5, 6 or 103 *	4.0 or 5.0	
4.01	Immersion in salt water or in many chemical solutions, condensation, very severe weather exposure or chemical atmospheres	10	3 **	G (1.5)	G (1.5)	9	9	9	5.5
4.02	Fresh water immersion, condensation, very severe weather or chemical atmospheres	10	Not Req'd	H (1.5)	H (1.5)	H (1.0)	H	H	6.0
4.03	Complete or alternate immersion in salt water, high humidity, condensation, and exposure to the weather	6 or 8	3 **	G (1.5)	9 (1.5)	8			4.0
4.04	Condensation, or very severe weather exposure, or chemical atmospheres	6 or 8	Not Req'd	9 (1.2)	9 (1.2)	9	9	9	4.5
4.05	Condensation, severe weather, mild chemical atmospheres	6 or 8	3 **	G (1.5)	F (1.5)	F			4.0
6.01	Steel vessels and floating structures exposed to fresh or salt water, fouling water and weather	10 or 8 or 6 or 8	3	G (1.5)	G (1.5)	G (2.0)	G (2.0)	G (2.0)	7.0
6.02				G (1.5)	G (1.5)	G (1.0)	J (1.0)	J (1.0)	7.0
6.03				G (1.5)	G (1.5)	G (1.0)	L (1.0)	K (1.0)	6.25
7.01	Dry, non corrosive environment, inside of buildings or temporary weather protection	nominal cleaning	Not Req'd	13 (1.0)					1.0
8.01	Longtime protection in sheltered or inaccessible places, short term or temporary protection in corrosive environments	1 and 2 or 3	Not Req'd	M (31 wet)					31 (wet)
9.01	Corrosive or chemical atmospheres, but should not be used in contact with oils, solvents, or other agents	6	Not Req'd	12 (31)	N (31)	N (31)			63
10.01	Underground and underwater steel structures	6	Not Req'd	N (31)	N (31)	N (31)			63-100
10.02	Underground, underwater or for damp, corrosive environments. Not recommended for potable water or for high temperature	6	Not Req'd	0 (15-18)	0 (25)	P (8-15)			35

\*Four coats are recommended in severe exposures

\*\*The dry film thickness of the wash coat 0.3-0.5 mils.



TABLE I. PAINT SYSTEMS (continued)

System Number SSPC-PS	CONDITION	Surface Preparation Table II	Pretreatment Table III	Paint and Dry Thickness, mils See Table IV					Total Thick- ness
11.01	Fresh or sea water immersion, tidal and splash zone exposure, condensation, burial in soil and exposure of brine, crude oil, sewage and alkalies, chemical fumes, mists	6 or 10	Not Req'd	1st Coat (16)	2nd Coat (16)	3rd Coat	4th Coat	5th Coat	32
12.00	High humidity or marine atmospheric exposures, fresh water immersion. With proper topcoating in brackish and sea-water immersion and exposure to chemical acid and alkali fumes			Zinc-rich coatings comprise a number of different commercial types such as: chlorinated rubber, styrene, epoxies, polyesters, vinyls, urethanes, silicones, silicate esters, silicates, phosphates.					
13.00	Industrial exposure, marine environment fresh and salt water immersion, and areas subject to chemical exposure such as acid and alkali.			Epoxy Paint System					

TABLE III. PRETREATMENT SPECIFICATIONS

Reference to Table I	Title and Purpose	Specification Number
1	<b>WETTING OIL TREATMENT</b> Saturation of the surface layer of rusty and scaled steel with wetting oil that is compatible with the priming paint, thus improving the adhesion and performance of the paint system to be applied.	SSPC-PT 1-64
2	<b>COLD PHOSPHATE SURFACE TREATMENT</b> Converting the surface of steel to insoluble salts of phosphoric acid for the purpose of inhibiting corrosion and improving the adhesion and performance of paints to be applied.	SSPC-PT 2-64
3	<b>BASIC ZINC CHROMATE-VINYL BUTYRAL WASHCOAT (Wash Primer)</b> Pretreatment which reacts with the metal and at the same time forms a protective vinyl film which contains an inhibitive pigment to help prevent rusting.	SSPC-PT 3-64
4	<b>HOT PHOSPHATE SURFACE TREATMENT</b> Converting the surface of steel to a heavy crystalline layer of insoluble salts of phosphoric acid for the purpose of inhibiting corrosion and improving the adhesion and performance of paints to be applied.	SSPC-PT 4-64

## PAINTING

TABLE II. SURFACE PREPARATION SPECIFICATIONS

Reference to Table I	Title and Purpose	Specification Number
1	<b>SOLVENT CLEANING</b> Removal of oil, grease, dirt, soil, salts, and contaminants with solvents, emulsions, cleaning compounds, or steam.	SSPC-SP 1-63
2	<b>HAND TOOL CLEANING</b> Removal of loose mill scale, loose rust, and loose paint by hand brushing, hand sanding, hand scraping, hand chipping or other hand impact tools, or by combination of these methods.	SSPC-SP 2-63
3	<b>POWER TOOL CLEANING</b> Removal of loose mill scale, loose rust, and loose paint with power wire brushes, power impact tools, power grinders, power sanders, or by combination of these methods.	SSPC-SP 3-63
4	<b>FLAME CLEANING OF NEW STEEL</b> Removal of scale, rust and other detrimental foreign matter by high-velocity oxyacetylene flames, followed by wire brushing.	SSPC-SP 4-63
5	<b>WHITE METAL BLAST CLEANING</b> Removal of all mill scale, rust, rust-scale, paint or foreign matter by the use of sand, grit or shot to obtain a gray-white, uniform metallic color surface.	SSPC-SP 5-63
6	<b>COMMERCIAL BLAST CLEANING</b> Removal of mill scale, rust, rust-scale, paint or foreign matter completely except for slight shadows, streaks, or discolorations caused by rust, stain, mill scale oxides or slight, tight residues of paint or coating that may remain.	SSPC-SP 6-63
7	<b>BRUSH-OFF BLAST CLEANING</b> Removal of all except tightly adhering residues of mill scale, rust and paint by the impact of abrasives. (Sand, grit or shot)	SSPC-SP 7-63
8	<b>PICKLING</b> Complete removal of all mill scale, rust, and rust-scale by chemical reaction, or by electrolysis, or by both. The surface shall be free of unreacted or harmful acid, alkali, or smut.	SSPC-SP 8-63
10	<b>NEAR-WHITE BLAST CLEANING</b> Removal of nearly all mill scale, rust, rust-scale, paint, or foreign matter by the use of abrasives (sand, grit, shot). Very light shadows, very slight streaks, or slight discolorations caused by rust stain, mill scale oxides, or slight, tight residues of paint or coating may remain.	SSPC-SP 10-63T



**PAINTING**  
**TABLE IV, PAINTS**

Reference to Table I	Material	Number
1	Red Lead and Raw Linseed Oil Primer	1-64T No. 1
2	Red Lead, Iron Oxide, Raw Linseed Oil and Alkyd Primer	2-64 No. 2
3	Red Lead, Iron Oxide, and Fractionated Linseed Oil Primer	3-64T No. 3
4	Extended Red Lead, Raw and Bodied Linseed Oil Primer	4-64T No. 4
5	Zinc Dust, Zinc Oxide, and Phenolic Varnish Paint	5-64T No. 5
6	Red Lead, Iron Oxide, and Phenolic Varnish Paint	6-64T No. 6
8	Aluminum Vinyl Paint	8-64 No. 8
9	White (or Colored) Vinyl Paint	9-64 No. 9
11	Red Iron Oxide, Zinc Chromate, Raw Linseed Oil and Alkyd Primer	11-64T No. 11
12	Cold Applied Asphalt Mastic (Extra Thick Film)	12-64 No. 12
13	Red or Brown One-Coat Shop Paint	13-64 No. 13
14	Red Lead, Iron Oxide & Linseed Oil Primer	14-64T No. 14
15	Steel Joist Shop Paint	15-68T No. 15
16	Coal Tar Epoxy-Polyamide Black (or Dark Red) Paint	16-68T No. 16
102	Black Alkyd Paint	102-64 No. 102
103	Black Phenolic Paint	103-64T No. 103
104	White or Tinted Alkyd Paint, Types I, II, III, IV	104-64 No. 104
106	Black Vinyl Paint	106-64 No. 106
107	Red Lead, Iron Oxide and Alkyd Intermediate Paint	107-64T No. 107
A	Paint; Red-Lead Base, Ready-Mixed	TT-P-86c
B	Type I red lead-rav and bodied linseed oil	TT-P-86c
C	Type II red lead, iron oxide, mixed pigment-alkyd-linseed oil	TT-P-86c
D	Type III red lead alkyd	TT-P-86c
E	Primer; Zinc Chromate, alkyd Type	TT-P-86c
F	Paint; Zinc Yellow-Iron Oxide Base, Ready Mixed, Type II-yellow, alkyd	TT-P-645
G	Paint; Outside, White, Vinyl, Alkyd Type	MIL-P-15929B
H	Primer; Vinyl-Red Lead Type	MIL-P-16738B
I	Vinyl Resin Paint	MIL-P-15929B
J	Paint; Antifouling, Vinyl Type	VR-3
K	Undercoat and Indian Red Finish Coat	MIL-P-15931A
L	Enamel, Outside, Gray No. 11 (Vinyl-Alkyd)	MAP-44
M	Compounds; Rust Preventive	MIL-E-15935B
N	Coal Tar Enamel and Primers	MIL-E-15936B
O	Coal Tar Base Coating	MIL-P-15147C
P	Coating, Bituminous Emulsion	MIL-C-18480A MIL-C-15203c

**SSPC SPECIFICATIONS**

MIL = Military, TT = Federal Spec., MAP or MA = Mari-time Admin., VR = Bureau of Reclamations.

**PAINTING**  
**TABLE V, CHEMICAL RESISTANCE OF COATING MATERIAL**

	Natural Rubber	Butadiene-Styrene Rubber	Neoprene	Phenolics	Furanes	Epoxys	Oleoresinous	Vinyls	Vinylidene Chloride	Chlorinated Rubber	Styrene-Butadiene	Polyethylene	Bitumens
Acetaldehyde	1	2	1	1	1	1	1	1	1	1	1	1	1
Acetic acid, 10%	1	2	1	1	1	1	1	1	1	1	1	1	1
Acetic acid, glacial	1	2	1	1	1	1	1	1	1	1	1	1	1
Acetone	3	3	3	1	1	1	1	1	1	1	1	1	1
Alcohol, amyl	1	1	1	1	1	1	1	1	1	1	1	1	1
Alcohol, butyl, normal	1	1	1	1	1	1	1	1	1	1	1	1	1
Alcohol, ethyl	1	1	1	1	1	1	1	1	1	1	1	1	1
Alcohol, isopropyl	1	1	1	1	1	1	1	1	1	1	1	1	1
Alcohol, methyl	1	1	1	1	1	1	1	1	1	1	1	1	1
Aluminum chloride	1	1	1	1	1	1	1	1	1	1	1	1	1
Aluminum sulphate	1	1	1	1	1	1	1	1	1	1	1	1	1
Ammonia, liquid	1	1	1	1	1	1	1	1	1	1	1	1	1
Ammonium chloride	1	1	1	1	1	1	1	1	1	1	1	1	1
Ammonium hydroxide	1	1	1	1	1	1	1	1	1	1	1	1	1
Ammonium nitrate	1	1	1	1	1	1	1	1	1	1	1	1	1
Ammonium sulphate	1	1	1	1	1	1	1	1	1	1	1	1	1
Aniline	2	3	2	2	2	2	2	2	2	2	2	2	2
Benzene	4	4	1	1	1	1	1	1	1	1	1	1	1
Boric acid	1	1	1	1	1	1	1	1	1	1	1	1	1
Butyl acetate	1	1	1	1	1	1	1	1	1	1	1	1	1
Calcium chloride	1	1	1	1	1	1	1	1	1	1	1	1	1
Calcium hydroxide	1	1	1	1	1	1	1	1	1	1	1	1	1
Calcium hypochlorite	1	1	1	1	1	1	1	1	1	1	1	1	1
Carbon disulphide	4	4	4	1	1	1	1	1	1	1	1	1	1
Carbon tetrachloride	4	4	4	1	1	1	1	1	1	1	1	1	1
Chlorine gas	1	2	2	4	1	1	1	1	1	1	1	1	1
Chlorobenzene	4	4	4	1	1	1	1	1	1	1	1	1	1
Chloroform	4	4	4	1	1	1	1	1	1	1	1	1	1
Chromic acid, 10%	2	2	2	4	3	3	4	2	2	2	2	2	2
Chromic acid, 60%	2	2	2	4	3	3	4	2	2	2	2	2	2
Citric acid	1	1	1	1	1	1	1	1	1	1	1	1	1
Copper sulphate	1	1	1	1	1	1	1	1	1	1	1	1	1
Diethyl ether	4	4	4	1	1	1	1	1	1	1	1	1	1
Ethylene glycol	1	1	1	1	1	1	1	1	1	1	1	1	1
Ferric chloride	1	1	1	1	1	1	1	1	1	1	1	1	1
Ferric sulphate	1	1	1	1	1	1	1	1	1	1	1	1	1
Formaldehyde, 40%	1	1	1	1	1	1	1	1	1	1	1	1	1
Formic acid, 20%	1	1	1	1	1	1	1	1	1	1	1	1	1
Formic acid, conc.	1	1	1	1	1	1	1	1	1	1	1	1	1
Gasoline	4	4	1	1	1	1	1	1	1	1	1	1	1
Glycerine	1	1	1	1	1	1	1	1	1	1	1	1	1
Hydrochloric acid, 10%	1	1	1	1	1	1	1	1	1	1	1	1	1
Hydrochloric acid, 30%	1	1	1	1	1	1	1	1	1	1	1	1	1
Hydrochloric acid, conc.	1	1	1	1	1	1	1	1	1	1	1	1	1
Hydrofluoric acid, 10%	1	1	1	1	1	1	1	1	1	1	1	1	1
Hydrofluoric acid, 40%	1	1	1	1	1	1	1	1	1	1	1	1	1

**CLASSES OF EXPOSURE** (Numbers in the table refer to most severe class of exposure for general use.)

**Class 1.** Continual and direct contact with the corrosive

**Class 2.** High concentration of corrosive fumes and under frequent splash and spillage

**Class 3.** Relatively high concentrations of fumes, but with little or no splash or spillage or direct contact with the corrosive

**Class 4.** Mild concentrations of corrosive fumes. Weathering.

The table was presented by Kenneth Tator, Chemical Engineering December, 1952, copyright by McGraw-Hill Publishing Co., Inc., 1952



**PAINTING**  
**TABLE V, CHEMICAL RESISTANCE OF COATING MATERIAL**  
(continued)

	Natural Rubber	Butadiene-Styrene Rubber	Neoprene	Phenolics	Furanes	Epoxys	Oleoresinous	Vinyls	Vinylidene Chloride	Chlorinated Rubber	Styrene-Butadiene	Polyethylene	Bitumens
Hydrofluoric acid, 75%...	1	2	1	1	1	1	3	2	2	2	2	2	3
Hydrogen peroxide, 3%...	1	1	1	1	1	1	3	2	2	2	2	2	4
Hydrogen peroxide, 30%...	2	2	1	1	1	1	3	2	2	2	2	2	4
Hydrogen sulphide...	1	1	1	1	1	1	1	2	1	2	2	2	2
Hypochlorous acid...	1	2	1	1	1	1	4	3	3	4	1	1	4
Kerosene...	4	4	1	1	1	1	1	1	1	1	4	4	2
Lubricating oil...	4	4	1	1	1	1	1	1	1	1	4	4	2
Magnesium sulphate...	1	1	1	1	1	1	1	1	1	1	2	2	1
Methyl ethyl ketone...	1	1	1	1	1	1	1	1	1	1	2	2	1
Mineral oil...	4	4	1	1	1	1	1	1	1	1	4	4	2
Nitric acid, 5%...	1	1	1	1	1	1	1	1	1	1	1	1	3
Nitric acid, 10%...	2	2	1	1	1	1	1	1	1	1	1	1	3
Nitric acid, 40%...	2	2	1	1	1	1	1	1	1	1	1	1	3
Nitric acid, conc...	3	3	2	2	2	2	2	2	2	2	2	2	4
Nitrobenzene...	4	4	1	1	1	1	1	1	1	1	1	1	4
Oleic acid...	3	3	2	1	1	1	1	1	1	1	1	1	2
Oxalic acid...	1	1	1	1	1	1	1	1	1	1	1	1	2
Phenol, 15-25%...	3	3	1	1	1	1	1	1	1	1	1	1	4
Phenol...	3	3	1	1	1	1	1	1	1	1	1	1	4
Phosphoric acid, 10%...	1	1	1	1	1	1	1	1	1	1	1	1	3
Phosphoric acid, 60%...	1	1	1	1	1	1	1	1	1	1	1	1	3
Phosphoric acid, conc...	1	1	1	1	1	1	1	1	1	1	1	1	3
Potassium alum...	1	1	1	1	1	1	1	1	1	1	1	1	2
Potassium hydroxide, 20%...	1	1	1	1	1	1	1	1	1	1	1	1	2
Potassium hydroxide, 95%...	2	2	1	1	1	1	1	1	1	1	1	1	3
Potassium permanganate...	2	2	1	1	1	1	1	1	1	1	1	1	4
Potassium sulphate...	1	1	1	1	1	1	1	1	1	1	1	1	2
Sea water...	1	1	1	1	1	1	1	1	1	1	1	1	1
Silver nitrate...	1	1	1	1	1	1	1	1	1	1	1	1	1
Sodium bisulphate...	1	1	1	1	1	1	1	1	1	1	1	1	2
Sodium carbonate...	1	1	1	1	1	1	1	1	1	1	1	1	4
Sodium chloride...	1	1	1	1	1	1	1	1	1	1	1	1	1
Sodium hydroxide, 10%...	1	1	1	1	1	1	1	1	1	1	1	1	1
Sodium hydroxide, 20%...	1	1	1	1	1	1	1	1	1	1	1	1	1
Sodium hydroxide, 40%...	1	1	1	1	1	1	1	1	1	1	1	1	1
Sodium hypochlorite...	1	2	1	1	1	1	1	1	1	1	1	1	3
Sodium nitrate...	1	1	1	1	1	1	1	1	1	1	1	1	2
Sodium sulphate...	1	1	1	1	1	1	1	1	1	1	1	1	2
Sulphur dioxide...	1	1	1	1	1	1	1	1	1	1	1	1	2
Sulphuric acid, 10%...	1	1	1	1	1	1	1	1	1	1	1	1	2
Sulphuric acid, 30%...	1	1	1	1	1	1	1	1	1	1	1	1	2
Sulphuric acid, 60%...	1	1	1	1	1	1	1	1	1	1	1	1	3
Sulphuric acid, conc...	2	2	1	1	1	1	1	1	1	1	1	1	3
Toluene...	4	4	1	1	1	1	1	1	1	1	1	1	4
Trichloroethylene...	4	4	1	1	1	1	1	1	1	1	1	1	4

**CLASSES OF EXPOSURE** (Numbers in the table refer to most severe class of exposure for general use.)

**Class 1.** Continual and direct contact with the corrosive

**Class 2.** High concentration of corrosive fumes and under frequent splash and spillage

**Class 3.** Relatively high concentrations of fumes, but with little or no splash or spillage or direct contact with the corrosive

**Class 4.** Mild concentrations of corrosive fumes. Weathering.

The table was presented by Kenneth Tator, Chemical Engineering December, 1952, copyright by McGraw-Hill Publishing Co., Inc., 1952

## CHECK LIST FOR INSPECTORS

	QC	AI
1. Codes and Addenda .....		
2. Drawings:		
a) All info & details required by QC Manual shown on drawing .....		
b) Heads correctly identified .....		
c) All metal correctly identified .....		
d) Name plate facsimile stamped correctly:		
MAWP, MDMT and RT .....		
e) Approval by fabricator (on drawing) .....		
f) Revisions or metal substitution shown and approved .....		
3. Bill of Material:		
a) All material identified as SA or SB .....		
b) Requirements of UCS 79 (d) specified were applicable .....		
c) Required material test reports specified .....		
d) Shop order, serial number, and/or job number shown .....		
e) Material revision or substitution approved and shown when applicable .....		
4. Calculations:		
a) Dimensions used match drawing .....		
b) Correct stress values and joint efficiencies (S & E) used .....		
c) Correct formula & dimensions used for heads .....		
d) Do nozzle necks comply with UG-45? .....		
e) Required reinforcement calculations available for all openings .....		
f) Special flange or structural loading calculations available .....		
g) Identification with S/O or S/N and approved by fabricator .....		
h) External design pressure correct - template calculations & template available .....		
i) MAWP & MDMT matches drawing and specifications. MDMT correct for materials used (UCS-66, UHA-51) .....		
5. Purchase Orders:		
a) Is job number shown (when applicable)? .....		
b) Correct specification (SA or SB) used .....		
c) USC 79(d) & UG 81 requirements specified as applicable .....		
d) Material Test Reports requested .....		
e) Is material ordered identical to Bill of Material or drawing requirements? .....		
6. Welding:		
a) Are correct WPS(s) shown on drawings? .....		
b) Are complete weld details for all welds shown on drawing? .....		
c) Are copies of WPS(s) available to shop supervisor for instruction? .....		



## CHECK LIST FOR INSPECTORS (continued)

	QC	AI
d) Is a Welder's Log and Qualification Directory kept up-to-date and available? .....		
e) Are WPS, PQR, & WPO forms correct and signed? .....		
f) Are welders properly qualified for thickness, position, pipe diameter and welding with no backing (when required)? .....		
g) Is sub-arc flux, electrodes and shielding gas(es) used the same as specified on applicable WPS? .....		
h) Do weld sizes (fillet & butt weld reinforcement) comply with drawing and Code requirements? .....		
i) Is welder identification stamped or recorded per QC Manual and/or Code requirements? .....		
7. Non-Destructive Examination & Calibration:		
a) Are SNT-TC-1A qualification records with current visual examination available for all RT technicians used? .....		
b) Do film reader sheets or check off records show film interpretation by a SNT-TC Level I or II examiner or interpreter? .....		
c) Are the required number of film shots in the proper locations for the joint efficiency and welders used (UW-11, 12, & 52)? .....		
d) Is an acceptable PT and/or MT procedure and personnel qualified and certified in accordance with Sec. VIII, Appendix 6 or 8 available? .....		
e) Is the PT material being used the same as specified in the PT procedure? .....		
f) Do all radiographs comply with identification, density, penetrometer, and acceptance requirements of Sect. VIII and V? .....		
g) For B31.1 fabrication, is a visual examination procedure and certified personnel available? .....		
h) Are tested gases marked or identified and calibrated as stated in QC Manual? .....		
i) Is a calibrated gage size per UG-102 available for demo vessel? .....		

### ABBREVIATIONS:

AI	Authorized Inspector
MAWP	Maximum Allowable Working Pressure
MDMT	Maximum Design Metal Temperature
QC	Quality Control
RT	Radiographic Examination
S/N	Serial Number
S/O	Shop Order
WPS	Welding Procedure Specification

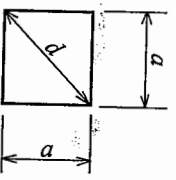
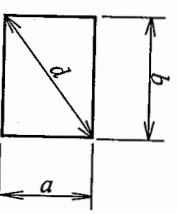
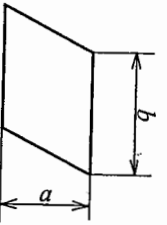
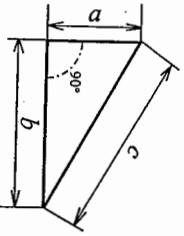
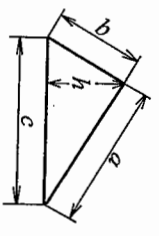
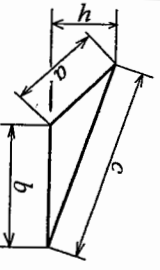
## PART II. GEOMETRY AND LAYOUT OF PRESSURE VESSELS

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## GEOMETRICAL FORMULAS

(See examples on the facing page.)

	<b>SQUARE</b> $A = \text{Area}$ $A = a^2$ $d = 1.414a$ $A = \frac{d^2}{2}$ $a = 0.7071d \text{ or } a = \sqrt{A}$
	<b>RECTANGLE</b> $A = \text{Area}$ $A = a \times b$ $d = \sqrt{a^2 + b^2}$ $a = \sqrt{d^2 - b^2} \text{ or } a = \frac{A}{b}$ $b = \sqrt{d^2 - a^2} \text{ or } b = \frac{A}{a}$
	<b>PARALLELOGRAM</b> $A = \text{Area}$ $A = a \times b$ $a = \frac{A}{b}$ $b = \frac{A}{a}$
	<b>RIGHT-ANGLED TRIANGLE</b> $A = \text{Area}$ $A = \frac{a \times b}{2}$ $a = \sqrt{c^2 - b^2}$ $b = \sqrt{c^2 - a^2}$ $c = \sqrt{a^2 + b^2}$
	<b>ACUTE ANGLED TRIANGLE</b> $A = \frac{\text{Area}}{2}$ $A = \frac{c \times h}{2}$ $A = \frac{\sqrt{s(s-a)(s-b)(s-c)}}{2}$ $s = \frac{1}{2}(a+b+c)$
	<b>OBTUSE ANGLED TRIANGLE</b> $A = \frac{\text{Area}}{2}$ $A = \frac{b \times h}{2}$ $A = \frac{\sqrt{s(s-a)(s-b)(s-c)}}{2}$ $s = \frac{1}{2}(a+b+c)$

## EXAMPLES

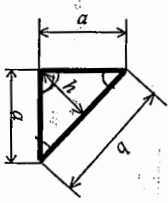
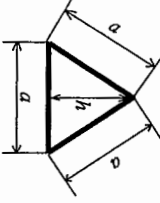
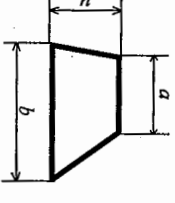

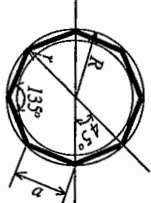
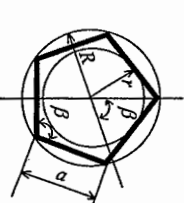
(See formulas on the facing page.)

<b>SQUARE</b> Given: Side $a = 8 \text{ in.}$ Find: Area $A = a^2 = 8^2 = 64 \text{ sq. in.}$ Diagonal $d = 1.414a = 1.414 \times 8 = 11.312 \text{ in.}$ Area $A = \frac{d^2}{2} = \frac{11.312^2}{2} = 64 \text{ sq. in.}$ Side $a = 0.7071d = 0.7071 \times 11.312 = 8 \text{ in.}$ Side $a = \sqrt{A} = \sqrt{64} = 8 \text{ in.}$	<b>RECTANGLE</b> Given: Side $a = 3 \text{ in.}$ , and $b = 4 \text{ in.}$ Find: Area $A = a \times b = 3 \times 4 = 12 \text{ sq. in.}$ Diagonal $d = \sqrt{a^2 + b^2} = \sqrt{3^2 + 4^2} = \sqrt{9 + 16} = \sqrt{25} = 5 \text{ in.}$ Side $a = \frac{A}{b} = \frac{12}{4} = 3 \text{ in.}$ Side $b = \frac{A}{a} = \frac{12}{3} = 4 \text{ in.}$	<b>PARALLELOGRAM</b> Given: Height $a = 8 \text{ in.}$ , and the side $b = 12 \text{ in.}$ Find: Area $A = a \times b = 8 \times 12 = 96 \text{ sq. in.}$ Height $a = \frac{A}{b} = \frac{96}{12} = 8 \text{ in.}$ Side $b = \frac{A}{a} = \frac{96}{8} = 12 \text{ in.}$	<b>RIGHT ANGLED TRIANGLE</b> Given: Side $a = 6 \text{ in.}$ , and side $b = 12 \text{ in.}$ Find: Area $A = \frac{a \times b}{2} = \frac{6 \times 12}{2} = 24 \text{ sq. in.}$ Side $c = \sqrt{a^2 + b^2} = \sqrt{6^2 + 12^2} = \sqrt{36 + 144} = \sqrt{180} = 10 \text{ in.}$ Side $a = \sqrt{c^2 - b^2} = \sqrt{10^2 - 12^2} = \sqrt{100 - 144} = \sqrt{36} = 6 \text{ in.}$ Side $b = \sqrt{c^2 - a^2} = \sqrt{10^2 - 6^2} = \sqrt{100 - 36} = \sqrt{64} = 8 \text{ in.}$	<b>ACUTE ANGLED TRIANGLE</b> Given: Side $a = 6 \text{ in.}$ , side $b = 8 \text{ in.}$ , and side $c = 10 \text{ in.}$ Find: Area $A = \frac{1}{2}(a+b+c) \times s = \frac{1}{2}(6+8+10) \times 12 = 12$ $A = \frac{\sqrt{s(s-a)(s-b)(s-c)}}{2} = \frac{\sqrt{12(12-6)(12-8)(12-10)}}{2} = 24 \text{ sq. in.}$	<b>OBTUSE ANGLED TRIANGLE</b> Given: Side $a = 3 \text{ in.}$ , side $b = 4 \text{ in.}$ , and side $c = 5 \text{ in.}$ Find: Area $A = \frac{1}{2}(a+b+c) \times s = \frac{1}{2}(3+4+5) \times 6 = 6$ $A = \frac{\sqrt{s(s-a)(s-b)(s-c)}}{2} = \frac{\sqrt{6(6-3)(6-4)(6-5)}}{2} = \sqrt{36} = 6 \text{ sq. in.}$
--	--	---	--	--	---



## GEOMETRICAL FORMULAS

(See examples on the facing page.)

	<b>RIGHT TRIANGLE WITH 2 45° ANGLES</b> $A = \text{Area}$ $A = \frac{a^2}{2}$ $b = 1.414a$ $h = 0.7071a$ $a = 1.414h$
	<b>EQUILATERAL TRIANGLE</b> $A = \text{Area}$ $A = \frac{a \times h}{2}$ $h = 0.866a$ $a = 1.155h$
	<b>TRAPEZOID</b> $A = \text{Area}$ $A = \frac{(a+b)h}{2}$
	<b>REGULAR HEXAGON</b> $A = \text{Area}$ $R = \text{Radius of circumscribed circle}$ $r = \text{Radius of inscribed circle}$ $A = 2.598a^2 = 2.598R^2 = 3.464r^2$ $R = a = 1.155r$ $r = 0.866a = 0.866R$ $a = R = 1.155r$
	<b>REGULAR OCTAGON</b> $A = \text{Area}$ $R = \text{Radius of circumscribed circle}$ $r = \text{Radius of inscribed circle}$ $A = 4.828a^2 = 2.828R^2 = 3.314r^2$ $R = 1.307a = 1.082r$ $r = 1.207a = 0.924R$ $a = 0.765R = 0.828r$
	<b>REGULAR POLYGON</b> $A = \text{Area}$ $\alpha = \frac{360^\circ}{n}$ $\beta = 180^\circ - \alpha$ $n = \text{Number of sides}$ $A = \frac{nr^2}{2}$ $r = \sqrt{R^2 - \frac{a^2}{4}}$ $a = 2\sqrt{R^2 - r^2}$ $R = \sqrt{r^2 + \frac{a^2}{4}}$

## EXAMPLES

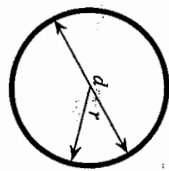
(See formulas on the facing page.)

<b>RIGHT TRIANGLE WITH 2 45° ANGLES</b> Given: Side $a = 8$ in. Find: Area $A = \frac{a^2}{2} = \frac{8^2}{2} = 32$ sq. in. Side $b = 1.414$ $a = 1.414 \times 8 = 11.312$ in. $h = 0.7071a = 0.7071 \times 8 = 5.6568$ in.	
<b>EQUILATERAL TRIANGLE</b> Given: Side $A = 8$ in. Find: $h = 0.866 \times a = 0.866 \times 8 = 6.928$ in. Area $A = \frac{a \times h}{2} = \frac{8 \times 6.928}{2} = 27.712$ sq. in.	
<b>TRAPEZOID</b> Given: Side $a = 4$ in., $b = 8$ in., and height $h = 6$ in. Find: Area $A = \frac{(a+b)h}{2} = \frac{(4+8) \times 6}{2} = 36$ sq. in.	
<b>REGULAR HEXAGON</b> Given: Side $a = 4$ in. Find: Area $A = 2.598 \times a^2 = 2.598 \times 4^2 = 41.568$ sq. in. $r = 0.866 \times a = 0.866 \times 4 = 3.464$ in. $R = a = 1.155r = 1.155 \times 3.464 = 4$ in.	
<b>REGULAR OCTAGON</b> Given: $R = 6$ in., radius of circumscribed circle Find: Area $A = 2.828R^2 = 2.828 \times 6^2 = 101.81$ sq. in. Side $a = 0.765R = 0.765 \times 6 = 4.59$ in.	
<b>REGULAR POLYGON</b> Number of sides $n = 5$ , side $a = 9.125$ in. Radius of circumscribed circle, $R = 7.750$ Find: $r = \sqrt{R^2 - \frac{a^2}{4}} = \sqrt{7.750^2 - \frac{9.125^2}{4}} = 6.25$ in. Area $A = \frac{nr^2}{2} = \frac{5 \times 6.25 \times 9.125}{2} = 142.58$ sq. in.	



## GEOMETRICAL FORMULAS

(See examples on the facing page.)



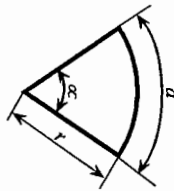
**CIRCLE**

$A$  = Area  $C$  = Circumference

$A = r^2 \pi = r^2 \times 3.1416 = d^2 \times 0.7854$

$C = d \times \pi = d \times 3.1416$

Length of arc for angle  $\alpha = 0.008727 d \times \alpha$



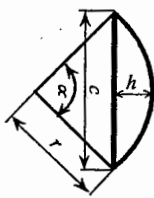
**CIRCULAR SECTOR**

$A$  = Area  $a$  = Arc  $\alpha$  = Angle

$A = r^2 \pi \times \frac{\alpha}{360}$

$a = \frac{r \times \alpha}{180} \times 3.1416$

$\alpha = \frac{57.297 \times a}{r}$   $r = \frac{2A}{\alpha}$



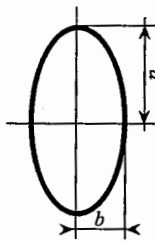
**CIRCULAR SEGMENT**

$A$  = Area  $\alpha$  = Angle  $c$  = Cord

$A$  = Area of sector minus area of triangle

$h$  = see table on page 290

$c$  = see table on page 290



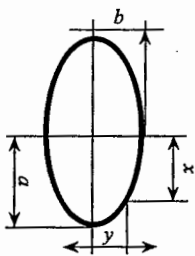
**ELLIPSE**

$A$  = Area  $P$  = Perimeter

$A = \pi \times a \times b = 3.1416 \times a \times b$

An approximate formula for perimeter:

$P = 3.1416 \sqrt{2(a^2 + b^2)}$



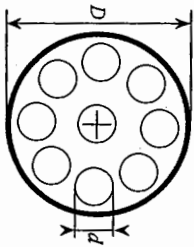
**ELLIPSE**

Locating points on ellipse

$\frac{a}{b} = C$  = Ratio of minor axis to major axis

$x = \sqrt{a^2 - 2C \times y^2}$

$y = \sqrt{\frac{a^2 - x^2}{C}}$



$N = \left(\frac{D}{d}\right)^2$ , where

$N$  = The required number of holes (diameter  $d$ ) of which total area equals area of circle diameter  $D$ .

## EXAMPLES

(See formulas on the facing page.)

**CIRCLE:**

Given: Radius  $r = 6$  in.

Find Area:  $A = r^2 \times \pi = 6^2 \times 3.1416 = 113.10$  sq. in. or

$A = d^2 \times 0.7854 = 12^2 \times 0.7854 = 113.10$  sq. in.

Circumference  $C = d \times \pi = 12 \times 3.1416 = 37.6991$  in.

The length of arc for an angle, if  $\alpha = 60^\circ$

$Arc = 0.008727 d \times \alpha = 0.008727 \times 12 \times 60 = 6.283$  in.

**CIRCULAR SECTOR:**

Given: Radius  $r = 6$  in. Angle  $\alpha = 60^\circ$

Find Area:  $A = r^2 \pi \times \frac{\alpha}{360} = 6^2 \pi \times \frac{60}{360} = 18.85$  sq. in.

Arc  $a = \frac{r \times \alpha}{180} \times 3.1416 = \frac{6 \times 60 \times 3.1416}{180} = 6.283$  in.

Angle  $\alpha = \frac{57.296 \times a}{r} = \frac{57.296 \times 6.283}{6} = 60^\circ$

**CIRCULAR SEGMENT:**

Given: Radius  $r = 6$  in. Angle  $\alpha = 90^\circ$

Find Area:  $A = r^2 \pi \times \frac{\alpha}{360} = 6^2 \times 3.1416 \times \frac{60}{360} = 28.274$  sq. in.

Area of sector  $r^2 \pi \times \frac{\alpha}{360} = 6^2 \times 3.1416 \times \frac{60}{360} = 28.274$  sq. in.

Minus area of triangle = 18.000 sq. in.

Area of segment  $A = 10.274$  sq. in.

Chord  $c = 2r \times \sin \frac{\alpha}{2} = 2 \times 6 \times \sin \frac{90}{2} = 2 \times 6 \times 0.7071 = 8.485$  in.

**ELLIPSE:**

Given: Half axis,  $a = 8$  in. and  $b = 3$  in.

Find: Area  $A = \pi \times a \times b = 3.1416 \times 8 \times 3 = 75.398$  in.

Perimeter  $P = 3.1416 \sqrt{2(a^2 + b^2)} = 3.1416 \sqrt{2(8^2 + 3^2)} = 3.1416 \sqrt{146} = 37.96$  in.

**ELLIPSE:**

Given: Half-axis,  $a = 8$  in. and  $b = 4$  in., then  $C = \frac{a}{b} = \frac{8}{4} = 2$ ,  $x = 6$  in.

Find:  $y = \frac{\sqrt{a^2 - x^2}}{C} = \frac{\sqrt{8^2 - 6^2}}{2} = \frac{\sqrt{64 - 36}}{2} = \frac{\sqrt{28}}{2} = \frac{5.2915}{2} = 2.6457$  in.

$x = \sqrt{a^2 - (2C \times y)^2} = \sqrt{8^2 - (2 \times 2 \times 2.6457)^2} = \sqrt{64 - 4 \times 7} = \sqrt{36} = 6$  in.

**EXAMPLE:**

How many  $\frac{1}{4}$  in.  $\phi$  holes have same areas as a 6 in. diam. pipe?

$N = (D/d)^2 = (6/0.25)^2 = 24^2 = 576$  holes

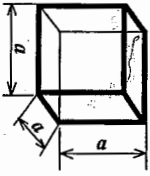
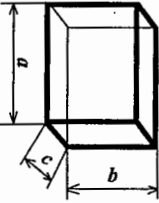
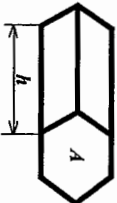
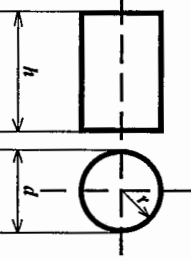
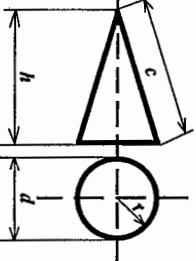
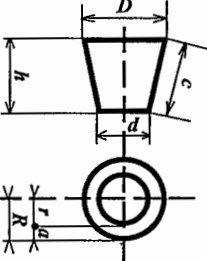
Area of 6 in.  $\phi$  pipe = 28.274 in.<sup>2</sup>

Area of 576,  $\frac{1}{4}$  in.  $\phi$  holes = 28,276 in.<sup>2</sup>



## GEOMETRICAL FORMULAS

(See examples on the facing page.)

	<b>CUBE</b> $V = \text{Volume}$ $V = a^3$ $a = \sqrt[3]{V}$
	<b>SQUARE PRISM</b> $V = \text{Volume}$ $V = a \times b \times c$ $a = \frac{V}{bc}$ $b = \frac{V}{ac}$ $c = \frac{V}{ab}$
	<b>PRISM</b> $V = \text{Volume}$ $A = \text{Area of end surface}$ $V = h \times A$ <p>This formula can be applied for any shape of end surface if <math>h</math> is perpendicular to end surface.</p>
	<b>CYLINDER</b> $V = \text{Volume}$ $S = \text{Area of cylindrical surface}$ $V = 3.1416 \times r^2 \times h = 0.785 \times d^2 \times h$ $S = 3.1416 \times d \times h$
	<b>CONE</b> $V = \text{Volume}$ $S = \text{Area of conical surface}$ $V = \frac{3.1416 \times r^2 \times h}{3} = 1.0472 \times r^2 \times h$ $c = \sqrt{r^2 + h^2}$ $S = 3.1416 \times rc = 1.5708 \times dc$
	<b>FRUSTUM OF CONE</b> $V = \text{Volume}$ $S = \text{Area of conical surface}$ $V = 0.2618h(D^2 + Dd + d^2)$ $a = R - r$ $c = \sqrt{a^2 + h^2}$ $S = 1.5708c(D + d)$

## EXAMPLES

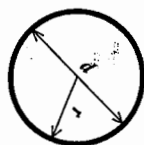
(See formulas on the facing page.)

<b>CUBE</b> Given: Side $a = 8$ in. Find: Volume $V = a^3 = 8^3 = 512$ cu. in. Side $a = \sqrt[3]{512} = 8$ in.	<b>SQUARE PRISM</b> Given: Side $a = 8$ in., $b = 6$ in., and $c = 4$ in. Find: Volume $V = a \times b \times c = 8 \times 6 \times 4 = 192$ cu. in. Side $a = \frac{V}{b \times c} = \frac{192}{6 \times 4} = 8$ in.; $b = \frac{V}{a \times c} = \frac{192}{8 \times 4} = 6$ in. $c = \frac{V}{a \times b} = \frac{192}{8 \times 6} = 4$ in.
<b>PRISM</b> Given: End surface $A = 12$ sq. in., and $h = 8$ in. Find: Volume $V = h \times A = 8 \times 12 = 96$ cu. in.	<b>CYLINDER</b> Given: $r = 6$ in., and $h = 12$ in. Find: Volume $V = 3.1416 \times r^2 \times h = 3.1416 \times 6^2 \times 12 = 1357.2$ cu. in. Area of Cylindrical Surface: $S = 3.1416 \times d \times h = 3.1416 \times 12 \times 12 = 452.389$ sq. in.
<b>CONE</b> Given: $r = 6$ in., and $h = 12$ in. Find: Volume $V = 1.0472 \times r^2 \times h = 1.0472 \times 6^2 \times 12 = 452.4$ cu. in. $c = \sqrt{r^2 + h^2} = \sqrt{36 + 144} = \sqrt{180} = 13.416$ in. Area of Conical Surface: $S = 3.1416 \times r \times c = 3.1416 \times 6 \times 13.416 = 252.887$ sq. in.	<b>FRUSTUM OF CONE</b> Given: Diameter $D = 24$ in., and $d = 12$ in., $h = 10.375$ in. Find: Volume $V = 0.2618h(D^2 + Dd + d^2) = 0.2618 \times 10.375(24^2 + 24 \times 12 + 12^2) = 2737.9$ cu. in. Surface: $S = 1.5708c(D + d) = 1.5708 \times 12(24 + 12) = 678.586$ sq. in.



## GEOMETRICAL FORMULAS

(See examples on the facing page.)

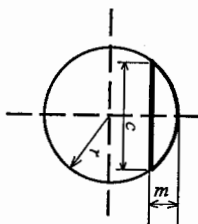


### SPHERE

$V$  = Volume     $A$  = Area of Surface

$$V = \frac{4\pi \times r^3}{3} = \frac{\pi \times d^3}{6} = 4.1888 r^3 = 0.5236 d^3$$

$$A = 4\pi \times r^2 = \pi d^2$$

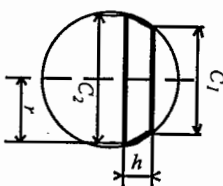


### SPHERICAL SEGMENT

$V$  = Volume     $A$  = Area of Spherical Surface

$$V = 3.1416 \times m^2 \left( r - \frac{m}{3} \right)$$

$$A = 2\pi \times r \times m$$

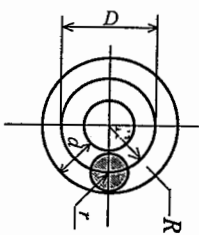


### SPHERICAL ZONE

$V$  = Volume     $A$  = Area of Spherical Surface

$$V = 0.5236h \left( \frac{3C_1^2}{4} + \frac{3C_2^2}{4} + h^2 \right)$$

$$A = 2\pi rh = 6.2832 rh$$



### TORUS

$V$  = Volume     $A$  = Area of Surface

$$V = 19.739 Rr^2$$

$$= 2.4674 Dd^2$$

$$A = 39.478 Rr$$

$$= 9.8696 Dd$$

See tables for volume and surface of cylindrical shell, spherical, elliptical and flanged and dished heads, beginning on page 416.

## EXAMPLES

(See formulas on the facing page.)

### SPHERE

Given: Radius  $r = 6$  in.

Find: Volume  $V = 4.1888 r^3 = 4.1888 \times 216 = 904.78$  cu. in.

or  $V = 0.5236 d^3 = 0.5236 \times 1728 = 904.78$  cu. in.

Area  $A = 4\pi r^2 = 4 \times 3.1416 \times 6^2 = 452.4$  sq. in.

or  $A = \pi d^2 = 3.1416 \times 12^2 = 452.4$  sq. in.

### SPHERICAL SEGMENT

Given: Radius  $r = 6$  in. and  $m = 3$  in.

Find: Volume  $V = 3.1416 m^2 \left( r - \frac{m}{3} \right) = 3.1416 \times 3^2 \left( 6 - \frac{3}{3} \right) = 141.37$  cu. in.

Area  $A = 2\pi \times r \times m = 2 \times 3.1416 \times 6 \times 3 = 113.10$  sq. in.

### SPHERICAL ZONE

Given: Radius  $r = 6$  in.,  $C_1 = 8$  in.,  $C_2 = 11.625$  in., and  $h = 3$  in.

Find: Volume  $V = 0.5236 \times 3 \times \left( \frac{3 \times 8^2}{4} + \frac{3 \times 11.625^2}{4} + 3^2 \right) = 248.74$  cu. in.

Area  $A = 6.2832 \times 6 \times 3 = 113.10$  sq. in.

### TORUS

Given: Radius  $R = 6$  in. and  $r = 2$  in.

Find: Volume  $V = 19.739 Rr^2 = 19.739 \times 6 \times 2^2 = 473.7$  cu. in.

Area  $A = 39.478 Rr = 39.478 \times 6 \times 2 = 473.7$  sq. in.



LOCATING POINTS ON A CIRCLE	
<p><b>EXAMPLE</b>  <math>R = 5 \text{ in.}</math>   <math>X = 3 \text{ in.}</math>  Find <math>Y = \sqrt{5^2 - 3^2} = \sqrt{25 - 9} = \sqrt{16} = 4 \text{ in.}</math></p>	
<p><b>LENGTH OF PLATE FOR CYLINDER</b>  <b>EXAMPLE</b>  Inside diameter = 24 in.  Thickness of plate: 1 in.  The length of plate =  <math>L = 25 \times 3.1416 = 78.5398 \text{ in.}</math></p>	
<p><b>TO FIND THE RADIUS OF A CIRCULAR ARC</b>  <b>EXAMPLE</b>  <math>c = 6 \text{ in.}, M = 2 \text{ in.}</math>  Find: <math>R = \frac{(6/2)^2 + 2^2}{2 \times 2} = 3.25 \text{ in.}</math></p>	
<p><b>TO FIND THE CENTER OF A CIRCULAR ARC</b>  When the radius, <math>R</math>, and chord, <math>C</math>, are known, strike an arc from point <math>A</math> and from point <math>B</math> with the given length of the radius. The intersecting point, <math>O</math>, of the two arcs is the center of the circular arc.</p> $Y = \sqrt{R^2 - (C/2)^2}$	
<p><b>TO FIND THE CENTER OF A CIRCULAR ARC</b>  When the chord, <math>C</math>, and dimension, <math>M</math>, are known, strike an arc from point <math>A</math> and from point <math>B</math> on both sides of the arc. Connect the intersecting points with straight lines. The intersecting point of the straight lines, <math>O</math>, is the center of the circular arc.</p> $R = \frac{C^2 + 4M^2}{8M}; \quad Y = R - M$	
<p><b>CONSTRUCTION OF A CIRCULAR ARC</b>  The radius is known, but because of its extreme length it is impossible to draw the arc with a compass. Determine the length of chord, <math>C</math> and dimension <math>M</math>. Draw at the center of the chord, <math>C</math> a perpendicular line. Measure on this line dimension <math>M</math>. Connect points <math>A</math> and <math>B</math>. Bisect lines <math>AD</math> and <math>BD</math> and measure <math>M/4</math> dimension perpendicular. Repeating this procedure to the requested accuracy, <math>M</math> will be 4 times less at each bisection 4 times less. The vertices of the triangles are the points of the circular arc.</p>	

<p><b>A</b></p>	<p><b>TO FIND THE FOCUS OF AN ELLIPSE</b></p> <p>Given the minor and major axis of the ellipse. Find the focus.</p> <p>Strike an arc with radius, a (one half of the major axis) with center at B. The intersecting points of the arc and major axis are the two foci of the ellipse.</p> $c = \sqrt{a^2 - b^2}$
<p><b>B</b></p>	<p><b>THE CONSTRUCTION OF ELLIPSE</b></p> <p>Place a looped string around points <math>F_1</math>, B and <math>F_2</math>. Draw the ellipse with a pencil moving it along the maximum orbit of the string while it is kept taut.</p> $Y = b \sqrt{1 - \frac{x^2}{a^2}}$
<p><b>C</b></p>	<p><b>THE CONSTRUCTION OF ELLIPSE</b></p> <p>Describe a circle of which diameter is equal to the major axis of the ellipse and with the same center a circle of which diameter is equal to the minor axis. Draw a number of diameters. From the intersecting points of the large circle draw perpendicular lines to the major axis and from the intersections of the small circle draw lines parallel with the minor axis. The intersections of these parallel and perpendicular lines are points of the elliptical curve.</p>
<p><b>D</b></p>	<p><b>PROPERTIES OF 2:1 ELLIPTICAL HEAD</b></p> <p><math>d = 0.8 D</math> (approx.)</p> <p><math>R = 0.9 D</math> (approx.)</p> <p><math>r = 0.173 D</math> (approx.)</p> <p>The upper portion of the head within diameter, d is a spherical segment with negligible deviation.</p>
<p><b>E</b></p>	<p><b>LOCATING POINTS ON A 2:1 ELLIPTICAL HEAD</b></p> $X = \sqrt{R^2 - 4Y^2} \quad Y = \frac{\sqrt{R^2 - X^2}}{2}$ <p>Note: The curvature of an elliptical head on one side only is a true ellipse (inside or outside). The opposite parallel curve is geometrically undetermined. To locate points on this curve especially in the case of a heavy walled head is possible by means of layout only. See tables on page 293.</p>

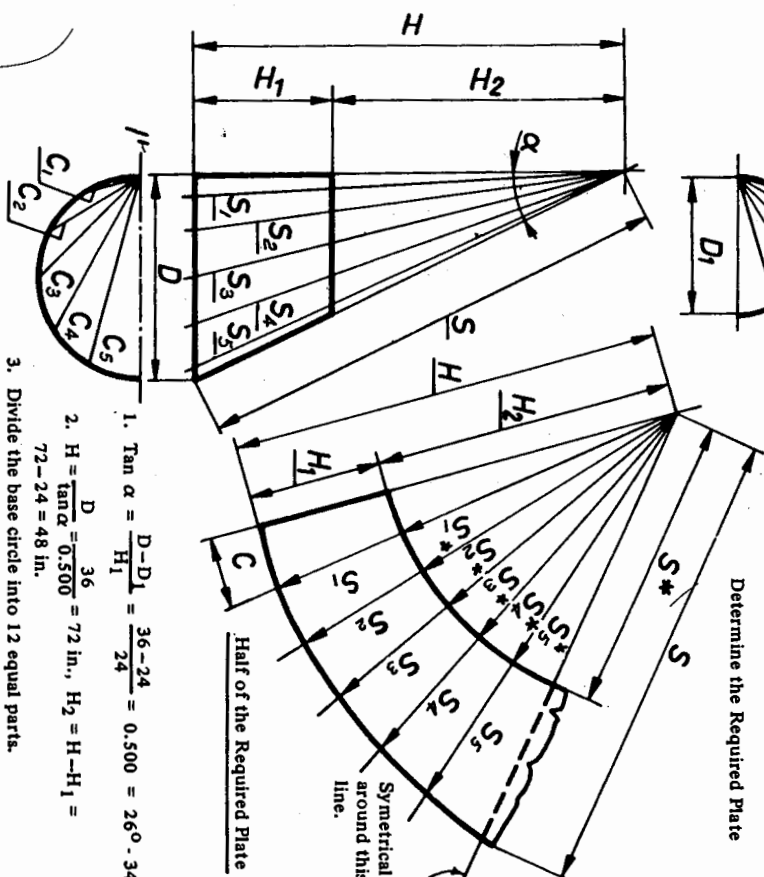


## SOLUTION OF RIGHT TRIANGLES

KNOWN SIDE OR ANGLE (ENCIRCLED)	REQUIRED SIDE OR ANGLE (ENCIRCLED)	FORMULAS	EXAMPLES
a, b 	$\tan A = \frac{a}{b}$	Side a = 6 in. b = 12.867 in. Find Angle A = $\frac{6}{12.867} = 0.4663$ $\tan 0.4663 = 250$	
a, b 	$\tan B = \frac{a}{b}$	Side a = 6 in. b = 12.867 in. Find Angle B = $\frac{12.867}{6} = 2.1445$ $\tan 2.1445 = 650$	
a, b 	$c = \sqrt{a^2 + b^2}$	Side a = 3 in. b = 4 in. Find side c = $\sqrt{3^2 + 4^2} = \sqrt{9 + 16} = \sqrt{25} = 5$ in.	
a, c 	$\sin A = \frac{a}{c}$	Side a = 6 in. c = 12 in. Find Angle A = $\frac{6}{12} = 0.500$ $\sin 0.500 = 300$	
a, c 	$\cos B = \frac{a}{c}$	Side a = 6 in. c = 12 in. Find Angle B = $\frac{6}{12} = 0.500$ $\cos 0.500 = 600$	
a, c 	$b = \sqrt{c^2 - a^2}$	Side a = 3 in. c = 5 in. Find side b = $\sqrt{5^2 - 3^2} = \sqrt{25 - 9} = \sqrt{16} = 4$ in.	
A, a 	$b = a \times \cot A$	Angle A = 250, side a = 6 in. Find side b = $6 \times \cot 250 = 6 \times 2.1445 = 12.867$ in.	
A, a 	$c = \frac{a}{\sin A}$	Angle A = 300, side a = 6 in. Find side c = $\frac{6}{\sin 300} = \frac{6}{0.500} = 12$ in.	
A, b 	$a = b \times \tan A$	Angle A = 250, side b = 12.867 in. Find side a = $12.867 \times \tan 250 = 12.867 \times 0.4663 = 6$ in.	
A, b 	$c = \frac{b}{\cos A}$	Angle A = 300, side b = 12 in. Find side c = $\frac{12}{\cos 300} = \frac{12}{0.866} = 13.856$ in.	
A, c 	$a = c \times \sin A$	Angle A = 300, side c = 12 in. Find side a = $12 \times \sin 300 = 12 \times 0.500 = 6$ in.	
A, c 	$b = c \times \cos A$	Angle A = 300, side c = 12 in. Find side b = $12 \times \cos 300 = 12 \times 0.866 = 10.392$ in.	

FRUSTUM OF ECCENTRIC CONE  
EXAMPLE

Given: Mean diameter at the large end,  $D = 36$  in.  
Mean diameter at the small end,  $D_1 = 24$  in.  
Height of frustum,  $H_1 = 24$  in.



1.  $\tan \alpha = \frac{D - D_1}{H_1} = \frac{36 - 24}{24} = 0.500 = 26^\circ - 34'$
2.  $H = \frac{D}{\tan \alpha} = \frac{36}{0.500} = 72$  in.,  $H_2 = H - H_1 = 72 - 24 = 48$  in.
3. Divide the base circle into 12 equal parts.
4. Draw chords  $C_1, C_2, C_3$ , etc. to the dividing points.
5. Calculate the length of the chords  $C_1, C_2, C_3$ , etc. using Factor, C from table "Segments of Circles for Radius = 1 on page 290."
6. Calculate the lengths of  $S_1, S_2$ , etc. and  $S_1^*, S_2^*$ , etc.

At The Bottom		At The Top	
Factor c times mean radius =	$\sqrt{H^2 + C^2} = S_{1,2} \dots$ ft.-in.	Factor c times mean radius =	$\sqrt{H_2^2 + C^2} = S_{1,2}^* \dots$ ft.-in.
Chords, $C_1, C_2, \dots$		Chords, $C_1, C_2$ , etc.	
300° $C_1 = 9.317'$	$S_1 = 6'-0 \frac{1}{2}''$	300° $C_1 = 6.212'$	$S_1^* = 4'-0 \frac{1}{2}''$
60° $C_2 = 18.000'$	$S_2 = 6'-2 \frac{3}{4}''$	60° $C_2 = 12.000'$	$S_2^* = 4'-1 \frac{1}{2}''$
90° $C_3 = 25.452'$	$S_3 = 6'-4 \frac{3}{8}''$	90° $C_3 = 16.968'$	$S_3^* = 4'-2 \frac{1}{8}''$
120° $C_4 = 31.176'$	$S_4 = 6'-6 \frac{7}{16}''$	120° $C_4 = 20.784'$	$S_4^* = 4'-4 \frac{1}{8}''$
150° $C_5 = 34.776'$	$S_5 = 6'-7 \frac{15}{16}''$	150° $C_5 = 23.184'$	$S_5^* = 4'-5 \frac{7}{8}''$
$S_6 = \sqrt{H^2 + D^2} = 6'-8 \frac{1}{2}''$		$S_6^* = \sqrt{H_2^2 + D_1^2} = 4'-5 \frac{11}{16}''$	



## OPTIMUM VESSEL SIZE\*

To build a vessel of a certain capacity with the minimum material, the correct ratio of length to diameter shall be determined.

The optimum ratio of length to the diameter can be found by the following procedure: (The pressure is limited to 1000 psi and ellipsoidal heads are assumed)

$$F = \frac{P}{CSE}, \text{ where}$$

$P$  = Design pressure, psi.

$C$  = Corrosion allowance, in.

$S$  = Stress value of material, psi.

$E$  = Joint efficiency

Enter chart on facing page at the left hand side at the desired capacity of the vessel. Move horizontally to the line representing the value of  $F$ . From the intersection move vertically and read the value of  $D$ .

The length of vessel =  $\frac{4V}{\pi D^2}$ , where  $V$  = Volume of vessel, cu. ft.  
 $D$  = Inside diameter of vessel, ft.

### EXAMPLE

Design Data:

$P = 100$  psi,  $V = 1,000$  cu. ft.,  $S = 16,000$  psi.,  $E = 0.80$ ,  $C = 0.0625$  in.

Find the optimum diameter and length

$$F = \frac{100}{0.0625 \times 16,000 \times 0.8} = 0.125 \text{ in.}^{-1}$$

From chart  $D = 5.6$  ft., say 5 ft. 6 in.

$$\text{Length} = \frac{4 \times 1,000}{3.14 \times 5.5^2} = 42.1, \text{ say } 42 \text{ ft. } 1 \text{ in.}$$

\*FROM:

"Nomographs Gives Optimum Vessel Size," by K. Abakians, Originally published in HYDRO-CARBON PROCESSING, Copyrighted Gulf Publishing Company, Houston. Used with permission.

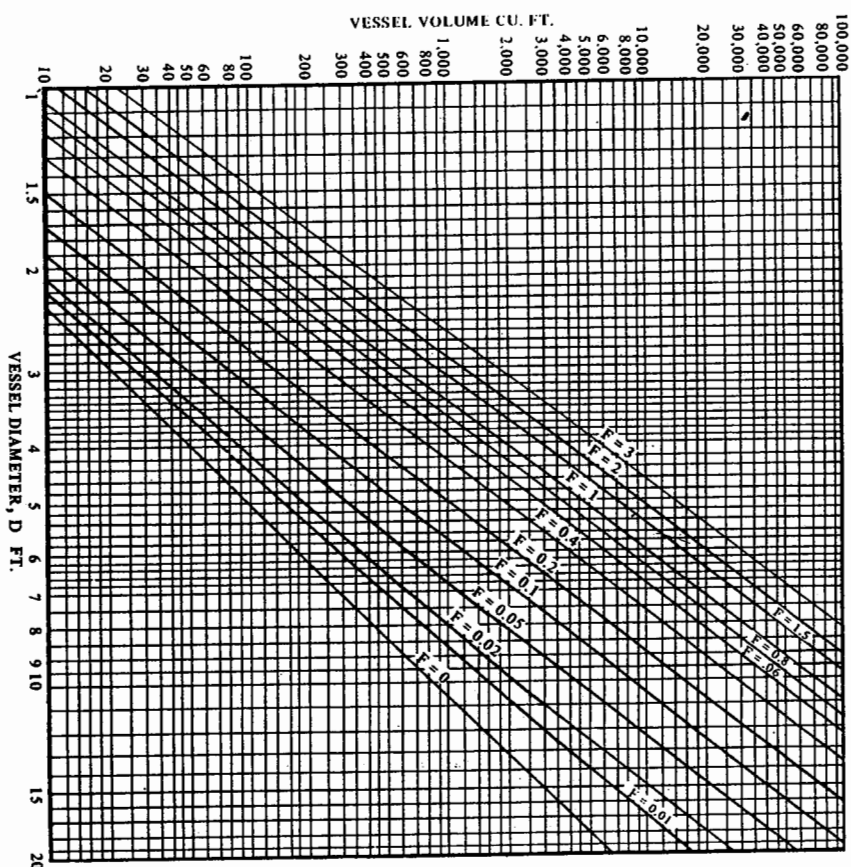


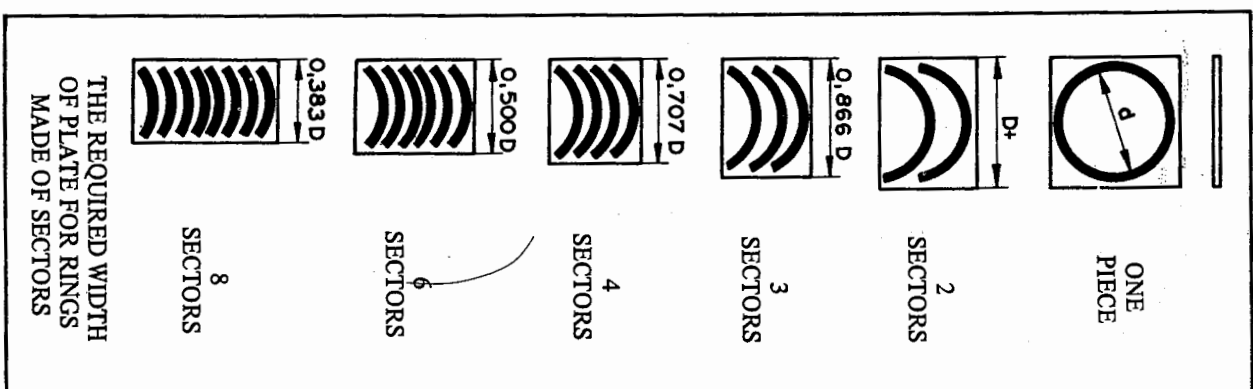
CHART FOR DETERMINING THE OPTIMUM VESSEL SIZE

(See facing page for explanation)

LAYOUT



## FLAT RINGS MADE OF SECTORS



Making flat rings for base, stiffeners etc., by dividing the ring into a number of sectors, less plate will be required.

Since the sectors shall be welded to each other, the welding will be increased by increasing the number of sectors.

The cost of the welding must be balanced against the saving in plate cost.

The chart on facing page shows the total plate area required when a ring is to be divided into sectors. This area is expressed as a percentage of the square that is needed to cut out the ring in one piece. The figures at the left of this page show the width of the required plate using different number of sectors.

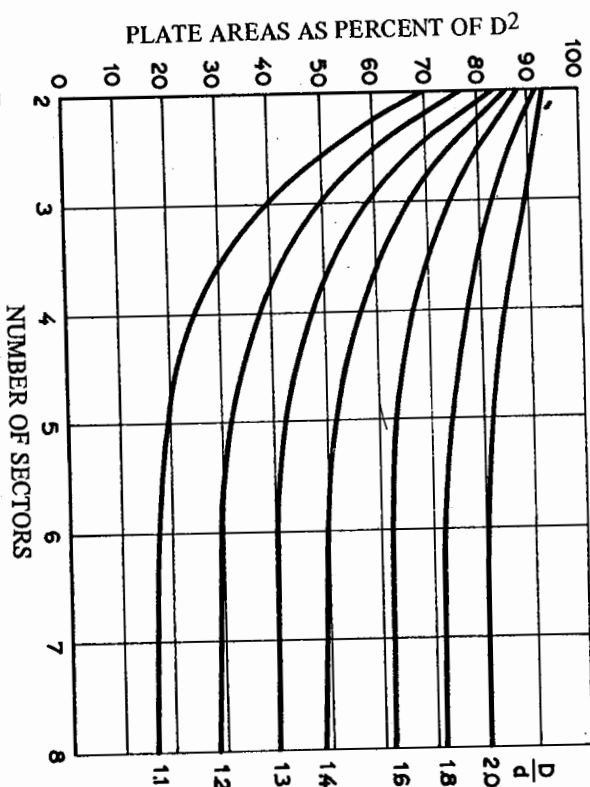
$D$  = Outside diameter of ring.  
 $d$  = Inside diameter of ring.

## DETERMINATION OF THE REQUIRED PLATE SIZE

1. Determine  $D/d$  and  $D^2$  (the area of square plate would be required for the ring made of one piece)
2. Read from chart (facing page) the percentage of the required area when the ring divided into the desired number of sectors
3. Determine the required area of plate
4. Divide the area by the required width of plate as shown at the left of this page to obtain the length of the plate.
5. Add allowance (max. 1 inch) for flame cutting between sectors and at the edges of the plate

See Example On Facing Page.

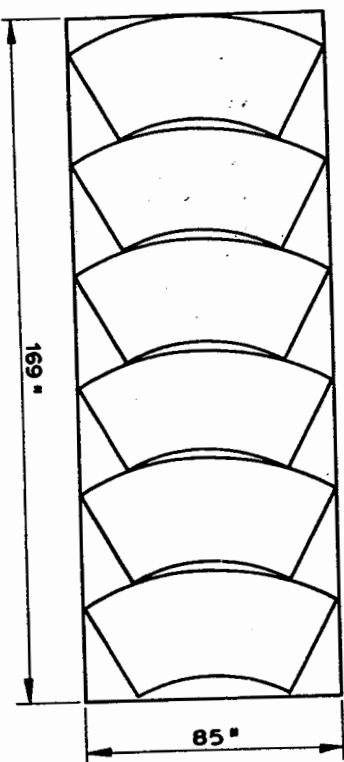
## FLAT RINGS MADE OF SECTORS (cont.)



## EXAMPLE

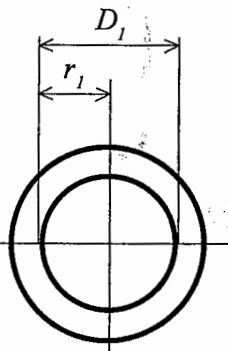
Determine the required plate size for a 168 in. O.D., 120 in. I.D. ring made of 6 sectors

1.  $D/d = 1.4$ ;  $D^2 = 28,224$  sq. in.
2. From chart (above) the required area of plate is 50% of the area that would be required for the ring made of one piece.
3. Area required  $28,224 \times 0.50 = 14,112$  sq. in.
4. Divide this area by the required width of plate (facing page). Width =  $0.5 \times 168 = 84$  14,112/84 = 167.9 inches, the length of plate.
5. Add allowance for flame cut.

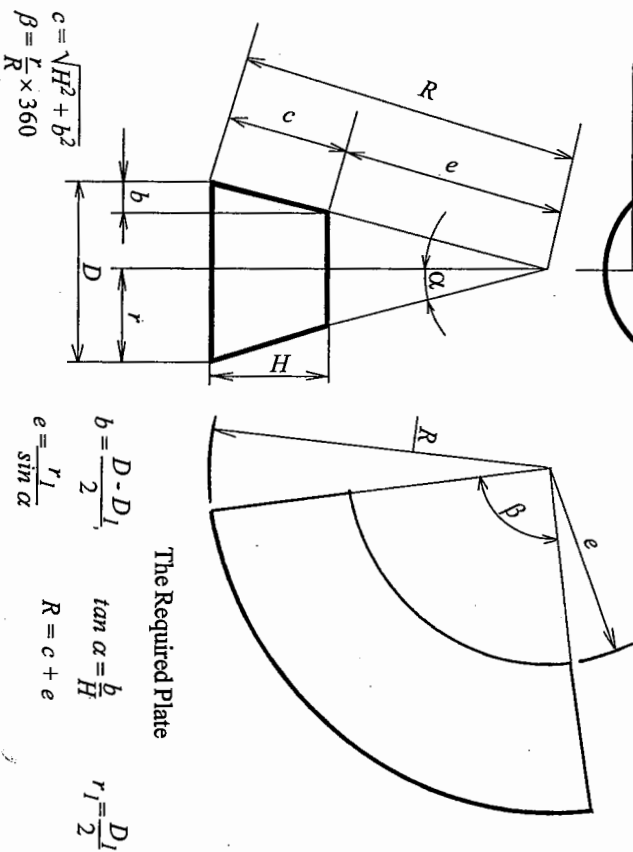




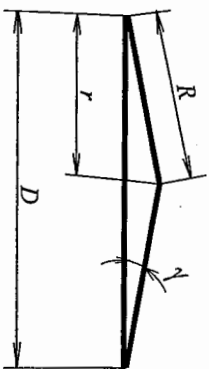
## FRUSTUM OF CONCENTRIC CONE



Given:  
 $D$  = Mean diameter at the large end.  
 $D_1$  = Mean diameter at the small end.  
 $H$  = Height of the frustum.  
 Determine the Required Plate.

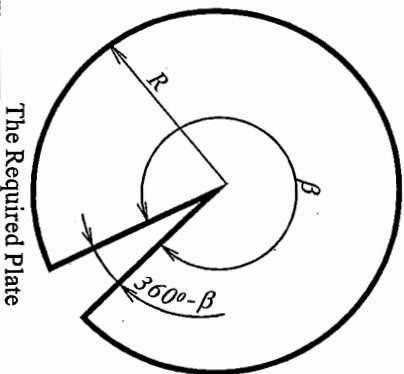


## CONICAL TANK ROOF



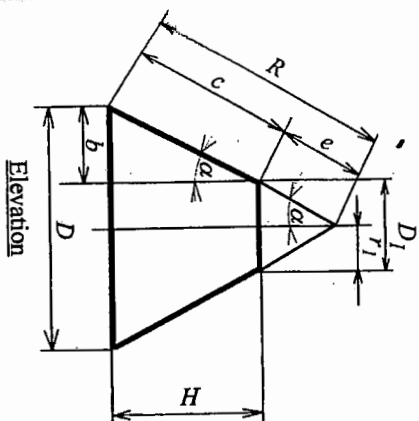
$$R = \frac{r}{\cos \gamma}$$

$$\beta = \frac{L}{R} \times 360$$



## FRUSTUM OF CONCENTRIC CONE

Made from two or more Plates



Given:  
 $D$  = Mean diameter at the large end.  
 $D_1$  = Mean diameter at the small end.  
 $H$  = Height of the frustum  
 $n$  = Number of plates (sector)

Determine the Required Plate

$$b = \frac{D - D_1}{2}$$

$$\tan \alpha = \frac{b}{H}$$

$$c = \sqrt{b^2 + H^2}$$

$$r_1 = D_1 / 2$$

$$e = \frac{r_1}{\sin \alpha}$$

$$R = c + e$$

$$\gamma = \frac{D \times \pi \times 57.296}{2 R n}$$

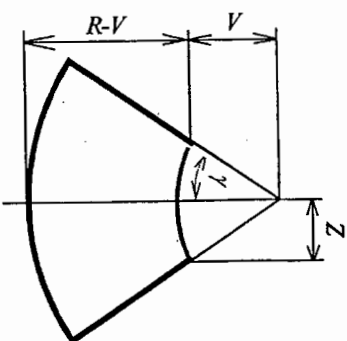
$$X = R \times \sin \gamma + \frac{1}{2}''$$

$$Y = R \times \sin \gamma + 1''$$

$$Z = e \times \sin \gamma$$

$$V = e \times \cos \gamma$$

## One Sector of Plate



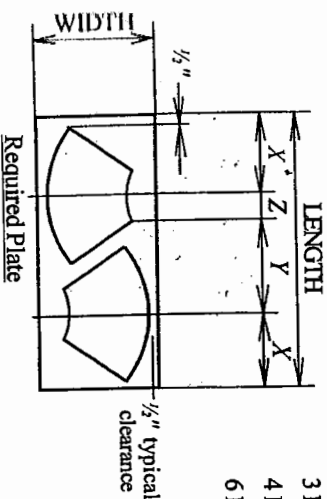
Width of the Required Plate =  $R - V + 1''$   
 Length of the Required Plate if the Frustum made from:

2 Plates:  $2X + Y + Z$

3 Plates:  $2X + 2Y + 2Z$

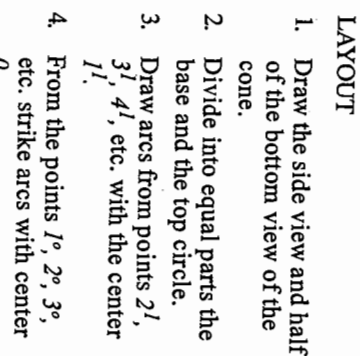
4 Plates:  $2X + 3Y + 3Z$

6 Plates:  $2X + 5Y + 5Z$



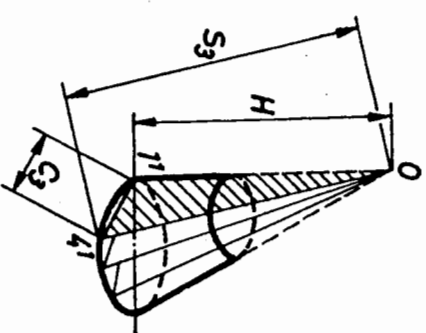


### Determination of the Required Plate by Layout and by Calculation



4. From the points  $1^\circ$ ,  $2^\circ$ ,  $3^\circ$ , etc. strike arcs with center  $O$ .
5. Starting from a point on arc  $1^\circ$ , (marked  $I$ ) measure the spacing of the bottom circle of the cone and intersect arc  $2^\circ$ . From the point marked 2 measure again one space intersecting arc  $3^\circ$ , etc. The points or intersections are points on the curvature of the plate at the bottom of the cone.
6. To determine the curvature of the plate at the top of the cone, repeat steps 4 and 5, but measure on the arcs drawn with center  $O$  the spaces of the top circle.

Fig. A



**Fig. B**

## CALCULATION

To find the curvature of the plate by calculation, the dimensions  $l^1 - 2^1$ ,  $l^1 - 3^1$ , etc. and  $0 - l^1$ ,  $0 - 2^1$ , etc. shall be determined.

Fig. B shows as an example the calculation of  $0.4I$  only (marked  $S_i$ ).

If the bottom circle is divided into 12 equal spaces,

$$C_3 = 2R \times \sin 45^\circ$$

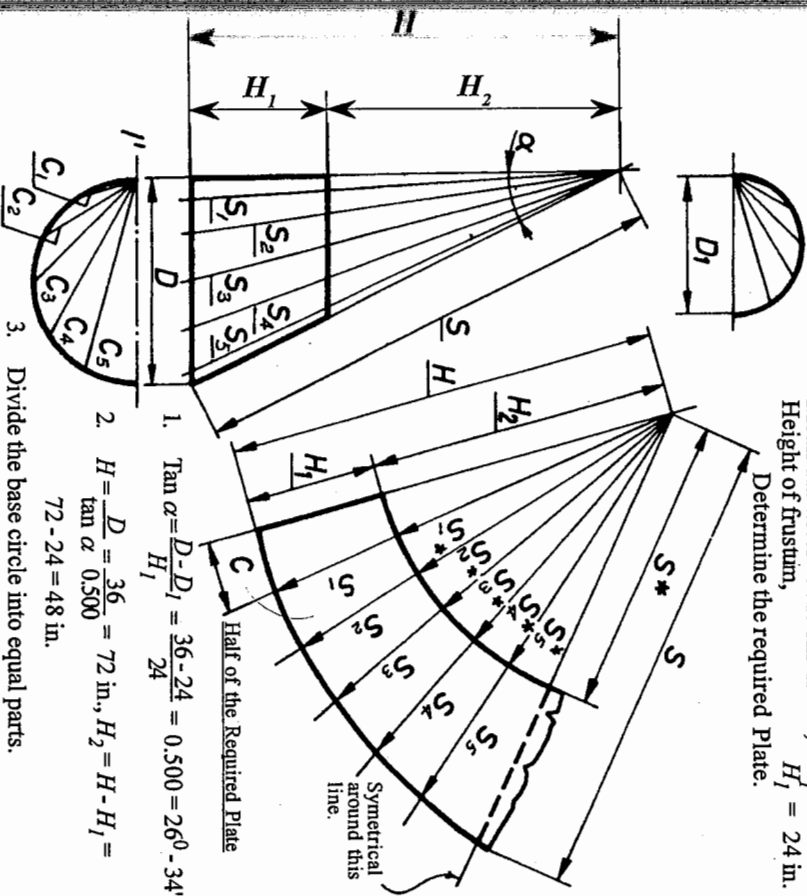
$$S_3 = \sqrt{H^2 + C_3^2}$$

Where  $R$  denotes the mean radius of the base circle. See example on the following page.

### EXAMPLE

Given: Mean diameter at the large end,  $D = 36$  in.  
Mean diameter at the small end,  $D_f = 24$  in.  
Height of frustum,  $H_f = 24$  in.

Determine the required Plate.



4. Draw chords  $C_1, C_2, C_3$ , etc. to the dividing points
5. Calculate the length of the chords  $C_1, C_2, C_3$ , etc. using Factor  $C$  from table "Segments of Circles for Radius = 1" on page 290.
6. Calculate the lengths of  $S_1, S_2$ , etc. and  $S_1^*, S_2^*$ , etc.

At The Bottom		At The Top	
Factor $c$ times mean radius =	$\sqrt{H^2 + C_1^2} = S_{t, 2} \dots$ ft. in.	Factor $c$ times mean radius =	$\sqrt{H_3^2 + C_1^2} = S_{t, 1, 2} \dots$ ft. in.
Chords, $C_1, C_2 \dots$ in.		Chords, $C_1, C_2$ etc. in.	
$C_1 = 9.137"$	$S_1 = 6' - 0.5/8$	$C_1 = 6.212"$	$S_1^* = 4' - 0.3/8$
$C_2 = 18.000"$	$S_2 = 6' - 2.3/6$	$C_2 = 12.000"$	$S_2^* = 4' - 1.1/2$
$C_3 = 25.452"$	$S_3 = 6' - 4.3/8$	$C_3 = 16.968"$	$S_3^* = 4' - 2.15/6$
$C_4 = 31.176"$	$S_4 = 6' - 6.7/6$	$C_4 = 20.784"$	$S_4^* = 4' - 4.5/6$
$C_5 = 34.776"$	$S_5 = 6' - 7.15/6$	$C_5 = 23.184"$	$S_5^* = 4' - 5.5/6$
$S_6 = \sqrt{H^2 + D^2} = 6' - 8.1/4$		$S_6^* = \sqrt{H_3^2 + D_1^2} = 4' - 5.11/6$	



## BENT AND MITERED PIPE



The length of a pipe bent to any shape is equal to the length measured on the centerline of pipe. Example: (The pipe bent as shown)

Given:  $R = 8$  in.,  $R_1 = 6$  in.,  $\alpha = 72^\circ$ ,  $\beta = 36^\circ$ ,  $l = 2$  in.

Find the length of pipe,  $L$ .

$$L = R \pi \times \frac{\alpha}{180} + R_1 \pi \frac{\beta}{180} + l$$

$$= 8 \times 3.14 \times \frac{72}{180} + 6 \times 3.14 \times \frac{36}{180} + 2$$

$$= 25.13 \times 0.40 + 18.85 \times 0.20 + 2 = 15.82 \text{ in.}$$

## The Required Length of Pipe for Coil

$$L = \sqrt{(n \times D \times \pi)^2 + H^2} \text{ Where}$$

$n$  = Number of turns

$L$  = Length of required pipe

EXAMPLE

Given:  $D = 10$  in.,  $H = 24$  in.,  $n = 12$

$$L = \sqrt{(12 \times 10 \times 3.14)^2 + 24^2} = 378 \text{ in.}$$

## The Required Length of Pipe for Coil

$$L = \frac{r^2 \pi}{d + c} \text{ Where}$$

$c$  = Clearance between turns of pipe.

(Approximation)  $d$  = Outside diameter of pipe.

$L$  = Required length of pipe.

EXAMPLE

Given:  $r = 10$  in.,  $d = 2.375$  in.,  $c = 1$  in.

$$L = \frac{10^2 \times 3.14}{2.375 + 1} = 93.08 \text{ in.}$$

## Mitered Elbow

To find the angle of cut for any elbow, divide the total number of degrees of the elbow by twice the number of cuts.

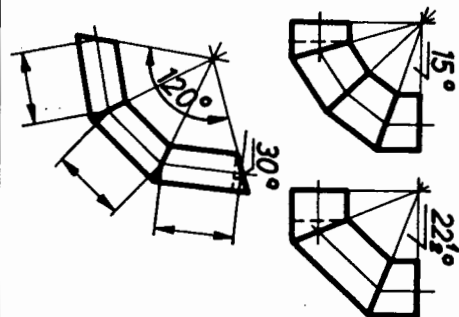
EXAMPLES

3 cuts  $\times 2 = 6$        $90^\circ : 6 = 15^\circ$

2 cuts  $\times 2 = 4$        $90^\circ : 4 = 22\frac{1}{2}^\circ$

2 cuts  $\times 2 = 4$        $120^\circ : 4 = 30^\circ$

The length of pipe required to form any shapes by mitering is the sum of the centerline lengths of the pipe sections.



## INTERSECTION OF CYLINDER &amp; PLANE

When the intersecting plane is not perpendicular to the axis of the cylinder, the intersection is an ellipse.

## CONSTRUCTION OF THE INTERSECTING ELLIPSE

Divide the circumference of the cylinder into equal parts and draw an element at each division point. The major axis of the ellipse is the longest distance between the intersecting points and the minor axis is the diameter of the cylinder. The points of the ellipse can be determined by using the chords of the cylinder spaced by projection as shown or by calculations as exemplified below. With this method may be laid out sloping trays, baffles, down-comers etc. The thickness of the plate and the required clearance shall also be taken into consideration.

## DEVELOPMENT

The length,  $H$  is equal to the circumference of the cylinder. Divide this line into the same number of equal parts as the circumference of the cylinder. Draw an element through each division perpendicular to this line. Determine the length of each element as shown or by calculation. By connecting the end points of the elements can be obtained the stretched-out line of the intersection and may be used for cutting out pattern for pipe mitering, etc.

## EXAMPLE

for calculation of length of elements.

The circumference of the cylinder is divided into 16 equal parts.

The angle of a section =  $22\frac{1}{2}$  degrees.

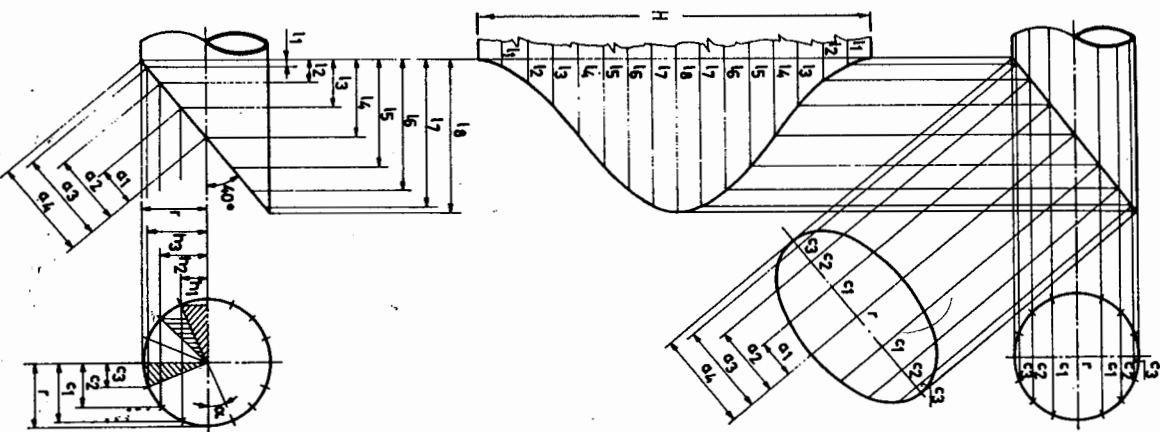
The angle of the intersecting plane to the axis of the cylinder = 40 degrees.

$$c_1 = r \times \cos 22\frac{1}{2}^\circ$$

$$c_2 = r \times \cos 45^\circ$$

$$c_3 = r \times \sin 22\frac{1}{2}^\circ$$

$$a_1 = \frac{h_1}{\sin 40^\circ} \quad a_2 = \frac{h_2}{\sin 40^\circ} \text{ etc.}$$



$$h_1 = \sqrt{r^2 - c_1^2} \quad h_2 = \sqrt{r^2 - c_2^2} \text{ etc.}$$

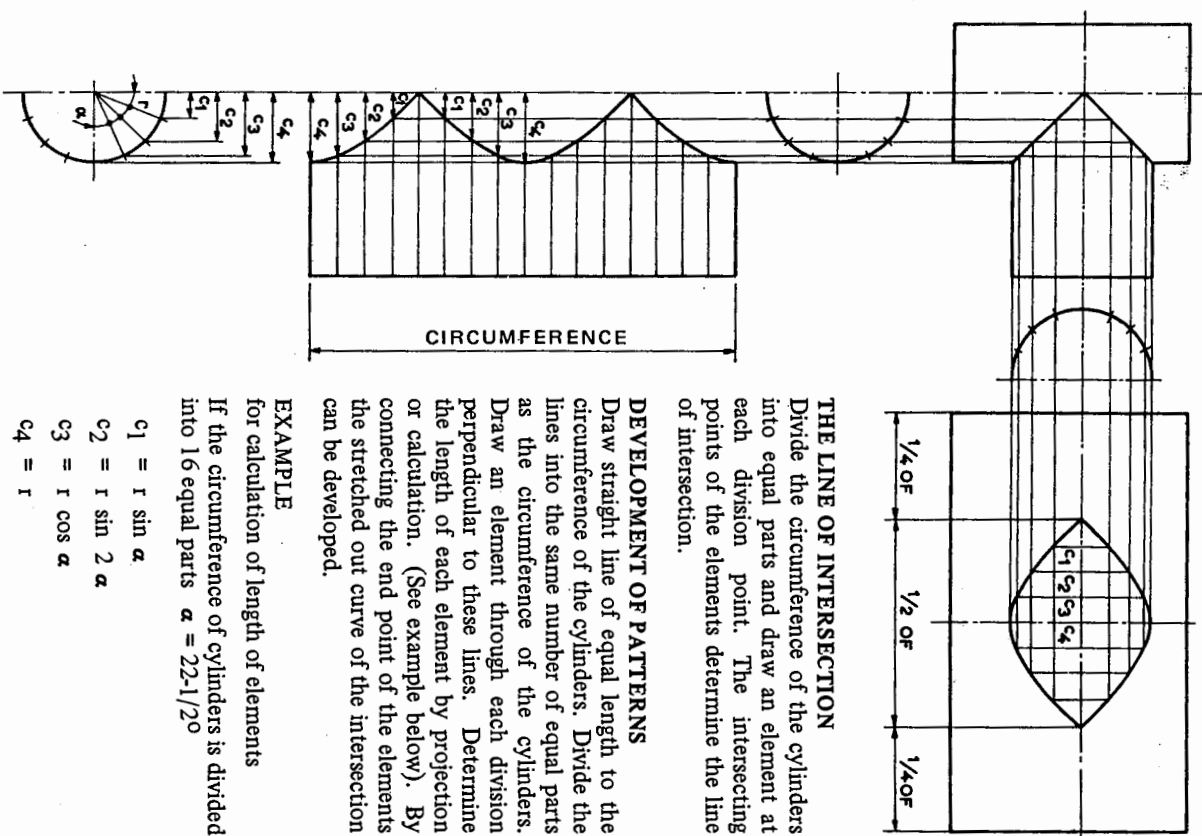
$$l_1 = (a_4 - a_3) \cos 40^\circ$$

$$l_2 = (a_4 - a_2) \cos 40^\circ \text{ etc.}$$



## INTERSECTION OF CYLINDERS

of equal diameters with angle of intersection  $90^\circ$



### THE LINE OF INTERSECTION

Divide the circumference of the cylinders into equal parts and draw an element at each division point. The intersecting points of the elements determine the line of intersection.

### DEVELOPMENT OF PATTERNS

Draw a straight line of equal length to the circumference of the cylinders. Divide the lines into the same number of equal parts as the circumference of the cylinders. Draw an element through each division perpendicular to these lines. Determine the length of each element by projection or calculation. (See example below). By connecting the end point of the elements the stretched out curve of the intersection can be developed.

### EXAMPLE

for calculation of length of elements

If the circumference of cylinders is divided into 16 equal parts  $\alpha = 22.5^\circ$

$$c_1 = r \sin \alpha$$

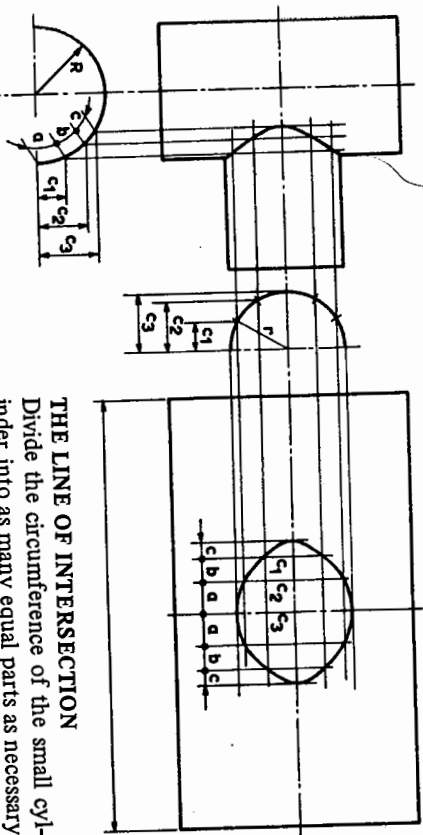
$$c_2 = r \sin 2\alpha$$

$$c_3 = r \cos \alpha$$

$$c_4 = r$$

## INTERSECTION OF CYLINDERS

of unequal diameters with angle of intersection  $90^\circ$



### THE LINE OF INTERSECTION

Divide the circumference of the small cylinder into as many equal parts as necessary for the desired accuracy. Draw an element at each division point. Project distances at  $c_1, c_2$  etc. to the circumference of the larger cylinder and draw elements at each point. The intersecting points of the elements of the large and small cylinder determine the curve of intersection.

### DEVELOPMENT OF PATTERNS

Draw a straight line of equal length to the circumference of the cylinders. Divide the line for the small cylinder into the same number of equal parts as the circumference of the small cylinder. Draw an element through each division perpendicular to the line. Determine the length of the elements by projection or calculation. (See example below). By connecting the end point of the elements the stretched out curve of the intersection can be developed.

The curvature of the hole in the large cylinder is determined by the length of elements  $c_1, c_2$  etc. spacing them at distances  $a, b, c$  etc., which are the length of arcs on the partial view of the large cylinder.

der.

### EXAMPLE

for calculation of length of elements.

Dividing the circumference of the cylinder into 12 equal parts,  $\alpha = 30^\circ$

$$c_1 = r \sin 30^\circ \quad c_2 = r \cos 30^\circ \quad c_3 = r$$

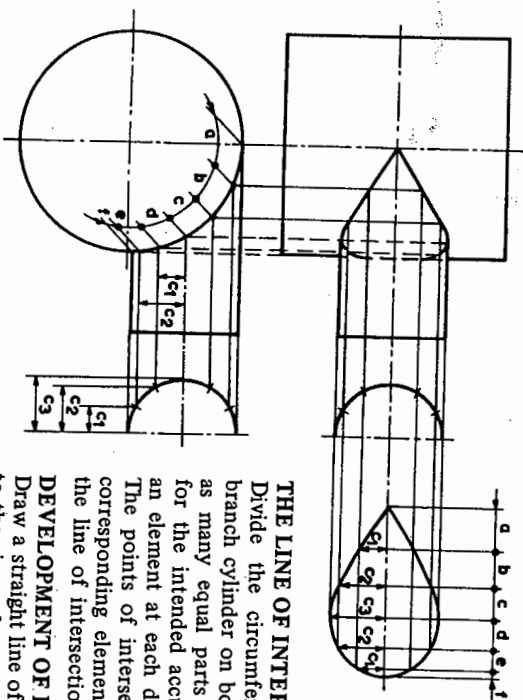
$$l_1 = \sqrt{R^2 - c_1^2} \quad l_3 = \sqrt{R^2 - c_3^2}$$

$$l_2 = \sqrt{R^2 - c_2^2} \quad l_4 = R$$



## INTERSECTION OF CYLINDERS

with non intersecting axes



### THE LINE OF INTERSECTION

Divide the circumference of the branch cylinder on both views into as many equal parts as necessary for the intended accuracy. Draw an element at each division point. The points of intersection of the corresponding elements determine the line of intersection.

### DEVELOPMENT OF PATTERN

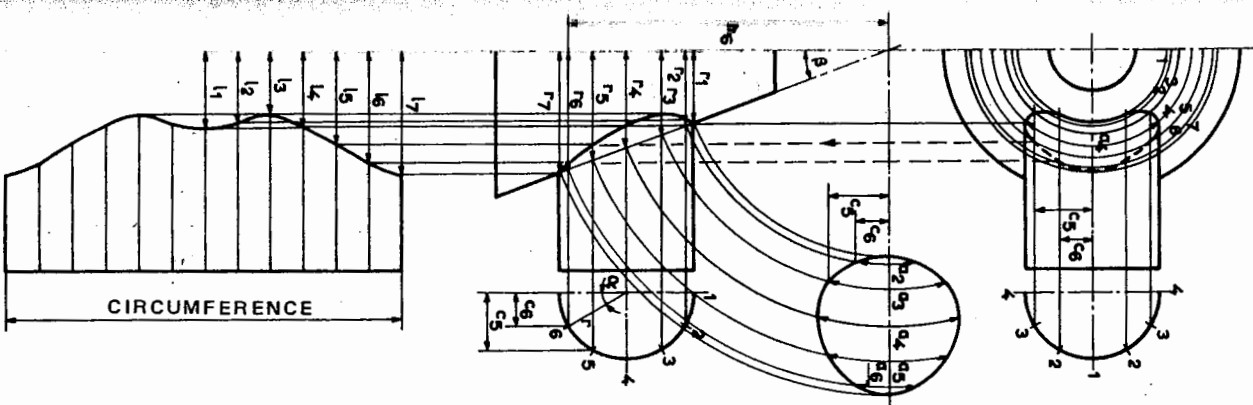
Draw a straight line of equal length to the circumference of the branch cylinder and divide it into the same number of equal parts as the circumference. Draw an element through each division perpendicular to the line. Determine the length of the elements by projection or calculation. (See example below). By connecting the end point of the elements the stretched out curve of the intersection can be developed.

The curvature of the hole in the main cylinder is determined by the length of elements  $c_1, c_2$  etc. spacing them at distances  $a, b, c$ , etc., which are the length of arcs on the main cylinder (see elevation).

### EXAMPLE

for calculation of length of elements  
Dividing the circumference of the cylinder into 12 equal parts,  $\alpha = 30^\circ$

$$\begin{aligned} c_1 &= r \sin 30^\circ & l_1 &= \sqrt{R^2 - (r + c_2)^2} \\ c_2 &= r \cos 30^\circ & l_2 &= \sqrt{R^2 - (r + c_1)^2} \\ c_3 &= r & l_3 &= \sqrt{R^2 - r^2} \\ & & l_4 &= \sqrt{R^2 - (r - c_1)^2} \\ & & l_5 &= \sqrt{R^2 - (r - c_2)^2} \\ l_6 &= R \end{aligned}$$



## INTERSECTION OF CONE AND CYLINDER

### THE LINE OF INTERSECTION

Divide the circumference of the cylinder on both views into as many equal parts as necessary for the desired accuracy. Draw an element at each division point. Draw circles on plan view with radius  $r_1, r_2$ , etc. The line of intersection on the plan is determined by the points of intersections of elements and the corresponding circles. Project these points to the elevation. The intersecting points of the projectors and elements will determine the line of intersection on the elevation. The stretched out curvature of the hole in the cone is to be determined by the length of arcs  $a_2, a_3$ , etc. transferred from the plan view or calculated as exemplified below. The spacing of arcs  $a_2, a_3$ , etc. may be obtained as shown or may be calculated. (See example below).

### DEVELOPMENT OF PATTERN

Draw a straight line of length equal to the circumference of the cylinder and divide it into the same number of equal parts as the circumference. Draw an element through each division point perpendicular to the line. Determine the length of the elements by projection or by calculating the length of  $l_1, l_2$ , etc. (See example below).

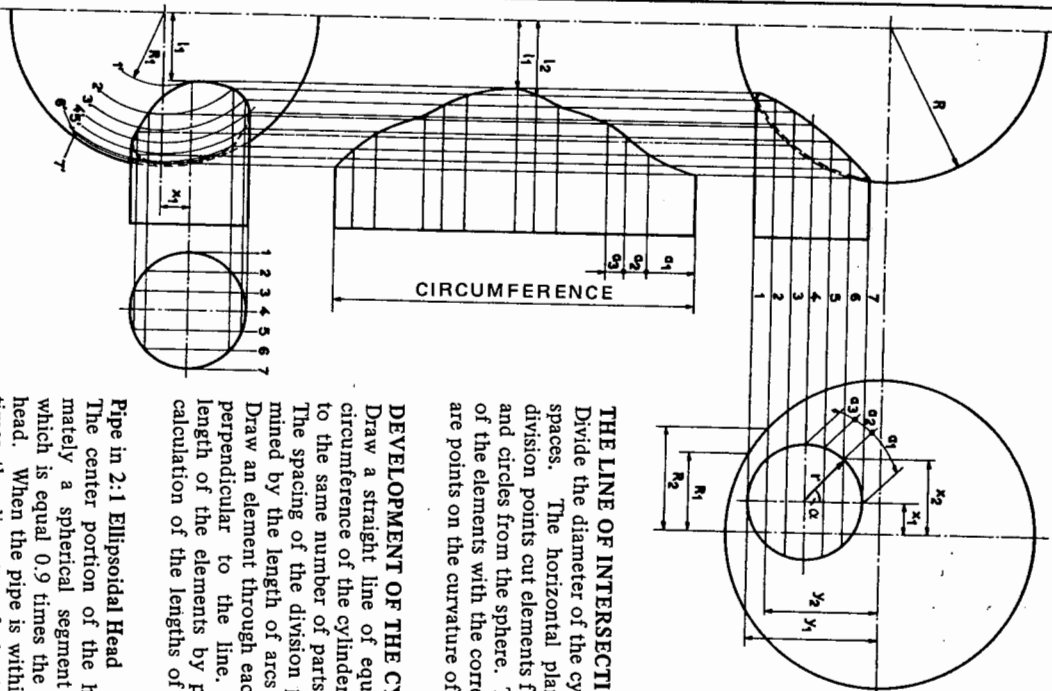
### EXAMPLE

for calculation of length of elements

$$\begin{aligned} c_6 &= r \sin \alpha \\ \text{radius, } R_6 &= h_6 \tan \alpha \\ \text{arc } a_6 &= 2R_6 \pi \times \frac{2\alpha}{360} \\ l_6 &= \sqrt{R_6^2 - c_6^2} \quad \text{etc.} \end{aligned}$$



## INTERSECTION OF CYLINDER AND SPHERE



### THE LINE OF INTERSECTION

Divide the diameter of the cylinder into equal spaces. The horizontal planes through the division points cut elements from the cylinder and circles from the sphere. The intersections of the elements with the corresponding circles are points on the curvature of intersection.

### DEVELOPMENT OF THE CYLINDER

Draw a straight line of equal length to the circumference of the cylinder and divide it into the same number of parts as the cylinder. The spacing of the division points are determined by the length of arcs of the cylinder. Draw an element through each division point perpendicular to the line. Determine the length of the elements by projection or by calculation of the lengths of  $l_1, l_2$ , etc.

### Pipe in 2:1 Ellipsoidal Head

The center portion of the head is approximately a spherical segment the radius of which is equal 0.9 times the diameter of the head. When the pipe is within a limit of 0.8 times the diameter of the head the line of intersection and development of the cylinder can be found in the above described manner.

### Pipe in Flanged and Dished Head

Similar way the center portion of the head within the knuckles is a spherical segment the radius of which is equal to the radius of the dish.

EXAMPLE  
for calculation of length of elements,  
Calculate the distances,  $x_1, x_2$ , etc.  
 $x_1$  is given;  $x_2 = x_1 + r \sin \alpha$ , etc.,  
 $l_1 = \sqrt{R_1^2 - x_1^2}$ , etc.,  
 $R_1 = \sqrt{R^2 - y_1^2}$ , etc.

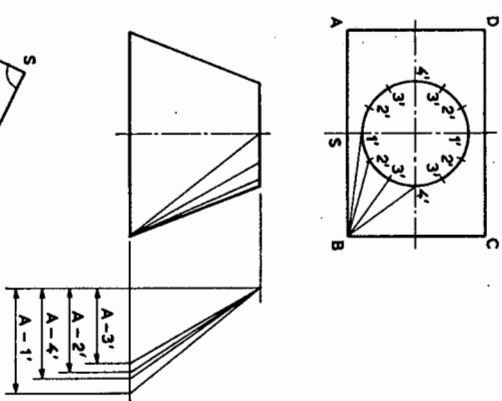
## TRANSITION PIECES

connecting cylindrical and rectangular shapes

### DEVELOPMENT

Divide the circle into equal parts and draw an element at each division point.

Find the length of each element by triangulation or by calculation. The elements are the hypotenuse of the triangles one side of which is  $A-1', A-2', A-3'$  etc. and the other side is the height of the transition piece.



Begin the development on the line 1-S and draw the right triangle 1-S-A, whose base SA is equal to half the side AD and whose hypotenuse A-1' found by triangulation or calculation. Find the points 1, 2, 3 etc. The length of 1-2, 2-3, 3-4 etc. may be taken equal to the cord of the divisions of the top circle if they are small enough for the desired accuracy. Strike an arc with 1 as center and the chord of divisions as radius. With A as center and A-2' as radius draw arc at 2. The intersection of these arcs give the point 2. The points 3, 4 etc. in the curve can be found in a similar manner.

### EXAMPLE

for calculation of length of elements

$$c = r \times \cos \alpha \quad d = r \times \sin \alpha$$

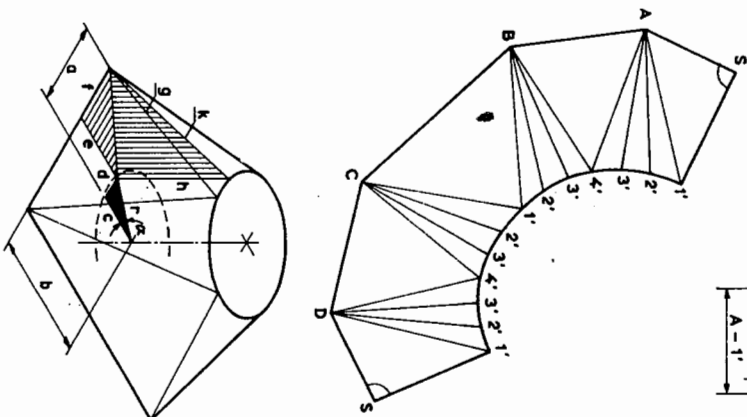
$$e = b - c \quad f = a - d$$

$$g = \sqrt{f^2 + e^2} \quad k = \sqrt{g^2 + h^2}$$

### LENGTH OF ELEMENTS

In the above described manner can be found the development for transition pieces when:

1. one end is square
2. one or both sides of the rectangle are equal to the diameter of the circle
3. the circular and rectangular planes are eccentric
4. the circular and rectangular planes are not parallel





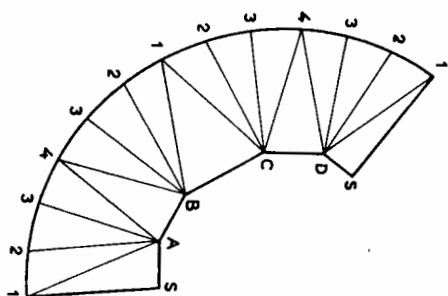
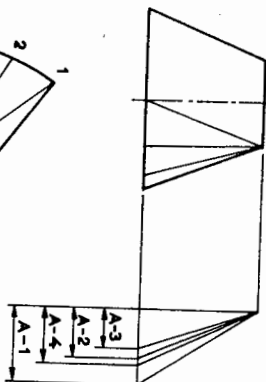
## TRANSITION PIECES

connecting cylindrical and rectangular shapes

### DEVELOPMENT

Divide the circle into equal parts and draw an element at each division point.

Find the length of each element by triangulation or by calculation. The elements are the hypotenuse of the triangles one side of which is A-1', A-2', A-3' etc. and the other side is the height of the transition piece.



Begin the development on the line 1-S and draw the right triangle 1-S-A, whose base SA is equal to half the side AD and whose hypotenuse A-1' is found by triangulation or calculation. Find the points 1, 2, 3 etc. The length of 1-2, 2-3, 3-4 etc. may be taken equal to the cord of the divisions of the top circle if they are small enough for the desired accuracy. Strike an arc with 1 as center and the chord of divisions as radius. With A as center and A-2' as radius draw arc at 2. The intersection of these arcs give the point 2. The points 3, 4 etc. in the curve can be found in a similar manner.

### EXAMPLE

for calculation of length of elements

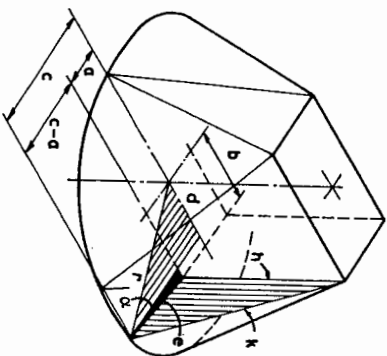
$$c = r \times \cos \alpha \quad d = r \times \sin \alpha$$

$$e = \sqrt{(b-d)^2 + (c-a)^2}$$

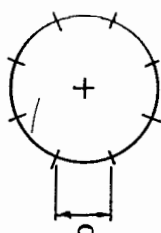
$$k = \sqrt{e^2 + h^2}$$

In the above described manner can be found the development for transition pieces when:

1. one end is square
2. one or both sides of the rectangle are equal to the diameter of the circle
3. the circular and rectangular planes are eccentric
4. the circular and rectangular planes are not parallel



## DIVISION OF CIRCLES INTO EQUAL PARTS



The best method for division of a circle into equal parts is to find the length of the chord of a part and measure this length with the divider on the circumference. The length of the chord, C = diameter of circle  $\times$  c, where c is a factor tabulated below.

### EXAMPLE:

It is required to divide a 20 inch diameter circle into 8 equal spaces.

For 8 spaces from the table: 0.38268

$$C = \text{Diameter} \times 0.38268 = 20 \times 0.38268 = 7.6536 \text{ inches}$$

To find the length of chords for any desired number of spaces not shown in the table:

$$C = \text{Diameter} \times \sin \frac{180}{\text{number of spaces}}$$

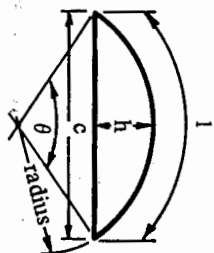
### EXAMPLE:

It is required to divide a 100 inch diameter circle into 120 equal parts

$$C = 100 \times \sin \frac{180}{120} = 100 \times \sin 1^\circ 30' = 100 \times 0.0262 = 2.62 \text{ inches}$$

No. of Spaces	C	No. of Spaces	C	No. of Spaces	C	No. of Spaces	C
1	0.00000	26	0.12054	51	0.06153	76	0.04132
2	1.00000	27	0.11609	52	0.06038	77	0.04079
3	0.86603	28	0.11196	53	0.05924	78	0.04027
4	0.70711	29	0.10812	54	0.05814	79	0.03976
5	0.58779	30	0.10453	55	0.05709	80	0.03926
6	0.50000	31	0.10117	56	0.05607	81	0.03878
7	0.43388	32	0.09802	57	0.05509	82	0.03830
8	0.38268	33	0.09506	58	0.05414	83	0.03784
9	0.34202	34	0.09227	59	0.05322	84	0.03739
10	0.30902	35	0.08964	60	0.05234	85	0.03695
11	0.28173	36	0.08716	61	0.05148	86	0.03652
12	0.25882	37	0.08481	62	0.05065	87	0.03610
13	0.23932	38	0.08258	63	0.04985	88	0.03569
14	0.22252	39	0.08047	64	0.04907	89	0.03529
15	0.20791	40	0.07846	65	0.04831	90	0.03490
16	0.19509	41	0.07655	66	0.04758	91	0.03452
17	0.18375	42	0.07473	67	0.04687	92	0.03414
18	0.17365	43	0.07300	68	0.04618	93	0.03377
19	0.16460	44	0.07134	69	0.04551	94	0.03341
20	0.15643	45	0.06976	70	0.04487	95	0.03306
21	0.14904	46	0.06824	71	0.04423	96	0.03272
22	0.14232	47	0.06679	72	0.04362	97	0.03238
23	0.13617	48	0.06540	73	0.04302	98	0.03205
24	0.13053	49	0.06407	74	0.04244	99	0.03173
25	0.12533	50	0.06279	75	0.04188	100	0.03141

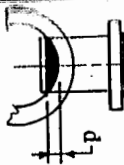




### SEGMENTS OF CIRCLES FOR RADIUS = 1

Length of arc, height of segment, length of chord, and area of segment for angles from 1 to 180 degrees and radius = 1. For other radii, multiply the values of  $l$ ,  $h$  and  $c$  in the table by the given radius  $r$ , and the values for areas, by  $r^2$ , the square of the radius.

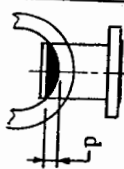
$\theta$ Deg	$l$	$h$	$c$	Area of Seg- ment A	$\theta$ Deg	$l$	$h$	$c$	Area of Seg- ment A
1	0.017	0.0000	0.017	0.0000	61	1.065	0.1384	1.015	0.9095
2	0.034	0.0001	0.034	0.0000	62	1.082	0.1428	1.030	0.9095
3	0.052	0.0003	0.052	0.0000	63	1.100	0.1474	1.045	0.9095
4	0.069	0.0006	0.069	0.0000	64	1.117	0.1520	1.060	0.9095
5	0.087	0.0009	0.087	0.0000	65	1.134	0.1566	1.075	0.9095
6	0.104	0.0013	0.104	0.0001	66	1.152	0.1613	1.089	0.9095
7	0.122	0.0018	0.122	0.0001	67	1.169	0.1661	1.104	0.9095
8	0.139	0.0024	0.139	0.0002	68	1.187	0.1710	1.118	0.9095
9	0.157	0.0030	0.156	0.0003	69	1.204	0.1759	1.133	0.9095
10	0.174	0.0038	0.174	0.0004	70	1.222	0.1808	1.147	0.9095
11	0.191	0.0046	0.191	0.0005	71	1.239	0.1859	1.161	0.9095
12	0.209	0.0054	0.209	0.0007	72	1.257	0.1910	1.176	0.9095
13	0.226	0.0064	0.226	0.0009	73	1.274	0.1961	1.190	0.9095
14	0.244	0.0074	0.243	0.0012	74	1.291	0.2014	1.204	0.9095
15	0.261	0.0085	0.261	0.0014	75	1.309	0.2066	1.217	0.9095
16	0.279	0.0097	0.278	0.0018	76	1.326	0.2120	1.231	0.9095
17	0.296	0.0113	0.295	0.0021	77	1.344	0.2174	1.245	0.9095
18	0.314	0.0123	0.312	0.0025	78	1.361	0.2229	1.259	0.9095
19	0.331	0.0137	0.330	0.0030	79	1.379	0.2284	1.272	0.9095
20	0.349	0.0151	0.347	0.0035	80	1.396	0.2336	1.286	0.9095
21	0.366	0.0167	0.364	0.0040	81	1.414	0.2390	1.299	0.9095
22	0.383	0.0183	0.381	0.0046	82	1.431	0.2443	1.312	0.9095
23	0.401	0.0200	0.398	0.0053	83	1.449	0.2500	1.325	0.9095
24	0.418	0.0217	0.415	0.0060	84	1.466	0.2559	1.338	0.9095
25	0.436	0.0237	0.432	0.0068	85	1.483	0.2627	1.351	0.9095
26	0.453	0.0256	0.449	0.0077	86	1.501	0.2696	1.364	0.9095
27	0.471	0.0276	0.466	0.0086	87	1.518	0.2767	1.377	0.9095
28	0.488	0.0297	0.483	0.0096	88	1.536	0.2840	1.389	0.9095
29	0.506	0.0318	0.500	0.0106	89	1.553	0.2916	1.402	0.9095
30	0.523	0.0340	0.517	0.0118	90	1.571	0.2992	1.414	0.9095
31	0.541	0.0363	0.534	0.0130	91	1.588	0.3069	1.426	0.9095
32	0.558	0.0387	0.551	0.0142	92	1.606	0.3146	1.439	0.9095
33	0.575	0.0411	0.568	0.0156	93	1.623	0.3223	1.451	0.9095
34	0.593	0.0436	0.584	0.0171	94	1.641	0.3300	1.463	0.9095
35	0.610	0.0462	0.601	0.0186	95	1.658	0.3377	1.475	0.9095
36	0.628	0.0489	0.618	0.0202	96	1.675	0.3454	1.486	0.9095
37	0.645	0.0516	0.634	0.0219	97	1.693	0.3531	1.498	0.9095
38	0.663	0.0544	0.651	0.0237	98	1.710	0.3608	1.509	0.9095
39	0.680	0.0573	0.667	0.0256	99	1.728	0.3685	1.521	0.9095
40	0.698	0.0603	0.684	0.0276	100	1.745	0.3762	1.532	0.9095
41	0.715	0.0634	0.700	0.0297	101	1.763	0.3839	1.543	0.9095
42	0.732	0.0664	0.716	0.0319	102	1.780	0.3916	1.554	0.9095
43	0.750	0.0695	0.733	0.0342	103	1.798	0.3993	1.565	0.9095
44	0.767	0.0728	0.749	0.0366	104	1.815	0.4070	1.576	0.9095
45	0.785	0.0761	0.765	0.0391	105	1.833	0.4147	1.587	0.9095
46	0.803	0.0795	0.781	0.0417	106	1.850	0.4224	1.597	0.9095
47	0.820	0.0829	0.797	0.0444	107	1.867	0.4301	1.608	0.9095
48	0.838	0.0865	0.813	0.0473	108	1.885	0.4378	1.618	0.9095
49	0.855	0.0903	0.829	0.0502	109	1.902	0.4455	1.628	0.9095
50	0.873	0.0947	0.845	0.0533	110	1.920	0.4532	1.638	0.9095
51	0.890	0.0994	0.861	0.0564	111	1.937	0.4609	1.648	0.9095
52	0.908	0.1042	0.877	0.0597	112	1.954	0.4686	1.658	0.9095
53	0.925	0.1091	0.892	0.0631	113	1.972	0.4763	1.668	0.9095
54	0.942	0.1139	0.908	0.0667	114	1.990	0.4840	1.677	0.9095
55	0.960	0.1187	0.923	0.0703	115	2.007	0.4917	1.687	0.9095
56	0.977	0.1234	0.939	0.0741	116	2.024	0.5000	1.696	0.9095
57	0.995	0.1282	0.954	0.0780	117	2.042	0.5083	1.705	0.9095
58	1.012	0.1330	0.970	0.0821	118	2.059	0.5166	1.714	0.9095
59	1.030	0.1378	0.985	0.0862	119	2.077	0.5250	1.723	0.9095
60	1.047	0.1426	1.000	0.0905	120	2.094	0.5333	1.732	0.9095



### DROP AT THE INTERSECTION OF SHELL AND NOZZLE (Dimension, d Inches)

Shell I.S. Drain.	NOMINAL PIPE SIZE									
	1½	1½	2	2½	3	3½	4	5	6	8
11	0.0625	0.0625	0.1250	0.1875	0.2500	0.3750	0.4375	0.6875	1.0000	1.8125
12	0.0625	0.0625	0.1250	0.1250	0.2500	0.3125	0.3750	0.5625	0.8125	1.5000
14	0.0625	0.0625	0.0625	0.1250	0.1875	0.2500	0.3125	0.5000	0.6875	1.2500
16	0.0625	0.0625	0.0625	0.1250	0.1875	0.2500	0.3125	0.4375	0.6250	1.1250
18	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.3750	0.5625	1.0000
20	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.3750	0.5000	0.8750
22	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125	0.4375	0.8125	
24	0.0625	0.0625	0.0625	0.0625	0.1250	0.1875	0.3125	0.4375	0.7500	
26	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125	0.4375	0.7500
28	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125	0.3750	0.6875
30	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.3750	0.6250
32	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1250	0.2500	0.3750	0.5625
34	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.2500	0.3125	0.5625
36	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.2500	0.3125	0.5000
38	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125	0.5000
40	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.5000
42	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.2500	0.4375
44	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1875	0.2500	0.3750
46	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3750
48	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3750
50	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
52	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
54	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
56	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
58	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
60	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
62	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
64	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
66	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
68	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
70	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
72	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
74	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
76	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
78	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
80	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
82	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
84	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
86	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
88	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
90	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
92	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
94	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
96	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
98	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
100	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
102	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
104	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
106	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
108	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
110	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
112	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
114	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
116	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
118	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
120	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
122	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
124	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
126	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
128	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
130	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
132	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
134	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
136	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
138	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
140	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
142	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125
144	0.0625	0.0625	0.0625	0.0625	0.0625	0.0625	0.1250	0.1250	0.1875	0.3125

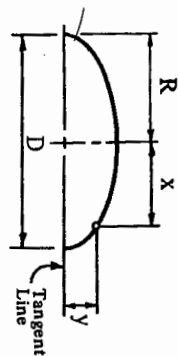




**DROP AT THE INTERSECTION  
OF SHELL AND NOZZLE**  
(Dimension d, Inches)

Shell I.S. Diam.		NOMINAL PIPE SIZE									
	10	12	14	16	18	20	22	24	26	30	
12	3.0625										
14	2.5000	4.1250	7.000								
16	2.0625	3.1875	4.1250	8.000							
18	1.7500	2.6250	3.3750	4.8750	9.0000						
20	1.5625	2.3125	2.8750	4.0000	5.6250	10.0000					
22	1.3750	2.0625	2.5000	3.4375	4.6875	6.4375	11.0000				
24	1.2500	1.8125	2.2500	3.0625	4.0625	5.3750	7.1875	12.0000			
26	1.1875	1.6875	2.0625	2.7500	3.6250	4.6875	6.0625	8.0000	13.0000		
28	1.0625	1.5000	1.8750	2.5000	3.2500	4.1875	5.3125	6.8125	8.9125		
30	1.0000	1.4375	1.7500	2.3125	3.0000	3.8125	4.8125	6.0000	7.5000	15.0000	
32	0.9375	1.3125	1.6250	2.1250	2.7500	3.5000	4.3750	5.4375	6.6875	10.4375	
34	0.8750	1.2500	1.5000	2.0000	2.5625	3.2500	4.0625	4.8125	6.0625	9.0000	
36	0.8125	0.8125	1.4375	1.8750	2.4375	3.0625	3.7500	4.5625	5.5625	8.1250	
38	0.7500	1.1250	1.3125	1.7500	2.2500	2.8750	3.5000	4.2500	5.1250	7.3125	
40	0.7500	1.0625	1.2500	1.6875	2.1250	2.6875	3.3125	4.0000	4.8125	6.7500	
42	0.6875	1.0000	1.1250	1.5675	2.0000	2.5625	3.1250	3.7500	4.5000	6.3125	
48	0.3125	0.875	1.0625	1.1875	1.7500	2.1875	2.6875	3.1875	3.8125	5.2500	
54	0.5625	0.7500	0.9375	1.1875	1.5625	1.9375	2.3125	2.8125	3.3125	4.5625	
60	0.4375	0.6875	0.8125	1.0625	1.3750	1.6875	2.1250	2.5000	2.9375	4.0000	
66	0.4375	0.6250	0.7500	1.0000	1.2500	1.5625	1.8750	2.2500	2.6875	3.6250	
72	0.3750	0.5625	0.6875	0.8750	1.1250	1.4375	1.7500	2.0625	2.4375	3.2500	
78	0.3750	0.5000	0.6250	0.8125	1.0625	1.3125	1.5625	1.8750	2.2500	3.0000	
84	0.3750	0.5000	0.5625	0.7500	1.0000	1.1875	1.4375	1.7500	2.0625	2.7500	
90	0.3125	0.4375	0.5625	0.6875	0.4375	1.1250	1.3750	1.8750	1.9375	2.5625	
96	0.3125	0.4375	0.5000	0.6875	0.8750	1.0625	1.2500	1.5000	1.8125	2.3750	
102	0.3125	0.3750	0.5000	0.6250	0.8125	1.0000	1.1875	1.4375	1.6875	2.2500	
108	0.2500	0.3750	0.4375	0.6250	0.7500	0.9375	1.1250	1.3750	1.5625	2.1250	
114	0.2500	0.1875	0.4375	0.5625	0.6875	0.8750	1.0625	1.2500	1.5000	2.0000	
120	0.2500	0.1875	0.4375	0.5625	0.6875	0.8125	1.0000	1.1875	1.4375	1.8750	
126	0.2500	0.3125	0.3750	0.5000	0.6250	0.8125	0.9375	1.1250	1.3750	1.8125	
132	0.2500	0.3125	0.3750	0.5000	0.6250	0.7500	0.9375	1.1250	1.3125	1.7500	
138	0.1825	0.3125	0.3750	0.4375	0.5625	0.7500	0.8750	1.0625	1.2500	1.6250	
144	0.1825	0.3125	0.3125	0.4375	0.5625	0.6875	0.8750	1.0000	1.1875	1.5625	

TABLE FOR LOCATING POINTS  
ON 2:1 ELLIPSOIDAL HEADS



From these tables the dimension  $y$  can be found if the diameter,  $D$  and dimension  $x$  are known, or  $x$  can be determined if  $D$  and  $y$  are given. The tables based on the formula:  $y = \frac{1}{2} \sqrt{R^2 - x^2}$ , where  $R$  = the radius of head.

D = 12	x	D = 20	12	0	D = 26	4	7.2284	7	7.7459
y	x	y	x	y	x	5	7.0710	8	7.5
2.9580	1	4.9749	1	6.4807	7	6.8738	6	7.2111	
2.8284	2	4.8989	2	6.4226	8	6.6332	10	6.8738	
2.5980	3	4.7697	3	6.3245	9	6.3442	11	6.4807	
2.2360	4	4.5825	4	6.1846	10	5.5901	12	6.0208	
1.6583	5	4.3301	5	6	11	5.0990	13	5.4772	
0	6	4	6	5.7662	12	4.5	14	4.8218	
D = 14	7	3.5707	7	5.4772	13	3.7416	15	4	
y	8	3	8	5.1234	14	2.6925	16	2.8722	
3.4641	9	2.1794	9	4.6904	15	0	17	0	
3.3541	D = 22	D = 22	10	4.1533	D = 32	D = 36			
3.1622	x	y	11	3.4641	x	y			
2.8722	1	5.4772	12	2.5	1	8.9861			
2.4494	2	5.4083	13	0	2	8.9442			
1.8027	3	5.2915	D = 28	0	3	8.8741			
0	4	5.1234	x	y	4	8.7749			
D = 16	5	4.8989	1	6.9821	5	8.6458			
y	6	4.6097	2	6.9282	6	8.4852			
3.9686	7	4.2426	3	6.8374	7	8.2915			
3.8729	8	3.7749	4	6.7082	8	8.0622			
3.7081	9	3.1622	5	6.5383	9	7.7942			
3.4641	10	2.2912	6	6.3245	10	7.4833			
3.1225	11	0	7	6.0621	11	7.1239			
2.6457	D = 24	D = 24	8	5.7445	12	6.7082			
1.9364	x	y	9	5.3619	13	6.2249			
0	1	5.9791	10	4.8989	14	5.6568			
D = 18	2	5.9160	11	4.3301	15	4.9749			
y	3	5.8094	12	3.6055	16	4.1231			
4.4721	4	5.6568	13	2.5980	17	2.9580			
4.3878	5	5.4543	14	0	D = 34	D = 38			
4.2426	6	5.1961	D = 30	D = 34	x	y			
4.0311	7	4.8734	x	y	1	9.4868			
3.7416	8	4.4721	1	7.4833	2	9.4472			
3.3541	9	3.9686	2	7.4330	3	9.3808			
2.8284	10	3.3166	3	7.3484	4	9.2870			
2.0615	11	2.3979	D = 30	D = 34	5	9.1651			
0			1	8.4852					
			2	8.4409					
			3	8.3666					
			4	8.2613					
			5	8.1240					
			6	7.9529					



TABLE FOR LOCATING POINTS  
ON 2:1 ELLIPSOIDAL HEADS (Cont.)

D = 38		D = 40		D = 48		D = 60		D = 66		D = 78	
6	9.0138	8	9.7082	6	13.1624	24	9	17.9374	3	17.9374	3
7	8.8317	9	9.4868	7	13.0384	25	8.2915	17.8885	4	17.8885	4
8	8.6168	10	9.2330	8	12.8939	26	7.4833	17.8255	5	17.8255	5
9	8.3666	11	8.9442	9	12.7279	27	6.5383	17.7482	6	17.7482	6
10	8.0777	12	8.6168	10	12.5399	28	5.5851	17.6564	7	17.6564	7
11	7.7459	13	8.2462	11	12.3288	29	3.8405	17.5499	8	17.5499	8
12	7.3654	14	7.8262	12	12.0934	30	0	17.4284	9	17.4284	9
13	6.9282	15	7.3484	13	11.8322			17.2916	10	17.2916	10
14	6.4226	16	6.8007	14	11.5434			17.1391	11	17.1391	11
15	5.8309	17	6.1644	15	11.225			16.9706	12	16.9706	12
16	5.1234	18	5.4083	16	10.8743			16.7854	13	16.7854	13
17	4.2426	19	4.4721	17	10.4881			16.5831	14	16.5831	14
18	3.0413	20	3.2015	18	10.0623			16.3631	15	16.3631	15
19	0	21	0	19	9.5916			16.1245	16	16.1245	16
D = 40		D = 48		D = 60		D = 66		D = 78		D = 84	
1	9.9874	1	11.9896	1	14.9917	1	16.4924	1	19.4936	1	20.994
2	9.9498	2	11.9583	2	14.9666	2	16.4697	2	19.4422	2	20.9762
3	9.8868	3	11.9059	3	14.9248	3	16.4317	3	19.3972	3	20.9464
4	9.7979	4	11.8322	4	14.8661	4	16.3783	4	19.3391	4	20.9045
5	9.6824	5	11.619	5	14.7902	5	16.3095	5	19.2678	5	20.8507
6	9.5393	6	11.4782	6	14.6969	6	16.225	6	19.1833	6	20.7846
7	9.3675	7	11.3137	7	14.586	7	16.1245	7	19.0853	7	20.7063
8	9.1651	8	11.1243	8	14.4568	8	15.9859	8	18.9737	8	20.6155
9	8.9302	9	10.9087	9	14.3091	9	15.8289	9	18.8481	9	20.5122
10	8.6602	10	10.6654	10	14.1421	10	15.6866	10	18.7083	10	20.3961
11	8.3516	11	10.3923	11	13.9553	11	15.5563	11		11	20.267
12	8	12	10.0871	12	13.7477	12	15.3704	12		12	20.1246
13	7.5993	13	9.7467	13	13.5185	13	15.1658	13		13	20.03
14	7.1414	14	9.3675	14	13.2665	14	14.9416	14		14	18.3848
15	6.6143	15	8.9442	15	13.0384	15	14.6969	15		15	18.2003
16	6	16	8.4705	16	12.8939	16	14.4309	16		16	18.03
17	5.2678	17	7.9372	17	12.7279	17	14.1421	17		17	17.834
18	4.3589	18	7.3314	18	12.5399	18	13.8293	18		18	17.5499
19	3.1225	19	6.6332	19	12.3288	19	13.4907	19		19	17.2916
20	0	20	5.8094	20	12.0934	20	13.1244	20		20	17.0294
D = 42		D = 54		D = 60		D = 66		D = 78		D = 84	
1	10.4881	1	13.4278	1	14.9917	1	16.4924	1	19.4936	1	20.994
2	10.4523	2	13.407	2	14.9666	2	16.4697	2	19.4422	2	20.9762
3	10.3923	3	13.429	3	14.9248	3	16.4317	3	19.3972	3	20.9464
4	10.3078	4	13.4164	4	14.8661	4	16.3783	4	19.3391	4	20.9045
5	10.198	5	13.351	5	14.7902	5	16.3095	5	19.2678	5	20.8507
6	10.0623	6	13.265	6	14.6969	6	16.225	6	19.1833	6	20.7846
7	9.8994	7	13.2665	7	14.586	7	16.1245	7	19.0853	7	20.7063

TABLE FOR LOCATING POINTS  
ON 2:1 ELLIPSOIDAL HEADS (Cont.)

D=78		D=90		D=96		D=108		D=120	
12	18.554	17	19.2029	20	20.1556	20	21.8174	17	25.6271
13	18.3848	18	18.9737	21	19.8997	21	21.5812	18	25.4558
14	18.2003	19	18.7283	22	19.6278	22	21.3307	19	25.2735
15	18	20	18.4662	23	19.3391	23	21.0654	20	25.0799
16	17.7834	21	18.1865	24	19.0329	24	20.7846	21	24.8747
17	17.5499	22	17.8885	25	18.7083	25	20.4878	22	24.6577
18	17.2988	23	17.5713	26	18.3644	26	20.1742	23	24.4285
19	17.0294	24	17.2337	27	18	20.8431	27	24.1868	
20	16.7407	25	16.8745	28	17.6139	28	19.4936	24	23.9322
21	16.4317	26	16.4924	29	17.2047	29	19.1246	25	23.6643
22	16.1012	27	16.0857	30	16.7705	30	18.735	26	23.3827
23	15.748	28	15.6525	31	16.3095	31	18.3235	27	23.0868
24	15.3704	29	15.1905	32	15.8193	32	17.8885	28	22.7761
25	14.9666	30	14.6969	33	15.2971	33	17.4284	29	22.4499
26	14.5344	31	14.1686	34	14.7394	34	16.9411	30	22.1077
27	14.0712	32	13.6015	35	14.1421	35	16.4241	31	21.7486
28	13.5739	33	12.9904	36	13.5	36	15.8745	32	21.3717
29	13.0384	34	12.3288	37	12.8062	37	15.2889	33	20.9762
30	12.4599	35	11.6082	38	12.052	38	14.6629	34	20.5609
31	11.8322	36	10.8167	39	11.225	39	13.9911	35	20.1246
32	11.1467	37	9.9373	40	10.3078	40	13.2665	36	19.666
33	10.3923	38	8.9442	41	9.2736	41	12.48	37	19.1833
34	9.5524	39	7.7942	42	8.0777	42	11.619	38	18.6748
35	8.6023	40	6.4031	43	6.6332	43	10.6654	39	18.1384
36	7.5	41	4.5552	44	4.7169	44	9.5916	40	17.5713
37	6.1644	42	0	45	0	45	8.3516	41	16.9706
38	4.3874					46	6.8556	42	16.3325
39	0					47	4.8734	43	15.6525
D=84		D=90		D=96		D=108		D=120	
x	y	x	y	x	y	x	y	x	y
1	20.994	1	22.4944	1	23.9948	1	26.9954	1	29.9958
2	20.9762	2	22.4778	2	23.9792	2	26.9815	2	29.9833
3	20.9464	3	22.4499	3	23.9531	3	26.9693	3	29.9625
4	20.9045	4	22.4109	4	23.9165	4	26.9583	4	29.9333
5	20.8507	5	22.3607	5	23.8694	5	26.9258	5	29.8957
6	20.7846	6	22.2991	6	23.8118	6	26.884	6	29.8496
7	20.7063	7	22.2261	7	23.7434	7	26.8328		
8	20.6155	8	22.1416	8	23.6643	8	26.7722		
9	20.5122	9	22.0454	9	23.5744	9	26.7021		
10	20.3961	10	21.9374	10	23.4734	10	26.6224		
11	20.267	11	21.8174	11	23.3613	11	26.533		
12	20.1246	12	21.6852	12	23.2379	12	26.4339		
13	19.9687	13	21.5407	13	23.103	13	26.3249		
14	19.799	14	21.3834	14	22.9565	14	26.2059		
15	19.615	15	21.2132	15	22.798	15	26.0768		
16	19.4165	16	21.0297	16	22.6274	16	25.9374		
		17	20.8327	17	22.4444				
		18	20.6216	18	22.2486				
		19	20.3961	19	22.0397				



TABLE FOR LOCATING POINTS  
ON 2:1 ELLIPSOIDAL HEADS (Cont.)

D=120	29.7321	55	10.9896	40	26.2488	19	34.7239	67	13.1814
8	29.7321	56	10.7703	41	25.8602	20	34.5832	68	11.8322
9	29.6606	57	9.3675	42	25.4558	21	34.4347	69	10.2835
10	29.5804	58	7.6811	43	25.035	22	34.2783	70	8.4261
11	29.4915	59	5.4543	44	24.5967	23	34.1138	71	5.9791
12	29.3939	60	0	45	24.1402	24	33.9411	72	0
13	29.2874			46	23.6643	25	33.7602		
14	29.1719			47	23.1679	26	33.5708		
15	29.0474			48	22.6495	27	33.3729		
16	28.9137	x	y	49	22.1077	28	33.1662		
17	28.7706	1	32.9962	50	21.5407	29	32.9507		
18	28.6182	2	32.9848	51	20.9464	30	32.7261		
19	28.4561	3	32.9393	52	20.3224	31	32.4923		
20	28.2843	4	32.9052	53	19.666	32	32.249		
21	28.1025	5	32.8634	54	18.9737	33	31.9961		
22	27.9106	6	32.8139	55	18.2414	34	31.7333		
23	27.7083	7	32.7567	56	17.4642	35	31.4603		
24	27.4955	8	32.6917	57	16.6358	36	31.1769		
25	27.2718	9	32.619	58	15.748	37	30.8828		
26	27.037	10	32.5384	59	14.7902	38	30.5778		
27	26.7909	11	32.45	60	13.7477	39	30.2614		
28	26.533	12	32.3535	61	12.5996	40	29.9333		
29	26.2631	13	32.249	62	11.3137	41	29.5931		
30	25.9808	14	32.1364	63	9.8361	42	29.2404		
31	25.6856	15	32.0156	64	8.0622	43	28.8747		
32	25.3772	16	31.8865	65	5.7227	44	28.4956		
33	25.0549	17	31.749	66	0	45	28.1025		
34	24.7184	18	31.603			46	27.6948		
35	24.367	20	31.4484			47	27.2718		
36	24	21	31.285			48	26.8328		
37	23.6167	22	31.1127	1	35.9965	49	26.3771		
38	23.2164	23	30.9314	2	35.9861	50	25.9037		
39	22.798	24	30.7409	3	35.9687	51	25.4116		
40	22.3607	25	30.541	4	35.9444	52	24.8998		
41	21.9032	26	30.3315	5	35.9131	53	24.367		
42	21.4243	27	30.1123	6	35.8748	54	23.8118		
43	20.9225	28	29.8831	7	35.8295	55	23.2325		
44	20.3961	29	29.6437	8	35.7771	56	22.6274		
45	19.8431	30	29.3939	9	35.7176	57	21.9943		
46	19.2614	31	29.1333	10	35.6511	58	21.3307		
47	18.6481	32	28.8617	11	35.5774	59	20.6337		
48	18	33	28.5788	12	35.4965	60	19.8997		
49	17.3133	34	28.2843	13	35.4083	61	19.1246		
50	16.5831	35	27.9777	14	35.3129	62	18.303		
51	15.8035	36	27.6586	15	35.2101	63	17.4284		
52	14.9666	37	27.3267	16	35.0999	64	16.4924		
53	14.0624	38	26.9815	17	34.9821	65	15.4839		
54	13.0767	39	26.6224	18	34.8569	66	14.3875		

NOTE:

The curvature of an ellipsoid: head either inside or outside ellipse.

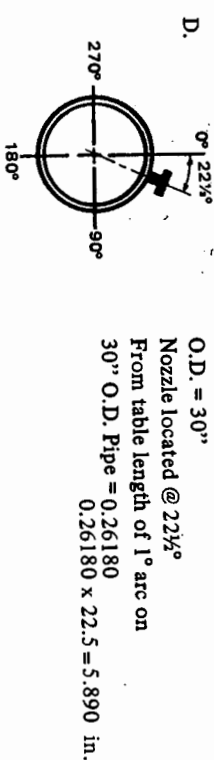
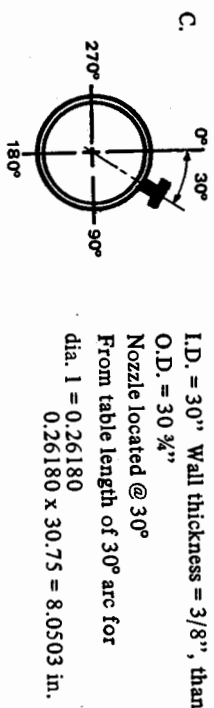
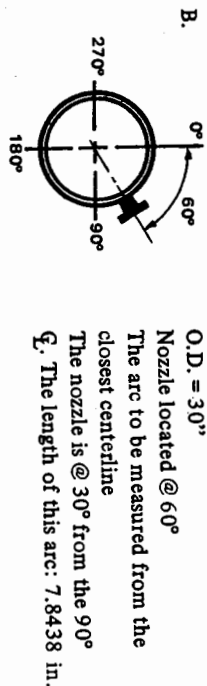
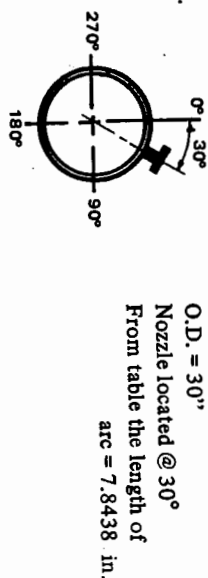
The parallel curve of the opposite side is not ellipse and the data of this table are not applicable to locate points on that geometrically undetermined curve.

(especially in the case of heavy walled heads)

# LENGTH OF ARCS

1. These tables are for locating points on pipes and shells by measuring the length of arcs.
2. The length of arcs are computed for the most commonly used pipe-sizes and vessel diameters.
3. The length of arcs for any diameters and any degrees, not shown in the table, can be obtained easily using the values given for diam. 1 or degree 1.
4. All dimensions are in inches.

## EXAMPLES



LAYOUT



## LENGTH OF ARCS

Diam.		DEGREES																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
		1	5	10	15	20	25	30																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
1		0.00873	0.04363	0.08727	0.13090	0.17453	0.21817	0.26180																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
NOMINAL PIPE SIZE		1	1½	2	2½	3	3¾	4	5	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	140	142	144																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
1		0.01148	0.0625	0.1250	0.1875	0.2188	0.2813	0.3438	0.4063	0.4688	0.5313	0.5938	0.6563	0.7188	0.7813	0.8438	0.9063	0.9688	1.0313	1.0938	1.1563	1.2188	1.2813	1.3438	1.4063	1.4688	1.5313	1.5938	1.6563	1.7188	1.7813	1.8438	1.9063	1.9688	2.0313	2.0938	2.1563	2.2188	2.2813	2.3438	2.4063	2.4688	2.5313	2.5938	2.6563	2.7188	2.7813	2.8438	2.9063	2.9688	3.0313	3.0938	3.1563	3.2188	3.2813	3.3438	3.4063	3.4688	3.5313	3.5938	3.6563	3.7188	3.7813	3.8438	3.9063	3.9688	4.0313	4.0938	4.1563	4.2188	4.2813	4.3438	4.4063	4.4688	4.5313	4.5938	4.6563	4.7188	4.7813	4.8438	4.9063	4.9688	5.0313	5.0938	5.1563	5.2188	5.2813	5.3438	5.4063	5.4688	5.5313	5.5938	5.6563	5.7188	5.7813	5.8438	5.9063	5.9688	6.0313	6.0938	6.1563	6.2188	6.2813	6.3438	6.4063	6.4688	6.5313	6.5938	6.6563	6.7188	6.7813	6.8438	6.9063	6.9688	7.0313	7.0938	7.1563	7.2188	7.2813	7.3438	7.4063	7.4688	7.5313	7.5938	7.6563	7.7188	7.7813	7.8438	7.9063	7.9688	8.0313	8.0938	8.1563	8.2188	8.2813	8.3438	8.4063	8.4688	8.5313	8.5938	8.6563	8.7188	8.7813	8.8438	8.9063	8.9688	9.0313	9.0938	9.1563	9.2188	9.2813	9.3438	9.4063	9.4688	9.5313	9.5938	9.6563	9.7188	9.7813	9.8438	9.9063	9.9688	10.0313	10.0938	10.1563	10.2188	10.2813	10.3438	10.4063	10.4688	10.5313	10.5938	10.6563	10.7188	10.7813	10.8438	10.9063	10.9688	11.0313	11.0938	11.1563	11.2188	11.2813	11.3438	11.4063	11.4688	11.5313	11.5938	11.6563	11.7188	11.7813	11.8438	11.9063	11.9688	12.0313	12.0938	12.1563	12.2188	12.2813	12.3438	12.4063	12.4688	12.5313	12.5938	12.6563	12.7188	12.7813	12.8438	12.9063	12.9688	13.0313	13.0938	13.1563	13.2188	13.2813	13.3438	13.4063	13.4688	13.5313	13.5938	13.6563	13.7188	13.7813	13.8438	13.9063	13.9688	14.0313	14.0938	14.1563	14.2188	14.2813	14.3438	14.4063	14.4688	14.5313	14.5938	14.6563	14.7188	14.7813	14.8438	14.9063	14.9688	15.0313	15.0938	15.1563	15.2188	15.2813	15.3438	15.4063	15.4688	15.5313	15.5938	15.6563	15.7188	15.7813	15.8438	15.9063	15.9688	16.0313	16.0938	16.1563	16.2188	16.2813	16.3438	16.4063	16.4688	16.5313	16.5938	16.6563	16.7188	16.7813	16.8438	16.9063	16.9688	17.0313	17.0938	17.1563	17.2188	17.2813	17.3438	17.4063	17.4688	17.5313	17.5938	17.6563	17.7188	17.7813	17.8438	17.9063	17.9688	18.0313	18.0938	18.1563	18.2188	18.2813	18.3438	18.4063	18.4688	18.5313	18.5938	18.6563	18.7188	18.7813	18.8438	18.9063	18.9688	19.0313	19.0938	19.1563	19.2188	19.2813	19.3438	19.4063	19.4688	19.5313	19.5938	19.6563	19.7188	19.7813	19.8438	19.9063	19.9688	20.0313	20.0938	20.1563	20.2188	20.2813	20.3438	20.4063	20.4688	20.5313	20.5938	20.6563	20.7188	20.7813	20.8438	20.9063	20.9688	21.0313	21.0938	21.1563	21.2188	21.2813	21.3438	21.4063	21.4688	21.5313	21.5938	21.6563	21.7188	21.7813	21.8438	21.9063	21.9688	22.0313	22.0938	22.1563	22.2188	22.2813	22.3438	22.4063	22.4688	22.5313	22.5938	22.6563	22.7188	22.7813	22.8438	22.9063	22.9688	23.0313	23.0938	23.1563	23.2188	23.2813	23.3438	23.4063	23.4688	23.5313	23.5938	23.6563	23.7188	23.7813	23.8438	23.9063	23.9688	24.0313	24.0938	24.1563	24.2188	24.2813	24.3438	24.4063	24.4688	24.5313	24.5938	24.6563	24.7188	24.7813	24.8438	24.9063	24.9688	25.0313	25.0938	25.1563	25.2188	25.2813	25.3438	25.4063	25.4688	25.5313	25.5938	25.6563	25.7188	25.7813	25.8438	25.9063	25.9688	26.0313	26.0938	26.1563	26.2188	26.2813	26.3438	26.4063	26.4688	26.5313	26.5938	26.6563	26.7188	26.7813	26.8438	26.9063	26.9688	27.0313	27.0938	27.1563	27.2188	27.2813	27.3438	27.4063	27.4688	27.5313	27.5938	27.6563	27.7188	27.7813	27.8438	27.9063	27.9688	28.0313	28.0938	28.1563	28.2188	28.2813	28.3438	28.4063	28.4688	28.5313	28.5938	28.6563	28.7188	28.7813	28.8438	28.9063	28.9688	29.0313	29.0938	29.1563	29.2188	29.2813	29.3438	29.4063	29.4688	29.5313	29.5938	29.6563	29.7188	29.7813	29.8438	29.9063	29.9688	30.0313	30.0938	30.1563	30.2188	30.2813	30.3438	30.4063	30.4688	30.5313	30.5938	30.6563	30.7188	30.7813	30.8438	30.9063	30.9688	31.0313	31.0938	31.1563	31.2188	31.2813	31.3438	31.4063	31.4688	31.5313	31.5938	31.6563	31.7188	31.7813	31.8438	31.9063	31.9688	32.0313	32.0938	32.1563	32.2188	32.2813	32.3438	32.4063	32.4688	32.5313	32.5938	32.6563	32.7188	32.7813	32.8438	32.9063	32.9688	33.0313	33.0938	33.1563	33.2188	33.2813	33.3438	33.4063	33.4688	33.5313	33.5938	33.6563	33.7188	33.7813	33.8438	33.9063	33.9688	34.0313	34.0938	34.1563	34.2188	34.2813	34.3438	34.4063	34.4688	34.5313	34.5938	34.6563	34.7188	34.7813	34.8438	34.9063	34.9688	35.0313	35.0938	35.1563	35.2188	35.2813	35.3438	35.4063	35.4688	35.5313	35.5938	35.6563	35.7188	35.7813	35.8438	35.9063	35.9688	36.0313	36.0938	36.1563	36.2188	36.2813	36.3438	36.4063	36.4688	36.5313	36.5938	36.6563	36.7188	36.7813	36.8438	36.9063	36.9688	37.0313	37.0938	37.1563	37.2188	37.2813	37.3438	37.4063	37.4688	37.5313	37.5938	37.6563	37.7188	37.7813	37.8438	37.9063	37.9688	38.0313	38.0938	38.1563	38.2188	38.2813	38.3438	38.4063	38.4688	38.5313	38.5938	38.6563	38.7188	38.7813	38.8438	38.9063	38.9688	39.0313	39.0938	39.1563	39.2188	39.2813	39.3438	39.4063	39.4688	39.5313	39.5938	39.6563	39.7188	39.7813	39.8438	39.9063	39.9688	40.0313	40.0938	40.1563	40.2188	40.2813	40.3438	40.4063	40.4688	40.5313	40.5938	40.6563	40.7188	40.7813	40.8438	40.9063	40.9688	41.0313	41.0938	41.1563	41.2188	41.2813	41.3438	41.4063	41.4688	41.5313	41.5938	41.6563	41.7188	41.7813	41.8438	41.9063	41.9688	42.0313	42.0938	42.1563	42.2188	42.2813	42.3438	42.4063	42.4688	42.5313	42.5938	42.6563	42.7188	42.7813	42.8438	42.9063	42.9688	43.0313	43.0938	43.1563	43.2188	43.2813	43.3438	43.4063	43.4688	43.5313	43.5938	43.6563	43.7188	43.7813	43.8438	43.9063	43.9688	44.0313	44.0938	44.1563	44.2188	44.2813	44.3438	44.4063	44.4688	44.5313	44.5938	44.6563	44.7188	44.7813	44.8438	44.9063	44.9688	45.0313	45.0938	45.1563	45.2188	45.2813	45.3438	45.4063	45.4688	45.5313	45.5938	45.6563	45.7188	45.7813	45.8438	45.9063	45.9688	46.0313	46.0938	46.1563	46.2188	46.2813	46.3438	46.4063	46.4688	46.5313	46.5938	46.6563	46.7188	46.7813	46.8438	46.9063	46.9688	47.0313	47.0938	47.1563	47.2188	47.2813	47.3438	47.4063	47.4688	47.5313	47.5938	47.6563	47.7188	47.7813	47.8438	47.9063	47.9688	48.0313	48.0938	48.1563	48.2188	48.2813	48.3438	48.4063	48.4688	48.5313	48.5938	48.6563	48.7188	48.7813	48.8438	48.9063	48.9688	49.0313	49.0938	49.1563	49.2188	49.2813	49.3438	49.4063	49.4688	49.5313	49.5938	49.6563	49.7188	49.7813	49.8438	49.9063	49.9688	50.0313	50.0938	50.1563	50.2188	50.2813	50.3438	50.4063	50.4688	50.5313	50.5938	50.6563	50.7188	50.7813	50.8438	50.9063	50.9688	51.0313	51.0938	51.1563	51.2188	51.2813	51.3438	51.4063	51.4688	51.5313	51.5938	51.6563	51.7188	51.7813	51.8438	51.9063	51.9688	52.0313	52.0938	52.1563	52.2188	52.2813	52.3438	52.4063	52.4688	52.5313	52.5938	52.6563	52.7188	52.7813	52.8438	52.9063	52.9688	53.0313	53.0938	53.1563	53.2188	53.2813	53.3438	53.4063	53.4688	53.5313	53.5938	53.6563	53.7188	53.7813	53.8438	53.9063	53.9688	54.0313	54.0938	54.1563	54.2188	54.2813	54.3438	54.4063	54.4688	54.5313	54.5938	54.6563	54.7188	54.7813	54.8438	54.9063	54.9688	55.0313	55.0938	55.1563	55.2188	55.2813	55.3438	55.4063	55.4688	55.5313	55.5938	55.6563	55.7188	55.7813	55.8438	55.9063	55.9688	56.0313	56.0938	56.1563	56.2188	56.2813	56.3438	56.4063	56.4688	56.5313	56.5938	56.6563	56.7188	56.7813	56.8438	56.9063	56.9688	57.0313	57.0938	57.1563	57.2188	57.2813	57.3438	57.4063	57.4688	57.5313	57.5938	57.6563	57.7188	57.7813	57.8438	57.9063	57.9688	58.0313	58.0938	58.1563	58.2188	58.2813	58.3438	58.4063	58.4688	58.5313	58.5938	58.6563	58.7188	58.7813	58.8438	58.9063	58.9688	59.0313	59.0938	59.1563	59.2188	59.2813	59.3438	59.4063	59.4688	59.5313	59.5938	59.6563	59.7188	59.7813	59.8438	59.9063	59.9688	60.0313	60.0938	60.1563	60.2188	60.2813	60.3438	60.4063	60.4688	60.5313	60.5938	60.6563	60.7188	60.7813	60.8438	60.9063	60.9688	61.0313	61.0938	61.1563	61.2188	6

## LENGTH OF ARCS

Diam.	DEGREES						
	35	40	45	90	180	270	360
1	0.30543	0.34907	0.39270	0.78540	1.57080	2.35619	3.14159
1	0.4063	0.4688	0.5313	1.0313	2.0625	3.0938	4.1250
1 1/4	0.5938	0.6563	0.7500	1.5000	3.0000	4.4688	5.9688
2	0.7188	0.8438	0.9375	1.8750	3.7188	5.5938	7.4688
2 1/4	0.8750	1.0000	1.1250	2.2500	4.5313	6.7813	9.0313
3	1.0625	1.2188	1.3750	2.7500	5.5000	8.2500	11.0000
3 1/4	1.2188	1.4003	1.5625	3.1563	6.2813	9.4375	12.5625
4	1.3750	1.5625	1.7813	3.5313	7.0625	10.5938	14.1250
5	1.6875	1.9375	2.1875	4.3750	8.7500	13.0938	17.4688
6	2.0313	2.3125	2.5938	5.2188	10.4063	15.6250	20.8125
8	2.6250	3.0938	3.3750	6.7813	13.5625	20.3125	27.0938
10	3.2813	3.7500	4.2188	8.4375	16.8750	25.3438	33.7813
12	3.9063	4.4375	5.0000	10.0000	20.0313	30.0313	40.0625
14	4.2813	4.8750	5.5000	11.0000	22.0000	33.0000	43.9688
16	4.8750	5.5938	6.2813	12.5625	25.1250	37.6875	50.2500
18	5.5000	6.2813	7.0313	14.1250	28.2813	42.4063	56.5625
20	6.0938	6.9688	7.8438	15.7188	31.4063	47.1250	62.8438
22	6.7188	7.6875	8.6563	17.2813	34.5625	51.8438	69.1250
24	7.3438	8.3750	9.4375	18.8438	37.6875	56.5625	75.4063
26	7.9375	9.0625	10.2188	20.4063	40.8438	61.2500	81.6875
28	8.5625	9.7813	11.0000	22.0000	43.9688	65.9688	87.9688
30	9.1563	10.4688	11.7813	23.5625	47.1250	70.6875	94.2500
32	9.7813	11.1563	12.5625	25.1250	50.2500	75.4063	100.5313
34	10.3750	11.8750	13.3438	26.7188	53.4060	80.1250	106.8125
36	11.0000	12.5625	14.1250	28.2813	56.5625	84.8125	113.0938
38	11.5938	13.2500	14.9375	29.8438	59.6875	89.5313	119.3750
40	12.2188	13.9688	15.7188	31.4063	62.8438	94.2500	125.6563
42	12.8438	14.6563	16.5000	33.0000	65.9688	98.9688	131.9375
44	13.4688	15.3438	17.2813	34.6063	69.1250	103.6875	138.2188
46	14.0938	16.0313	18.0625	36.2188	72.2813	108.4063	144.5000
48	14.6563	16.7500	18.8438	37.6875	75.4063	113.0938	150.7813
50	15.5000	18.8438	21.2188	42.4063	84.8125	127.2500	169.6563
54	18.3125	20.9375	23.5625	47.1250	94.2500	141.3750	188.5000
60	20.1563	23.0313	25.9065	51.8438	103.6875	155.5000	207.3458
66	22.0000	25.1250	28.2813	61.5625	113.0938	169.6563	226.1875
72	23.8125	27.2188	30.6250	66.2500	122.5313	183.7813	245.0313
78	25.6563	29.3125	33.0000	65.9688	131.9375	197.9063	263.9063
84	27.5000	31.4063	35.2438	70.6875	141.3750	212.0625	282.7500
90	29.3125	33.5000	37.6875	75.4063	150.7813	226.1875	301.5938
96	31.1563	35.5938	40.1250	80.1250	160.2188	240.3438	320.4375
102	33.0000	37.6875	42.4063	84.8125	169.6563	354.4688	339.2813
108	34.8125	39.7813	44.7813	89.5313	179.0625	268.5938	358.1250
114	36.6563	41.8750	47.1250	94.2500	188.5000	282.7500	377.0000
120	38.5000	43.9688	49.4688	98.9688	197.9063	296.8750	395.8438
126	40.3125	46.0625	51.8438	103.6563	207.3438	311.0313	414.6875
132	42.1563	48.1563	54.1875	108.3750	216.7813	325.1563	433.5313
138	43.9688	50.2500	56.5625	113.0938	226.1875	339.2813	452.3750



# CIRCUMFERENCES AND AREAS OF CIRCLES

Dia.	Circum.	Area
$\frac{1}{64}$	.04909	.00019
$\frac{1}{32}$	.09818	.00077
$\frac{3}{64}$	.14726	.00173
$\frac{1}{16}$	.19635	.00307
$\frac{5}{64}$	.24542	.00690
$\frac{3}{32}$	.29470	.01227
$\frac{1}{8}$	.34363	.01917
$\frac{5}{32}$	.39270	.02761
$\frac{3}{16}$	.44179	.03758
$\frac{1}{4}$	.49087	.04909
$\frac{5}{16}$	.53985	.06213
$\frac{3}{8}$	.58875	.07670
$\frac{1}{2}$	.63750	.09281
$\frac{5}{8}$	.68612	.11045
$\frac{3}{4}$	.73463	.12962
$\frac{7}{8}$	.78304	.15033
$\frac{1}{16}$	.83135	.17257
$\frac{1}{8}$	.87958	.19635
$\frac{3}{16}$	.92771	.22166
$\frac{1}{4}$	.97574	.24850
$\frac{5}{16}$	1.02363	.27688
$\frac{3}{8}$	1.07137	.30680
$\frac{1}{2}$	1.11896	.33824
$\frac{5}{8}$	1.16635	.37122
$\frac{3}{4}$	1.21354	.40574
$\frac{7}{8}$	1.26053	.44179
$\frac{1}{16}$	1.30732	.47937
$\frac{1}{8}$	1.35391	.51849
$\frac{3}{16}$	1.40030	.55914
$\frac{1}{4}$	1.44649	.60132
$\frac{5}{16}$	1.49248	.64504
$\frac{3}{8}$	1.53827	.69029
$\frac{1}{2}$	1.58386	.73708
$\frac{5}{8}$	1.62925	.7854
$\frac{3}{4}$	1.67444	.8366
$\frac{7}{8}$	1.71943	.8866
$\frac{1}{16}$	1.76422	.93940
$\frac{1}{8}$	1.80881	1.0075
$\frac{3}{16}$	1.85319	1.1075
$\frac{1}{4}$	1.89738	1.2272
$\frac{5}{16}$	1.94137	1.3530
$\frac{3}{8}$	1.98516	1.4849
$\frac{1}{2}$	2.02875	1.6230
$\frac{5}{8}$	2.07214	1.7671
$\frac{3}{4}$	2.11533	1.9175
$\frac{7}{8}$	2.15842	2.0739
$\frac{1}{16}$	2.20141	2.2365
$\frac{1}{8}$	2.24430	2.4053
$\frac{3}{16}$	2.28709	2.5802
$\frac{1}{4}$	2.32968	2.7612
$\frac{5}{16}$	2.37207	2.9483

Dia.	Circum.	Area
$\frac{1}{64}$	.04909	.00019
$\frac{1}{32}$	.09818	.00077
$\frac{3}{64}$	.14726	.00173
$\frac{1}{16}$	.19635	.00307
$\frac{5}{64}$	.24542	.00690
$\frac{3}{32}$	.29470	.01227
$\frac{1}{8}$	.34363	.01917
$\frac{5}{32}$	.39270	.02761
$\frac{3}{16}$	.44179	.03758
$\frac{1}{4}$	.49087	.04909
$\frac{5}{16}$	.53985	.06213
$\frac{3}{8}$	.58875	.07670
$\frac{1}{2}$	.63750	.09281
$\frac{5}{8}$	.68612	.11045
$\frac{3}{4}$	.73463	.12962
$\frac{7}{8}$	.78304	.15033
$\frac{1}{16}$	.83135	.17257
$\frac{1}{8}$	.87958	.19635
$\frac{3}{16}$	.92771	.22166
$\frac{1}{4}$	.97574	.24850
$\frac{5}{16}$	1.02363	.27688
$\frac{3}{8}$	1.07137	.30680
$\frac{1}{2}$	1.11896	.33824
$\frac{5}{8}$	1.16635	.37122
$\frac{3}{4}$	1.21354	.40574
$\frac{7}{8}$	1.26053	.44179
$\frac{1}{16}$	1.30732	.47937
$\frac{1}{8}$	1.35391	.51849
$\frac{3}{16}$	1.40030	.55914
$\frac{1}{4}$	1.44649	.60132
$\frac{5}{16}$	1.49248	.64504
$\frac{3}{8}$	1.53827	.69029
$\frac{1}{2}$	1.58386	.73708
$\frac{5}{8}$	1.62925	.7854
$\frac{3}{4}$	1.67444	.8366
$\frac{7}{8}$	1.71943	.8866
$\frac{1}{16}$	1.76422	.93940
$\frac{1}{8}$	1.80881	1.0075
$\frac{3}{16}$	1.85319	1.1075
$\frac{1}{4}$	1.89738	1.2272
$\frac{5}{16}$	1.94137	1.3530
$\frac{3}{8}$	1.98516	1.4849
$\frac{1}{2}$	2.02875	1.6230
$\frac{5}{8}$	2.07214	1.7671
$\frac{3}{4}$	2.11533	1.9175
$\frac{7}{8}$	2.15842	2.0739
$\frac{1}{16}$	2.20141	2.2365
$\frac{1}{8}$	2.24430	2.4053
$\frac{3}{16}$	2.28709	2.5802
$\frac{1}{4}$	2.32968	2.7612
$\frac{5}{16}$	2.37207	2.9483

# CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area
$\frac{1}{64}$	.04909	.00019
$\frac{1}{32}$	.09818	.00077
$\frac{3}{64}$	.14726	.00173
$\frac{1}{16}$	.19635	.00307
$\frac{5}{64}$	.24542	.00690
$\frac{3}{32}$	.29470	.01227
$\frac{1}{8}$	.34363	.01917
$\frac{5}{32}$	.39270	.02761
$\frac{3}{16}$	.44179	.03758
$\frac{1}{4}$	.49087	.04909
$\frac{5}{16}$	.53985	.06213
$\frac{3}{8}$	.58875	.07670
$\frac{1}{2}$	.63750	.09281
$\frac{5}{8}$	.68612	.11045
$\frac{3}{4}$	.73463	.12962
$\frac{7}{8}$	.78304	.15033
$\frac{1}{16}$	.83135	.17257
$\frac{1}{8}$	.87958	.19635
$\frac{3}{16}$	.92771	.22166
$\frac{1}{4}$	.97574	.24850
$\frac{5}{16}$	1.02363	.27688
$\frac{3}{8}$	1.07137	.30680
$\frac{1}{2}$	1.11896	.33824
$\frac{5}{8}$	1.16635	.37122
$\frac{3}{4}$	1.21354	.40574
$\frac{7}{8}$	1.26053	.44179
$\frac{1}{16}$	1.30732	.47937
$\frac{1}{8}$	1.35391	.51849
$\frac{3}{16}$	1.40030	.55914
$\frac{1}{4}$	1.44649	.60132
$\frac{5}{16}$	1.49248	.64504
$\frac{3}{8}$	1.53827	.69029
$\frac{1}{2}$	1.58386	.73708
$\frac{5}{8}$	1.62925	.7854
$\frac{3}{4}$	1.67444	.8366
$\frac{7}{8}$	1.71943	.8866
$\frac{1}{16}$	1.76422	.93940
$\frac{1}{8}$	1.80881	1.0075
$\frac{3}{16}$	1.85319	1.1075
$\frac{1}{4}$	1.89738	1.2272
$\frac{5}{16}$	1.94137	1.3530
$\frac{3}{8}$	1.98516	1.4849
$\frac{1}{2}$	2.02875	1.6230
$\frac{5}{8}$	2.07214	1.7671
$\frac{3}{4}$	2.11533	1.9175
$\frac{7}{8}$	2.15842	2.0739
$\frac{1}{16}$	2.20141	2.2365
$\frac{1}{8}$	2.24430	2.4053
$\frac{3}{16}$	2.28709	2.5802
$\frac{1}{4}$	2.32968	2.7612
$\frac{5}{16}$	2.37207	2.9483

LAYOUT



## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
28. $\frac{1}{8}$	87.965	615.75	34. $\frac{1}{8}$	106.814	907.92	40. $\frac{1}{8}$	125.664	1256.6
$\frac{1}{4}$	88.357	621.26	$\frac{1}{4}$	107.207	914.61	$\frac{1}{4}$	126.056	1264.5
$\frac{3}{8}$	88.750	626.80	$\frac{3}{8}$	107.600	921.32	$\frac{3}{8}$	126.449	1272.4
$\frac{1}{2}$	89.143	632.36	$\frac{1}{2}$	107.992	928.06	$\frac{1}{2}$	126.842	1280.3
$\frac{5}{8}$	89.535	637.94	$\frac{5}{8}$	108.385	934.82	$\frac{5}{8}$	127.235	1288.2
$\frac{3}{4}$	89.928	643.55	$\frac{3}{4}$	108.778	941.61	$\frac{3}{4}$	127.627	1296.2
$\frac{7}{8}$	90.321	649.18	$\frac{7}{8}$	109.170	948.42	$\frac{7}{8}$	128.020	1304.2
	90.713	654.84		109.563	955.25		128.413	1312.2
29. $\frac{1}{8}$	91.106	660.52	35. $\frac{1}{8}$	109.956	962.11	41. $\frac{1}{8}$	128.805	1320.3
$\frac{1}{4}$	91.499	666.23	$\frac{1}{4}$	110.348	969.00	$\frac{1}{4}$	129.198	1328.3
$\frac{3}{8}$	91.892	671.96	$\frac{3}{8}$	110.741	975.91	$\frac{3}{8}$	129.591	1336.4
$\frac{1}{2}$	92.284	677.71	$\frac{1}{2}$	111.134	982.84	$\frac{1}{2}$	129.983	1344.5
$\frac{5}{8}$	92.677	683.49	$\frac{5}{8}$	111.527	989.80	$\frac{5}{8}$	130.376	1352.7
$\frac{3}{4}$	93.070	689.30	$\frac{3}{4}$	111.919	996.78	$\frac{3}{4}$	130.769	1360.8
$\frac{7}{8}$	93.462	695.13	$\frac{7}{8}$	112.312	1003.8	$\frac{7}{8}$	131.161	1369.0
	93.855	700.98		112.705	1010.8		131.554	1377.2
30. $\frac{1}{8}$	94.248	706.86	36. $\frac{1}{8}$	113.097	1017.9	42. $\frac{1}{8}$	131.947	1385.4
$\frac{1}{4}$	94.640	712.76	$\frac{1}{4}$	113.490	1025.0	$\frac{1}{4}$	132.340	1393.7
$\frac{3}{8}$	95.033	718.69	$\frac{3}{8}$	113.883	1032.1	$\frac{3}{8}$	132.732	1402.0
$\frac{1}{2}$	95.426	724.64	$\frac{1}{2}$	114.275	1039.2	$\frac{1}{2}$	133.125	1410.3
$\frac{5}{8}$	95.819	730.62	$\frac{5}{8}$	114.668	1046.3	$\frac{5}{8}$	133.518	1418.6
$\frac{3}{4}$	96.211	736.62	$\frac{3}{4}$	115.061	1053.5	$\frac{3}{4}$	133.910	1427.0
$\frac{7}{8}$	96.604	742.64	$\frac{7}{8}$	115.454	1060.7	$\frac{7}{8}$	134.303	1435.4
	96.997	748.69		115.846	1068.0		134.696	1443.8
31. $\frac{1}{8}$	97.389	754.77	37. $\frac{1}{8}$	116.239	1075.2	43. $\frac{1}{8}$	135.088	1452.2
$\frac{1}{4}$	97.782	760.87	$\frac{1}{4}$	116.632	1082.5	$\frac{1}{4}$	135.481	1460.7
$\frac{3}{8}$	98.175	766.99	$\frac{3}{8}$	117.024	1089.8	$\frac{3}{8}$	135.874	1469.1
$\frac{1}{2}$	98.567	773.14	$\frac{1}{2}$	117.417	1097.1	$\frac{1}{2}$	136.267	1477.6
$\frac{5}{8}$	98.960	779.31	$\frac{5}{8}$	117.810	1104.5	$\frac{5}{8}$	136.659	1486.2
$\frac{3}{4}$	99.353	785.51	$\frac{3}{4}$	118.202	1111.8	$\frac{3}{4}$	137.052	1494.7
$\frac{7}{8}$	99.746	791.73	$\frac{7}{8}$	118.596	1119.2	$\frac{7}{8}$	137.445	1503.3
	100.138	797.98		118.988	1126.7		137.837	1511.9
32. $\frac{1}{8}$	100.531	804.25	38. $\frac{1}{8}$	119.381	1134.1	44. $\frac{1}{8}$	138.230	1520.5
$\frac{1}{4}$	100.924	810.54	$\frac{1}{4}$	119.773	1141.6	$\frac{1}{4}$	138.623	1529.2
$\frac{3}{8}$	101.316	816.86	$\frac{3}{8}$	120.166	1149.1	$\frac{3}{8}$	139.015	1537.9
$\frac{1}{2}$	101.709	823.21	$\frac{1}{2}$	120.559	1156.6	$\frac{1}{2}$	139.408	1546.6
$\frac{5}{8}$	102.102	829.58	$\frac{5}{8}$	120.951	1164.2	$\frac{5}{8}$	139.801	1555.3
$\frac{3}{4}$	102.494	835.97	$\frac{3}{4}$	121.344	1171.7	$\frac{3}{4}$	140.194	1564.0
$\frac{7}{8}$	102.887	842.39	$\frac{7}{8}$	121.737	1179.3	$\frac{7}{8}$	140.586	1572.8
	103.280	848.83		122.129	1186.9		140.979	1581.6
33. $\frac{1}{8}$	103.673	855.30	39. $\frac{1}{8}$	122.522	1194.6	45. $\frac{1}{8}$	141.372	1590.4
$\frac{1}{4}$	104.065	861.79	$\frac{1}{4}$	122.915	1202.3	$\frac{1}{4}$	141.764	1599.3
$\frac{3}{8}$	104.458	868.31	$\frac{3}{8}$	123.308	1210.6	$\frac{3}{8}$	142.157	1608.2
$\frac{1}{2}$	104.851	874.85	$\frac{1}{2}$	123.700	1217.7	$\frac{1}{2}$	142.550	1617.0
$\frac{5}{8}$	105.243	881.41	$\frac{5}{8}$	124.093	1225.4	$\frac{5}{8}$	142.942	1625.9
$\frac{3}{4}$	105.636	888.00	$\frac{3}{4}$	124.486	1233.2	$\frac{3}{4}$	143.335	1634.9
$\frac{7}{8}$	106.029	894.62	$\frac{7}{8}$	124.878	1241.0	$\frac{7}{8}$	143.728	1643.9
	106.421	901.26		125.271	1248.8		144.121	1652.9

## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
46. $\frac{1}{8}$	144.513	1661.9	52. $\frac{1}{8}$	163.363	2123.7	58. $\frac{1}{8}$	182.212	2642.1
$\frac{1}{4}$	144.906	1670.9	$\frac{1}{4}$	163.756	2133.9	$\frac{1}{4}$	182.605	2653.5
$\frac{3}{8}$	145.299	1680.0	$\frac{3}{8}$	164.148	2144.5	$\frac{3}{8}$	183.000	2664.9
$\frac{1}{2}$	145.691	1689.1	$\frac{1}{2}$	164.541	2154.5	$\frac{1}{2}$	183.390	2676.4
$\frac{5}{8}$	146.084	1698.2	$\frac{5}{8}$	164.934	2164.8	$\frac{5}{8}$	183.783	2687.8
$\frac{3}{4}$	146.477	1707.4	$\frac{3}{4}$	165.326	2175.1	$\frac{3}{4}$	184.176	2699.3
$\frac{7}{8}$	146.869	1716.5	$\frac{7}{8}$	165.719	2185.4	$\frac{7}{8}$	184.569	2710.9
	147.262	1725.7		166.112	2195.8		184.961	2722.4
47. $\frac{1}{8}$	147.655	1734.9	53. $\frac{1}{8}$	166.504	2206.2	59. $\frac{1}{8}$	185.354	2734.0
$\frac{1}{4}$	148.048	1744.2	$\frac{1}{4}$	166.897	2216.6	$\frac{1}{4}$	185.747	2745.6
$\frac{3}{8}$	148.440	1753.5	$\frac{3}{8}$	167.290	2227.0	$\frac{3}{8}$	186.139	2757.2
$\frac{1}{2}$	148.833	1762.7	$\frac{1}{2}$	167.683	2237.5	$\frac{1}{2}$	186.532	2768.8
$\frac{5}{8}$	149.226	1772.1	$\frac{5}{8}$	168.075	2248.0	$\frac{5}{8}$	186.925	2780.5
$\frac{3}{4}$	149.618	1781.4	$\frac{3}{4}$	168.468	2258.5	$\frac{3}{4}$	187.317	2792.2
$\frac{7}{8}$	150.011	1790.8	$\frac{7}{8}$	168.861	2269.1	$\frac{7}{8}$	187.710	2803.9
	150.404	1800.1		169.253	2279.6		188.103	2815.7
48. $\frac{1}{8}$	150.796	1809.6	54. $\frac{1}{8}$	169.646	2290.2	60. $\frac{1}{8}$	188.496	2827.4
$\frac{1}{4}$	151.189	1819.0	$\frac{1}{4}$	170.039	2300.8	$\frac{1}{4}$	188.888	2839.2
$\frac{3}{8}$	151.582	1828.5	$\frac{3}{8}$	170.431	2311.5	$\frac{3}{8}$	189.281	2851.0
$\frac{1}{2}$	151.975	1837.9	$\frac{1}{2}$	170.824	2322.1	$\frac{1}{2}$	189.674	2862.9
$\frac{5}{8}$	152.367	1847.5	$\frac{5}{8}$	171.217	2332.8	$\frac{5}{8}$	190.066	2874.8
$\frac{3}{4}$	152.760	1857.0	$\frac{3}{4}$	171.609	2343.5	$\frac{3}{4}$	190.459	2886.6
$\frac{7}{8}$	153.153	1866.5	$\frac{7}{8}$	172.002	2354.3	$\frac{7}{8}$	190.852	2898.6
	153.545	1876.1		172.395	2365.0		191.244	2910.5
49. $\frac{1}{8}$	153.938	1885.7	55. $\frac{1}{8}$	172.788	2375.8	61. $\frac{1}{8}$	191.637	2922.5
$\frac{1}{4}$	154.331	1895.4	$\frac{1}{4}$	173.180	2386.6	$\frac{1}{4}$	192.030	2934.5
$\frac{3}{8}$	154.723	1905.0	$\frac{3}{8}$	173.573	2397.5	$\frac{3}{8}$	192.423	2946.5
$\frac{1}{2}$	155.116	1914.7	$\frac{1}{2}$	173.966	2408.3	$\frac{1}{2}$	192.815	2958.5
$\frac{5}{8}$	155.509	1924.4	$\frac{5}{8}$	174.358	2419.2	$\frac{5}{8}$	193.208	2970.6
$\frac{3}{4}$	155.902	1934.2	$\frac{3}{4}$	174.751	2430.1	$\frac{3}{4}$	193.601	2982.7
$\frac{7}{8}$	156.294	1943.9	$\frac{7}{8}$	175.144	2441.1	$\frac{7}{8}$	193.993	2994.8
	156.687	1953.7		175.536	2452.0		194.386	3006.9
50. $\frac{1}{8}$	157.080	1963.5	56. $\frac{1}{8}$	175.929	2463.0	62. $\frac{1}{8}$	194.779	3019.1
$\frac{1}{4}$	157.472	1973.3	$\frac{1}{4}$	176.322	2474.0	$\frac{1}{4}$	195.171	3031.3
$\frac{3}{8}$	157.865	1983.2	$\frac{3}{8}$	176.715	2485.0	$\frac{3}{8}$	195.564	3043.5
$\frac{1}{2}$	158.258	1993.1	$\frac{1}{2}$	177.107	2496.1	$\frac{1}{2}$	195.957	3055.7
$\frac{5}{8}$	158.650	2003.0	$\frac{5}{8}$	177.500	2507.2	$\frac{5}{8}$	196.350	3068.0
$\frac{3}{4}$	159.043	2012.9	$\frac{3}{4}$	177.893	2518.3	$\frac{3}{4}$	196.742	3080.3
$\frac{7}{8}$	159.436	2022.8	$\frac{7}{8}$	178.285	2529.4	$\frac{7}{8}$	197.135	3092.6
	159.829	2032.8		178.678	2540.6		197.528	3104.9
51. $\frac{1}{8}$	160.221	2042.8	57. $\frac{1}{8}$	179.071	2551.8	63. $\frac{1}{8}$	197.920	3117.2
$\frac{1}{4}$	160.614	2052.8	$\frac{1}{4}$	179.463	2563.0	$\frac{1}{4}$	198.313	3129.6
$\frac{3}{8}$	161.007	2062.9	$\frac{3}{8}$	179.856	2574.2	$\frac{3}{8}$	198.706	3142.0
$\frac{1}{2}$	161.399	2073.0	$\frac{1}{2}$	180.249	2585.4	$\frac{1}{2}$	199.098	3154.5
$\frac{5}{8}$	161.792	2083.1	$\frac{5}{8}$	180.642	2596.7	$\frac{5}{8}$	199.491	3166.9
$\frac{3}{4}$	162.185	2093.2	$\frac{3}{4}$	181.034	2608.0	$\frac{3}{4}$	199.884	3179.4
$\frac{7}{8}$	162.577	2103.3	$\frac{7}{8}$	181.427	2619.4	$\frac{7}{8}$	200.277	3191.9
	162.970	2113.5		181.820	2630.7		200.669	3204.4

LAYOUT



## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
64. $\frac{1}{8}$	201.062	3217.0	70. $\frac{1}{8}$	219.911	3848.5	76. $\frac{1}{8}$	238.761	4536.5
$\frac{1}{4}$	201.455	3229.6	$\frac{1}{4}$	220.304	3862.2	$\frac{1}{4}$	239.154	4551.4
$\frac{3}{8}$	201.847	3242.2	$\frac{3}{8}$	220.697	3876.0	$\frac{3}{8}$	239.546	4566.4
$\frac{1}{2}$	202.240	3254.8	$\frac{1}{2}$	221.090	3889.8	$\frac{1}{2}$	240.939	4581.3
$\frac{5}{8}$	202.633	3267.5	$\frac{5}{8}$	221.482	3903.6	$\frac{5}{8}$	241.332	4596.3
$\frac{3}{4}$	203.025	3280.1	$\frac{3}{4}$	221.875	3917.5	$\frac{3}{4}$	241.725	4611.4
$\frac{7}{8}$	203.418	3292.8	$\frac{7}{8}$	222.268	3931.4	$\frac{7}{8}$	242.117	4626.4
	203.811	3305.6		222.660	3945.3		242.510	4641.5
65. $\frac{1}{8}$	204.204	3318.3	71. $\frac{1}{8}$	223.053	3959.2	77. $\frac{1}{8}$	242.903	4656.6
$\frac{1}{4}$	204.596	3331.1	$\frac{1}{4}$	223.446	3973.1	$\frac{1}{4}$	242.295	4671.8
$\frac{3}{8}$	204.989	3343.9	$\frac{3}{8}$	223.838	3987.1	$\frac{3}{8}$	242.688	4686.9
$\frac{1}{2}$	205.382	3356.7	$\frac{1}{2}$	224.231	4001.1	$\frac{1}{2}$	243.081	4702.1
$\frac{5}{8}$	205.774	3369.6	$\frac{5}{8}$	224.624	4015.2	$\frac{5}{8}$	243.473	4717.3
$\frac{3}{4}$	206.167	3382.4	$\frac{3}{4}$	225.017	4029.2	$\frac{3}{4}$	243.866	4732.5
$\frac{7}{8}$	206.560	3395.3	$\frac{7}{8}$	225.409	4043.3	$\frac{7}{8}$	244.259	4747.8
	206.952	3408.2		225.802	4057.4		244.652	4763.1
66. $\frac{1}{8}$	207.345	3421.2	72. $\frac{1}{8}$	226.195	4071.5	78. $\frac{1}{8}$	245.044	4778.4
$\frac{1}{4}$	207.738	3434.2	$\frac{1}{4}$	226.587	4085.7	$\frac{1}{4}$	245.437	4793.7
$\frac{3}{8}$	208.131	3447.2	$\frac{3}{8}$	226.980	4099.8	$\frac{3}{8}$	245.830	4809.0
$\frac{1}{2}$	208.523	3460.2	$\frac{1}{2}$	227.373	4114.0	$\frac{1}{2}$	246.222	4824.4
$\frac{5}{8}$	208.916	3473.2	$\frac{5}{8}$	227.765	4128.2	$\frac{5}{8}$	246.615	4839.8
$\frac{3}{4}$	209.309	3486.3	$\frac{3}{4}$	228.158	4142.5	$\frac{3}{4}$	247.008	4855.2
$\frac{7}{8}$	209.701	3499.4	$\frac{7}{8}$	228.551	4156.8	$\frac{7}{8}$	247.400	4870.7
	210.094	3512.5		228.944	4171.1		247.793	4886.2
67. $\frac{1}{8}$	210.487	3525.7	73. $\frac{1}{8}$	229.336	4185.4	79. $\frac{1}{8}$	248.186	4901.7
$\frac{1}{4}$	210.879	3538.8	$\frac{1}{4}$	229.729	4199.7	$\frac{1}{4}$	248.579	4917.2
$\frac{3}{8}$	211.272	3552.0	$\frac{3}{8}$	230.122	4214.1	$\frac{3}{8}$	248.971	4932.7
$\frac{1}{2}$	211.665	3565.2	$\frac{1}{2}$	230.514	4228.5	$\frac{1}{2}$	249.364	4948.3
$\frac{5}{8}$	212.058	3578.5	$\frac{5}{8}$	230.907	4242.9	$\frac{5}{8}$	249.757	4963.9
$\frac{3}{4}$	212.450	3591.7	$\frac{3}{4}$	231.300	4257.4	$\frac{3}{4}$	250.149	4979.5
$\frac{7}{8}$	212.843	3605.0	$\frac{7}{8}$	231.692	4271.8	$\frac{7}{8}$	250.542	4995.2
	213.236	3618.3		232.085	4286.3		250.935	5010.9
68. $\frac{1}{8}$	213.628	3631.7	74. $\frac{1}{8}$	232.478	4300.8	80. $\frac{1}{8}$	251.327	5026.5
$\frac{1}{4}$	214.021	3645.0	$\frac{1}{4}$	232.871	4315.4	$\frac{1}{4}$	251.720	5042.3
$\frac{3}{8}$	214.414	3658.4	$\frac{3}{8}$	233.263	4329.9	$\frac{3}{8}$	252.113	5058.0
$\frac{1}{2}$	214.806	3671.8	$\frac{1}{2}$	233.656	4344.5	$\frac{1}{2}$	252.506	5073.8
$\frac{5}{8}$	215.199	3685.3	$\frac{5}{8}$	234.049	4359.2	$\frac{5}{8}$	252.898	5089.6
$\frac{3}{4}$	215.592	3698.7	$\frac{3}{4}$	234.441	4373.8	$\frac{3}{4}$	253.291	5105.4
$\frac{7}{8}$	215.984	3712.2	$\frac{7}{8}$	234.834	4388.5	$\frac{7}{8}$	253.684	5121.2
	216.377	3725.7		235.227	4403.1		254.076	5137.1
69. $\frac{1}{8}$	216.770	3739.3	75. $\frac{1}{8}$	235.619	4417.9	81. $\frac{1}{8}$	254.469	5153.0
$\frac{1}{4}$	217.163	3752.8	$\frac{1}{4}$	236.012	4432.6	$\frac{1}{4}$	254.862	5168.9
$\frac{3}{8}$	217.555	3766.4	$\frac{3}{8}$	236.405	4447.4	$\frac{3}{8}$	255.254	5184.9
$\frac{1}{2}$	217.948	3780.0	$\frac{1}{2}$	236.798	4462.2	$\frac{1}{2}$	255.647	5200.8
$\frac{5}{8}$	218.341	3793.7	$\frac{5}{8}$	237.190	4477.0	$\frac{5}{8}$	256.040	5216.8
$\frac{3}{4}$	218.733	3807.3	$\frac{3}{4}$	237.583	4491.8	$\frac{3}{4}$	256.433	5232.8
$\frac{7}{8}$	219.126	3821.0	$\frac{7}{8}$	237.976	4506.7	$\frac{7}{8}$	256.825	5248.9
	219.519	3834.7		238.368	4521.5		257.218	5264.9

## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
82. $\frac{1}{8}$	257.611	5281.0	88. $\frac{1}{8}$	276.460	6082.1	94. $\frac{1}{8}$	295.310	6939.8
$\frac{1}{4}$	258.003	5297.1	$\frac{1}{4}$	276.853	6099.4	$\frac{1}{4}$	295.702	6958.2
$\frac{3}{8}$	258.396	5313.3	$\frac{3}{8}$	277.246	6116.7	$\frac{3}{8}$	296.095	6976.7
$\frac{1}{2}$	258.789	5329.4	$\frac{1}{2}$	277.638	6134.1	$\frac{1}{2}$	296.488	6995.3
$\frac{5}{8}$	259.181	5345.6	$\frac{5}{8}$	278.031	6151.4	$\frac{5}{8}$	296.881	7013.8
$\frac{3}{4}$	259.574	5361.8	$\frac{3}{4}$	278.424	6168.8	$\frac{3}{4}$	297.273	7032.4
$\frac{7}{8}$	259.967	5378.1	$\frac{7}{8}$	278.816	6186.2	$\frac{7}{8}$	297.666	7051.0
	260.359	5394.3		279.209	6203.7		298.059	7069.6
83. $\frac{1}{8}$	260.752	5410.6	89. $\frac{1}{8}$	279.602	6221.1	95. $\frac{1}{8}$	298.451	7088.2
$\frac{1}{4}$	261.145	5426.9	$\frac{1}{4}$	279.994	6238.6	$\frac{1}{4}$	298.844	7106.9
$\frac{3}{8}$	261.538	5443.3	$\frac{3}{8}$	280.387	6256.1	$\frac{3}{8}$	299.237	7125.6
$\frac{1}{2}$	261.930	5459.6	$\frac{1}{2}$	280.780	6273.7	$\frac{1}{2}$	299.629	7144.3
$\frac{5}{8}$	262.323	5476.0	$\frac{5}{8}$	281.173	6291.2	$\frac{5}{8}$	300.022	7163.0
$\frac{3}{4}$	262.716	5492.4	$\frac{3}{4}$	281.565	6308.8	$\frac{3}{4}$	300.415	7181.8
$\frac{7}{8}$	263.108	5508.8	$\frac{7}{8}$	281.958	6326.4	$\frac{7}{8}$	300.807	7200.6
	263.501	5525.3		282.351	6344.1		301.200	7219.4
84. $\frac{1}{8}$	263.894	5541.8	90. $\frac{1}{8}$	282.743	6361.7	96. $\frac{1}{8}$	301.593	7238.2
$\frac{1}{4}$	264.286	5558.3	$\frac{1}{4}$	283.136	6379.4	$\frac{1}{4}$	301.986	7257.1
$\frac{3}{8}$	264.679	5574.8	$\frac{3}{8}$	283.529	6397.1	$\frac{3}{8}$	302.378	7276.0
$\frac{1}{2}$	265.072	5591.4	$\frac{1}{2}$	283.921	6414.9	$\frac{1}{2}$	302.771	7294.9
$\frac{5}{8}$	265.465	5607.9	$\frac{5}{8}$	284.314	6432.6	$\frac{5}{8}$	303.164	7313.8
$\frac{3}{4}$	265.857	5624.5	$\frac{3}{4}$	284.707	6450.4	$\frac{3}{4}$	303.556	7332.8
$\frac{7}{8}$	266.250	5641.2	$\frac{7}{8}$	285.100	6468.2	$\frac{7}{8}$	303.949	7351.8
	266.643	5657.8		285.492	6486.0		304.342	7370.8
85. $\frac{1}{8}$	267.035	5674.5	91. $\frac{1}{8}$	285.885	6503.9	97. $\frac{1}{8}$	304.734	7389.8
$\frac{1}{4}$	267.428	5691.2	$\frac{1}{4}$	286.278	6521.8	$\frac{1}{4}$	305.127	7408.9
$\frac{3}{8}$	267.821	5707.9	$\frac{3}{8}$	286.670	6539.7	$\frac{3}{8}$	305.520	7428.0
$\frac{1}{2}$	268.213	5724.7	$\frac{1}{2}$	287.063	6557.6	$\frac{1}{2}$	305.913	7447.1
$\frac{5}{8}$	268.606	5741.5	$\frac{5}{8}$	287.456	6575.5	$\frac{5}{8}$	306.305	7466.2
$\frac{3}{4}$	268.999	5758.3	$\frac{3}{4}$	287.848	6593.5	$\frac{3}{4}$	306.698	7485.3
$\frac{7}{8}$	269.392	5775.1	$\frac{7}{8}$	288.241	6611.5	$\frac{7}{8}$	307.091	7504.5
	269.784	5791.9		288.634	6629.6		307.483	7523.7
86. $\frac{1}{8}$	270.177	5808.8	92. $\frac{1}{8}$	289.027	6647.6	98. $\frac{1}{8}$	307.876	7543.0
$\frac{1}{4}$	270.570	5825.7	$\frac{1}{4}$	289.419	6665.7	$\frac{1}{4}$	308.269	7562.2
$\frac{3}{8}$	270.962	5842.6	$\frac{3}{8}$	289.812	6683.8	$\frac{3}{8}$	308.661	7581.5
$\frac{1}{2}$	271.355	5859.6	$\frac{1}{2}$	290.205	6701.9	$\frac{1}{2}$	309.054	7600.8
$\frac{5}{8}$	271.748	5876.5	$\frac{5}{8}$	290.597	6720.1	$\frac{5}{8}$	309.447	7620.1
$\frac{3}{4}$	272.140	5893.5	$\frac{3}{4}$	290.990	6738.2	$\frac{3}{4}$	309.840	7639.5
$\frac{7}{8}$	272.533	5910.6	$\frac{7}{8}$	291.383	6756.4	$\frac{7}{8}$	310.232	7658.9
	272.926	5927.6		291.775	6774.7		310.625	7678.3
87. $\frac{1}{8}$	273.319	5944.7	93. $\frac{1}{8}$	292.168	6792.9	99. $\frac{1}{8}$	311.018	7697.7
$\frac{1}{4}$	273.711	5961.8	$\frac{1}{4}$	292.561	6811.2	$\frac{1}{4}$	311.410	7717.1
$\frac{3}{8}$	274.104	5978.9	$\frac{3}{8}$	292.954	6829.5	$\frac{3}{8}$	311.803	7736.6
$\frac{1}{2}$	274.497	5996.0	$\frac{1}{2}$	293.346	6847.8	$\frac{1}{2}$	312.196	7756.1
$\frac{5}{8}$	274.889	6013.2	$\frac{5}{8}$	293.739	6866.1	$\frac{5}{8}$	312.588	7775.6
$\frac{3}{4}$	275.282	6030.4	$\frac{3}{4}$	294.132	6884.5	$\frac{3}{4}$	312.981	7795.2
$\frac{7}{8}$	275.675	6047.6	$\frac{7}{8}$	294.524	6902.9	$\frac{7}{8}$	313.374	7814.8
	276.067	6064.9		294.917	6921.3		313.767	7834.4

LAYOUT



## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
100. $\frac{1}{8}$	314.16	7854	106. $\frac{1}{8}$	333.01	8825	112. $\frac{1}{8}$	351.86	9852
$\frac{1}{4}$	314.55	7873	$\frac{1}{4}$	333.40	8846	$\frac{1}{4}$	352.25	9874
$\frac{3}{8}$	314.95	7893	$\frac{3}{8}$	333.80	8866	$\frac{3}{8}$	352.65	9897
$\frac{1}{2}$	315.34	7913	$\frac{1}{2}$	334.19	8887	$\frac{1}{2}$	353.04	9919
$\frac{5}{8}$	315.73	7933	$\frac{5}{8}$	334.58	8908	$\frac{5}{8}$	353.43	9941
$\frac{3}{4}$	316.12	7952	$\frac{3}{4}$	334.97	8929	$\frac{3}{4}$	353.82	9963
$\frac{7}{8}$	316.52	7972	$\frac{7}{8}$	335.37	8950	$\frac{7}{8}$	354.22	9985
	316.91	7992		335.76	8971		354.61	10007
101. $\frac{1}{8}$	317.30	8012	107. $\frac{1}{8}$	336.15	8992	113. $\frac{1}{8}$	355.00	10029
$\frac{1}{4}$	317.69	8032	$\frac{1}{4}$	336.54	9014	$\frac{1}{4}$	355.39	10052
$\frac{3}{8}$	318.09	8052	$\frac{3}{8}$	336.94	9035	$\frac{3}{8}$	355.79	10074
$\frac{1}{2}$	318.48	8071	$\frac{1}{2}$	337.33	9056	$\frac{1}{2}$	356.18	10097
$\frac{5}{8}$	318.87	8091	$\frac{5}{8}$	337.72	9077	$\frac{5}{8}$	356.57	10119
$\frac{3}{4}$	319.27	8111	$\frac{3}{4}$	338.12	9098	$\frac{3}{4}$	356.96	10141
$\frac{7}{8}$	319.66	8131	$\frac{7}{8}$	338.51	9119	$\frac{7}{8}$	357.36	10163
	320.05	8151		338.90	9140		357.75	10185
102. $\frac{1}{8}$	320.44	8171	108. $\frac{1}{8}$	339.29	9161	114. $\frac{1}{8}$	358.14	10207
$\frac{1}{4}$	320.84	8191	$\frac{1}{4}$	339.69	9183	$\frac{1}{4}$	358.54	10230
$\frac{3}{8}$	321.23	8211	$\frac{3}{8}$	340.08	9204	$\frac{3}{8}$	358.93	10252
$\frac{1}{2}$	321.62	8231	$\frac{1}{2}$	340.47	9225	$\frac{1}{2}$	359.32	10275
$\frac{5}{8}$	322.01	8252	$\frac{5}{8}$	340.86	9246	$\frac{5}{8}$	359.71	10297
$\frac{3}{4}$	322.40	8272	$\frac{3}{4}$	341.26	9268	$\frac{3}{4}$	360.11	10320
$\frac{7}{8}$	322.81	8292	$\frac{7}{8}$	341.65	9289	$\frac{7}{8}$	360.50	10342
	323.19	8312		342.04	9310		360.89	10365
103. $\frac{1}{8}$	323.59	8332	109. $\frac{1}{8}$	342.43	9331	115. $\frac{1}{8}$	361.28	10387
$\frac{1}{4}$	323.98	8352	$\frac{1}{4}$	342.83	9353	$\frac{1}{4}$	361.68	10410
$\frac{3}{8}$	324.37	8372	$\frac{3}{8}$	343.22	9374	$\frac{3}{8}$	362.07	10432
$\frac{1}{2}$	324.76	8393	$\frac{1}{2}$	343.61	9396	$\frac{1}{2}$	362.46	10455
$\frac{5}{8}$	325.16	8413	$\frac{5}{8}$	344.01	9417	$\frac{5}{8}$	362.86	10477
$\frac{3}{4}$	325.55	8434	$\frac{3}{4}$	344.40	9439	$\frac{3}{4}$	363.25	10500
$\frac{7}{8}$	325.94	8454	$\frac{7}{8}$	344.79	9460	$\frac{7}{8}$	363.64	10522
	326.33	8474		345.18	9481		364.03	10545
104. $\frac{1}{8}$	326.73	8495	110. $\frac{1}{8}$	345.58	9503	116. $\frac{1}{8}$	364.43	10568
$\frac{1}{4}$	327.12	8515	$\frac{1}{4}$	345.97	9525	$\frac{1}{4}$	364.82	10590
$\frac{3}{8}$	327.51	8536	$\frac{3}{8}$	346.36	9546	$\frac{3}{8}$	365.21	10613
$\frac{1}{2}$	327.91	8556	$\frac{1}{2}$	346.75	9568	$\frac{1}{2}$	365.60	10636
$\frac{5}{8}$	328.30	8577	$\frac{5}{8}$	347.15	9589	$\frac{5}{8}$	366.00	10659
$\frac{3}{4}$	328.69	8597	$\frac{3}{4}$	347.54	9611	$\frac{3}{4}$	366.39	10682
$\frac{7}{8}$	329.08	8618	$\frac{7}{8}$	347.93	9633	$\frac{7}{8}$	366.78	10705
	329.48	8638		348.33	9655		367.18	10728
105. $\frac{1}{8}$	329.87	8659	111. $\frac{1}{8}$	348.72	9677	117. $\frac{1}{8}$	367.57	10751
$\frac{1}{4}$	330.26	8679	$\frac{1}{4}$	349.11	9698	$\frac{1}{4}$	367.96	10774
$\frac{3}{8}$	330.65	8700	$\frac{3}{8}$	349.50	9720	$\frac{3}{8}$	368.35	10798
$\frac{1}{2}$	331.05	8721	$\frac{1}{2}$	349.90	9742	$\frac{1}{2}$	368.75	10821
$\frac{5}{8}$	331.44	8741	$\frac{5}{8}$	350.29	9764	$\frac{5}{8}$	369.14	10844
$\frac{3}{4}$	331.83	8762	$\frac{3}{4}$	350.68	9786	$\frac{3}{4}$	369.53	10867
$\frac{7}{8}$	332.22	8783	$\frac{7}{8}$	351.07	9808	$\frac{7}{8}$	369.92	10890
	332.62	8804		351.47	9830		370.32	10913

## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
118. $\frac{1}{8}$	370.71	10936	124. $\frac{1}{8}$	389.56	12076	130. $\frac{1}{8}$	408.41	13273
$\frac{1}{4}$	371.11	10960	$\frac{1}{4}$	389.95	12101	$\frac{1}{4}$	408.80	13299
$\frac{3}{8}$	371.49	10983	$\frac{3}{8}$	390.34	12125	$\frac{3}{8}$	409.19	13324
$\frac{1}{2}$	371.89	11007	$\frac{1}{2}$	390.74	12150	$\frac{1}{2}$	409.59	13350
$\frac{5}{8}$	372.28	11030	$\frac{5}{8}$	391.13	12174	$\frac{5}{8}$	409.98	13375
$\frac{3}{4}$	372.67	11053	$\frac{3}{4}$	391.52	12199	$\frac{3}{4}$	410.37	13401
$\frac{7}{8}$	373.07	11076	$\frac{7}{8}$	391.92	12223	$\frac{7}{8}$	410.76	13426
	373.46	11099		392.31	12248		411.16	13452
119. $\frac{1}{8}$	373.85	11122	125. $\frac{1}{8}$	392.70	12272	131. $\frac{1}{8}$	411.55	13478
$\frac{1}{4}$	374.24	11146	$\frac{1}{4}$	393.09	12297	$\frac{1}{4}$	411.94	13504
$\frac{3}{8}$	374.64	11169	$\frac{3}{8}$	393.49	12321	$\frac{3}{8}$	412.34	13529
$\frac{1}{2}$	375.03	11193	$\frac{1}{2}$	393.88	12346	$\frac{1}{2}$	412.73	13555
$\frac{5}{8}$	375.42	11216	$\frac{5}{8}$	394.27	12370	$\frac{5}{8}$	413.12	13581
$\frac{3}{4}$	375.81	11240	$\frac{3}{4}$	394.66	12395	$\frac{3}{4}$	413.51	13607
$\frac{7}{8}$	376.21	11265	$\frac{7}{8}$	395.06	12419	$\frac{7}{8}$	413.91	13633
	376.60	11287		395.45	12444		414.30	13659
120. $\frac{1}{8}$	376.99	11310	126. $\frac{1}{8}$	395.84	12469	132. $\frac{1}{8}$	414.69	13685
$\frac{1}{4}$	377.39	11334	$\frac{1}{4}$	396.23	12494	$\frac{1}{4}$	415.08	13711
$\frac{3}{8}$	377.78	11357	$\frac{3}{8}$	396.63	12518	$\frac{3}{8}$	415.48	13737
$\frac{1}{2}$	378.17	11381	$\frac{1}{2}$	397.02	12543	$\frac{1}{2}$	415.87	13763
$\frac{5}{8}$	378.56	11404	$\frac{5}{8}$	397.41	12568	$\frac{5}{8}$	416.26	13789
$\frac{3}{4}$	378.96	11428	$\frac{3}{4}$	397.81	12593	$\frac{3}{4}$	416.66	13815
$\frac{7}{8}$	379.35	11451	$\frac{7}{8}$	398.20	12618	$\frac{7}{8}$	417.05	13841
	379.74	11475		398.59	12643		417.44	13867
121. $\frac{1}{8}$	380.13	11499	127. $\frac{1}{8}$	398.98	12668	133. $\frac{1}{8}$	417.83	13893
$\frac{1}{4}$	380.53	11522	$\frac{1}{4}$	399.38	12693	$\frac{1}{4}$	418.23	13919
$\frac{3}{8}$	380.92	11546	$\frac{3}{8}$	399.77	12718	$\frac{3}{8}$	418.62	13946
$\frac{1}{2}$	381.31	11570	$\frac{1}{2}$	400.16	12743	$\frac{1}{2}$	419.01	13972
$\frac{5}{8}$	381.70	11594	$\frac{5}{8}$	400.55	12768	$\frac{5}{8}$	419.40	13999
$\frac{3}{4}$	382.10	11618	$\frac{3}{4}$	400.95	12793	$\frac{3}{4}$	419.80	14025
$\frac{7}{8}$	382.49	11642	$\frac{7}{8}$	401.34	12818	$\frac{7}{8}$	420.19	14051
	382.88	11666		401.73	12843		420.58	14077
122. $\frac{1}{8}$	383.28	11690	128. $\frac{1}{8}$	402.13	12868	134. $\frac{1}{8}$	420.97	14103
$\frac{1}{4}$	383.67	11714	$\frac{1}{4}$	402.52	12893	$\frac{1}{4}$	421.37	14130
$\frac{3}{8}$	384.06	11738	$\frac{3}{8}$	402.91	12919	$\frac{3}{8}$	421.76	14156
$\frac{1}{2}$	384.45	11762	$\frac{1}{2}$	403.30	12944	$\frac{1}{2}$	422.15	14183
$\frac{5}{8}$	384.85	11786	$\frac{5}{8}$	403.70	12970	$\frac{5}{8}$	422.55	14209
$\frac{3}{4}$	385.24	11810	$\frac{3}{4}$	404.09	12995	$\frac{3}{4}$	422.94	14236
$\frac{7}{8}$	385.63	11834	$\frac{7}{8}$	404.48	13020	$\frac{7}{8}$	423.33	14262
	386.02	11858		404.87	13045		423.72	14288
123. $\frac{1}{8}$	386.42	11882	129. $\frac{1}{8}$	405.27	13070	135. $\frac{1}{8}$	424.12	14314
$\frac{1}{4}$	386.81	11907	$\frac{1}{4}$	405.66	13096	$\frac{1}{4}$	424.51	14341
$\frac{3}{8}$	387.20	11931	$\frac{3}{8}$	406.05	13121	$\frac{3}{8}$	424.90	14367
$\frac{1}{2}$	387.60	11956	$\frac{1}{2}$	406.44	13147	$\frac{1}{2}$	425.29	14394
$\frac{5}{8}$	387.99	11980	$\frac{5}{8}$	406.84	13172	$\frac{5}{8}$	425.69	14420
$\frac{3}{4}$	388.38	12004	$\frac{3}{4}$	407.23	13198	$\frac{3}{4}$	426.08	14447
$\frac{7}{8}$	388.77	12028	$\frac{7}{8}$	407.62	13223	$\frac{7}{8}$	426.47	14473
	389.17	12052		408.02	13248		426.87	14500

LAYOUT



## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
136.	427.26	14527	142.	446.11	15837	148.	464.96	17203
$\frac{1}{8}$	427.65	14533	$\frac{1}{8}$	446.50	15865	$\frac{1}{8}$	465.35	17232
$\frac{1}{4}$	428.04	14580	$\frac{1}{4}$	446.89	15893	$\frac{1}{4}$	465.74	17262
$\frac{3}{8}$	428.44	14607	$\frac{3}{8}$	447.29	15921	$\frac{3}{8}$	466.14	17291
$\frac{1}{2}$	428.83	14633	$\frac{1}{2}$	447.68	15949	$\frac{1}{2}$	466.53	17321
$\frac{5}{8}$	429.22	14660	$\frac{5}{8}$	448.07	15977	$\frac{5}{8}$	466.92	17350
$\frac{3}{4}$	429.61	14687	$\frac{3}{4}$	448.46	16005	$\frac{3}{4}$	467.31	17379
$\frac{7}{8}$	430.01	14714	$\frac{7}{8}$	448.86	16033	$\frac{7}{8}$	467.71	17408
137.	430.40	14741	143.	449.25	16061	149.	468.10	17437
$\frac{1}{8}$	430.79	14768	$\frac{1}{8}$	449.64	16089	$\frac{1}{8}$	468.49	17466
$\frac{1}{4}$	431.19	14795	$\frac{1}{4}$	450.03	16117	$\frac{1}{4}$	468.88	17496
$\frac{3}{8}$	431.58	14822	$\frac{3}{8}$	450.43	16145	$\frac{3}{8}$	469.28	17525
$\frac{1}{2}$	431.97	14849	$\frac{1}{2}$	450.82	16173	$\frac{1}{2}$	469.67	17555
$\frac{5}{8}$	432.36	14876	$\frac{5}{8}$	451.21	16201	$\frac{5}{8}$	470.06	17584
$\frac{3}{4}$	432.76	14903	$\frac{3}{4}$	451.61	16229	$\frac{3}{4}$	470.46	17614
$\frac{7}{8}$	433.15	14930	$\frac{7}{8}$	452.00	16258	$\frac{7}{8}$	470.85	17643
138.	433.54	14957	144.	452.39	16286	150.	471.24	17672
$\frac{1}{8}$	433.93	14984	$\frac{1}{8}$	452.78	16314	$\frac{1}{8}$	471.63	17702
$\frac{1}{4}$	434.33	15012	$\frac{1}{4}$	453.18	16342	$\frac{1}{4}$	472.03	17731
$\frac{3}{8}$	434.72	15039	$\frac{3}{8}$	453.57	16371	$\frac{3}{8}$	472.42	17761
$\frac{1}{2}$	435.11	15067	$\frac{1}{2}$	453.96	16399	$\frac{1}{2}$	472.81	17790
$\frac{5}{8}$	435.50	15094	$\frac{5}{8}$	454.35	16428	$\frac{5}{8}$	473.20	17820
$\frac{3}{4}$	435.90	15121	$\frac{3}{4}$	454.75	16456	$\frac{3}{4}$	473.60	17849
$\frac{7}{8}$	436.29	15148	$\frac{7}{8}$	455.14	16485	$\frac{7}{8}$	473.99	17879
139.	436.68	15175	145.	455.53	16513	151.	474.38	17908
$\frac{1}{8}$	437.08	15203	$\frac{1}{8}$	455.93	16542	$\frac{1}{8}$	474.77	17938
$\frac{1}{4}$	437.47	15230	$\frac{1}{4}$	456.32	16570	$\frac{1}{4}$	475.17	17967
$\frac{3}{8}$	437.86	15258	$\frac{3}{8}$	456.71	16599	$\frac{3}{8}$	475.56	17997
$\frac{1}{2}$	438.25	15285	$\frac{1}{2}$	457.10	16627	$\frac{1}{2}$	475.95	18026
$\frac{5}{8}$	438.65	15313	$\frac{5}{8}$	457.50	16656	$\frac{5}{8}$	476.35	18056
$\frac{3}{4}$	439.04	15340	$\frac{3}{4}$	457.89	16684	$\frac{3}{4}$	476.74	18086
$\frac{7}{8}$	439.43	15367	$\frac{7}{8}$	458.28	16713	$\frac{7}{8}$	477.13	18116
140.	439.82	15394	146.	458.67	16742	152.	477.52	18146
$\frac{1}{8}$	440.22	15422	$\frac{1}{8}$	459.07	16770	$\frac{1}{8}$	477.92	18175
$\frac{1}{4}$	440.61	15449	$\frac{1}{4}$	459.46	16799	$\frac{1}{4}$	478.31	18205
$\frac{3}{8}$	441.00	15477	$\frac{3}{8}$	459.85	16827	$\frac{3}{8}$	478.70	18235
$\frac{1}{2}$	441.40	15504	$\frac{1}{2}$	460.24	16856	$\frac{1}{2}$	479.09	18265
$\frac{5}{8}$	441.79	15532	$\frac{5}{8}$	460.64	16885	$\frac{5}{8}$	479.49	18295
$\frac{3}{4}$	442.18	15559	$\frac{3}{4}$	461.03	16914	$\frac{3}{4}$	479.88	18325
$\frac{7}{8}$	442.57	15587	$\frac{7}{8}$	461.42	16943	$\frac{7}{8}$	480.27	18355
141.	442.97	15615	147.	461.82	16972	153.	480.67	18385
$\frac{1}{8}$	443.36	15642	$\frac{1}{8}$	462.21	17000	$\frac{1}{8}$	481.06	18415
$\frac{1}{4}$	443.75	15670	$\frac{1}{4}$	462.60	17029	$\frac{1}{4}$	481.45	18446
$\frac{3}{8}$	444.14	15697	$\frac{3}{8}$	462.99	17058	$\frac{3}{8}$	481.84	18476
$\frac{1}{2}$	444.54	15725	$\frac{1}{2}$	463.39	17087	$\frac{1}{2}$	482.24	18507
$\frac{5}{8}$	444.93	15753	$\frac{5}{8}$	463.78	17116	$\frac{5}{8}$	482.63	18537
$\frac{3}{4}$	445.32	15781	$\frac{3}{4}$	464.17	17145	$\frac{3}{4}$	483.02	18567
$\frac{7}{8}$	445.72	15809	$\frac{7}{8}$	464.56	17174	$\frac{7}{8}$	483.41	18597

## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
154.	483.81	18627	160.	502.66	20106	166.	521.51	21642
$\frac{1}{8}$	484.20	18658	$\frac{1}{8}$	503.05	20138	$\frac{1}{8}$	521.90	21675
$\frac{1}{4}$	484.59	18688	$\frac{1}{4}$	503.44	20169	$\frac{1}{4}$	522.29	21707
$\frac{3}{8}$	484.99	18719	$\frac{3}{8}$	503.83	20201	$\frac{3}{8}$	522.68	21740
$\frac{1}{2}$	485.38	18749	$\frac{1}{2}$	504.22	20232	$\frac{1}{2}$	523.08	21772
$\frac{5}{8}$	485.77	18779	$\frac{5}{8}$	504.62	20264	$\frac{5}{8}$	523.47	21805
$\frac{3}{4}$	486.16	18809	$\frac{3}{4}$	505.01	20295	$\frac{3}{4}$	523.86	21838
$\frac{7}{8}$	486.56	18839	$\frac{7}{8}$	505.41	20327	$\frac{7}{8}$	524.26	21871
155.	486.95	18869	161.	505.80	20358	167.	524.65	21904
$\frac{1}{8}$	487.34	18900	$\frac{1}{8}$	506.19	20390	$\frac{1}{8}$	525.04	21937
$\frac{1}{4}$	487.73	18930	$\frac{1}{4}$	506.58	20421	$\frac{1}{4}$	525.43	21969
$\frac{3}{8}$	488.13	18961	$\frac{3}{8}$	506.98	20453	$\frac{3}{8}$	525.83	22002
$\frac{1}{2}$	488.52	18991	$\frac{1}{2}$	507.37	20484	$\frac{1}{2}$	526.22	22035
$\frac{5}{8}$	488.91	19022	$\frac{5}{8}$	507.76	20516	$\frac{5}{8}$	526.61	22068
$\frac{3}{4}$	489.30	19052	$\frac{3}{4}$	508.15	20548	$\frac{3}{4}$	527.00	22101
$\frac{7}{8}$	489.70	19083	$\frac{7}{8}$	508.55	20580	$\frac{7}{8}$	527.40	22134
156.	490.09	19113	162.	508.94	20612	168.	527.79	22167
$\frac{1}{8}$	490.48	19144	$\frac{1}{8}$	509.33	20644	$\frac{1}{8}$	528.18	22200
$\frac{1}{4}$	490.88	19174	$\frac{1}{4}$	509.73	20675	$\frac{1}{4}$	528.57	22233
$\frac{3}{8}$	491.27	19205	$\frac{3}{8}$	510.12	20707	$\frac{3}{8}$	528.97	22266
$\frac{1}{2}$	491.66	19235	$\frac{1}{2}$	510.51	20739	$\frac{1}{2}$	529.36	22299
$\frac{5}{8}$	492.05	19266	$\frac{5}{8}$	510.90	20771	$\frac{5}{8}$	529.75	22332
$\frac{3}{4}$	492.45	19297	$\frac{3}{4}$	511.30	20803	$\frac{3}{4}$	530.15	22366
$\frac{7}{8}$	492.84	19328	$\frac{7}{8}$	511.69	20835	$\frac{7}{8}$	530.54	22399
157.	493.23	19359	163.	512.08	20867	169.	530.93	22432
$\frac{1}{8}$	493.62	19390	$\frac{1}{8}$	512.47	20899	$\frac{1}{8}$	531.32	22465
$\frac{1}{4}$	494.02	19421	$\frac{1}{4}$	512.87	20931	$\frac{1}{4}$	531.72	22499
$\frac{3}{8}$	494.41	19452	$\frac{3}{8}$	513.26	20964	$\frac{3}{8}$	532.11	22532
$\frac{1}{2}$	494.80	19483	$\frac{1}{2}$	513.65	20996	$\frac{1}{2}$	532.50	22566
$\frac{5}{8}$	495.20	19514	$\frac{5}{8}$	514.04	21028	$\frac{5}{8}$	532.89	22599
$\frac{3}{4}$	495.59	19545	$\frac{3}{4}$	514.44	21060	$\frac{3}{4}$	533.29	22632
$\frac{7}{8}$	495.98	19576	$\frac{7}{8}$	514.83	21092	$\frac{7}{8}$	533.68	22665
158.	496.37	19607	164.	515.22	21124	170.	534.07	22698
$\frac{1}{8}$	496.77	19638	$\frac{1}{8}$	515.62	21157	$\frac{1}{8}$	534.47	22731
$\frac{1}{4}$	497.16	19669	$\frac{1}{4}$	516.01	21189	$\frac{1}{4}$	534.86	22765
$\frac{3}{8}$	497.55	19701	$\frac{3}{8}$	516.40	21222	$\frac{3}{8}$	535.25	22798
$\frac{1}{2}$	497.94	19732	$\frac{1}{2}$	516.79	21254	$\frac{1}{2}$	535.64	22832
$\frac{5}{8}$	498.34	19763	$\frac{5}{8}$	517.19	21287	$\frac{5}{8}$	536.04	22865
$\frac{3}{4}$	498.73	19794	$\frac{3}{4}$	517.58	21319	$\frac{3}{4}$	536.43	22899
$\frac{7}{8}$	499.12	19825	$\frac{7}{8}$	517.97	21351	$\frac{7}{8}$	536.82	22932
159.	499.51	19856	165.	518.36	21383	171.	537.21	22966
$\frac{1}{8}$	499.91	19887	$\frac{1}{8}$	518.76	21416	$\frac{1}{8}$	537.61	22999
$\frac{1}{4}$	500.30	19919	$\frac{1}{4}$	519.15	21448	$\frac{1}{4}$	538.00	23033
$\frac{3}{8}$	500.69	19950	$\frac{3}{8}$	519.54	21481	$\frac{3}{8}$	538.39	23066
$\frac{1}{2}$	501.09	19982	$\frac{1}{2}$	519.94	21513	$\frac{1}{2}$	538.78	23100
$\frac{5}{8}$	501.48	20013	$\frac{5}{8}$	520.33	21546	$\frac{5}{8}$	539.18	23133
$\frac{3}{4}$	501.87	20044	$\frac{3}{4}$	520.72	21578	$\frac{3}{4}$	539.57	23167
$\frac{7}{8}$	502.26	20075	$\frac{7}{8}$	521.11	21610	$\frac{7}{8}$	539.96	23201

LAYOUT



## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
172.	540.36	23235	178.	559.21	24885	184.	578.05	26590
$\frac{1}{16}$	540.75	23268	$\frac{1}{16}$	559.60	24920	$\frac{1}{16}$	578.45	26626
$\frac{1}{8}$	541.14	23302	$\frac{1}{8}$	559.99	24955	$\frac{1}{8}$	578.84	26663
$\frac{3}{16}$	541.53	23336	$\frac{3}{16}$	560.38	24990	$\frac{3}{16}$	579.23	26699
$\frac{1}{2}$	541.93	23370	$\frac{1}{2}$	560.78	25025	$\frac{1}{2}$	579.63	26736
$\frac{5}{8}$	542.32	23404	$\frac{5}{8}$	561.17	25060	$\frac{5}{8}$	580.02	26772
$\frac{3}{4}$	542.71	23438	$\frac{3}{4}$	561.56	25095	$\frac{3}{4}$	580.41	26808
$\frac{7}{8}$	543.10	23472	$\frac{7}{8}$	561.95	25130	$\frac{7}{8}$	580.80	26844
173.	543.50	23506	179.	562.35	25165	185.	581.20	26880
$\frac{1}{16}$	543.89	23540	$\frac{1}{16}$	562.74	25200	$\frac{1}{16}$	581.59	26916
$\frac{1}{8}$	544.28	23575	$\frac{1}{8}$	563.13	25236	$\frac{1}{8}$	581.98	26953
$\frac{3}{16}$	544.68	23609	$\frac{3}{16}$	563.53	25271	$\frac{3}{16}$	582.37	26989
$\frac{1}{2}$	545.07	23643	$\frac{1}{2}$	563.92	25307	$\frac{1}{2}$	582.77	27026
$\frac{5}{8}$	545.46	23677	$\frac{5}{8}$	564.31	25342	$\frac{5}{8}$	583.16	27062
$\frac{3}{4}$	545.85	23711	$\frac{3}{4}$	564.70	25377	$\frac{3}{4}$	583.55	27099
$\frac{7}{8}$	546.25	23745	$\frac{7}{8}$	565.10	25412	$\frac{7}{8}$	583.95	27135
174.	546.64	23779	180.	565.49	25447	186.	584.34	27172
$\frac{1}{16}$	547.03	23813	$\frac{1}{16}$	565.88	25482	$\frac{1}{16}$	584.73	27208
$\frac{1}{8}$	547.42	23848	$\frac{1}{8}$	566.27	25518	$\frac{1}{8}$	585.12	27245
$\frac{3}{16}$	547.82	23882	$\frac{3}{16}$	566.67	25553	$\frac{3}{16}$	585.52	27281
$\frac{1}{2}$	548.21	23917	$\frac{1}{2}$	567.06	25589	$\frac{1}{2}$	585.91	27318
$\frac{5}{8}$	548.60	23951	$\frac{5}{8}$	567.45	25624	$\frac{5}{8}$	586.30	27354
$\frac{3}{4}$	549.00	23985	$\frac{3}{4}$	567.84	25660	$\frac{3}{4}$	586.69	27391
$\frac{7}{8}$	549.39	24019	$\frac{7}{8}$	568.24	25695	$\frac{7}{8}$	587.09	27428
175.	549.78	24053	181.	568.63	25730	187.	587.48	27465
$\frac{1}{16}$	550.17	24087	$\frac{1}{16}$	569.02	25765	$\frac{1}{16}$	587.87	27501
$\frac{1}{8}$	550.57	24122	$\frac{1}{8}$	569.42	25801	$\frac{1}{8}$	588.27	27538
$\frac{3}{16}$	550.96	24156	$\frac{3}{16}$	569.81	25836	$\frac{3}{16}$	588.66	27574
$\frac{1}{2}$	551.35	24191	$\frac{1}{2}$	570.20	25872	$\frac{1}{2}$	589.05	27611
$\frac{5}{8}$	551.74	24225	$\frac{5}{8}$	570.59	25908	$\frac{5}{8}$	589.44	27648
$\frac{3}{4}$	552.14	24260	$\frac{3}{4}$	570.99	25944	$\frac{3}{4}$	589.84	27685
$\frac{7}{8}$	552.53	24294	$\frac{7}{8}$	571.38	25980	$\frac{7}{8}$	590.23	27722
176.	552.92	24329	182.	571.77	26016	188.	590.62	27759
$\frac{1}{16}$	553.31	24363	$\frac{1}{16}$	572.16	26051	$\frac{1}{16}$	591.01	27796
$\frac{1}{8}$	553.71	24398	$\frac{1}{8}$	572.56	26087	$\frac{1}{8}$	591.41	27833
$\frac{3}{16}$	554.10	24432	$\frac{3}{16}$	572.95	26122	$\frac{3}{16}$	591.80	27870
$\frac{1}{2}$	554.49	24467	$\frac{1}{2}$	573.34	26158	$\frac{1}{2}$	592.19	27907
$\frac{5}{8}$	554.89	24501	$\frac{5}{8}$	573.74	26194	$\frac{5}{8}$	592.58	27944
$\frac{3}{4}$	555.28	24536	$\frac{3}{4}$	574.13	26230	$\frac{3}{4}$	592.98	27981
$\frac{7}{8}$	555.67	24571	$\frac{7}{8}$	574.52	26266	$\frac{7}{8}$	593.37	28018
177.	556.06	24606	183.	574.91	26302	189.	593.76	28055
$\frac{1}{16}$	556.46	24640	$\frac{1}{16}$	575.31	26338	$\frac{1}{16}$	594.16	28092
$\frac{1}{8}$	556.85	24675	$\frac{1}{8}$	575.70	26374	$\frac{1}{8}$	594.55	28129
$\frac{3}{16}$	557.24	24710	$\frac{3}{16}$	576.09	26410	$\frac{3}{16}$	594.94	28167
$\frac{1}{2}$	557.63	24745	$\frac{1}{2}$	576.48	26446	$\frac{1}{2}$	595.33	28204
$\frac{5}{8}$	558.03	24780	$\frac{5}{8}$	576.88	26482	$\frac{5}{8}$	595.73	28242
$\frac{3}{4}$	558.42	24815	$\frac{3}{4}$	577.27	26518	$\frac{3}{4}$	596.12	28279
$\frac{7}{8}$	558.81	24850	$\frac{7}{8}$	577.66	26554	$\frac{7}{8}$	596.51	28316

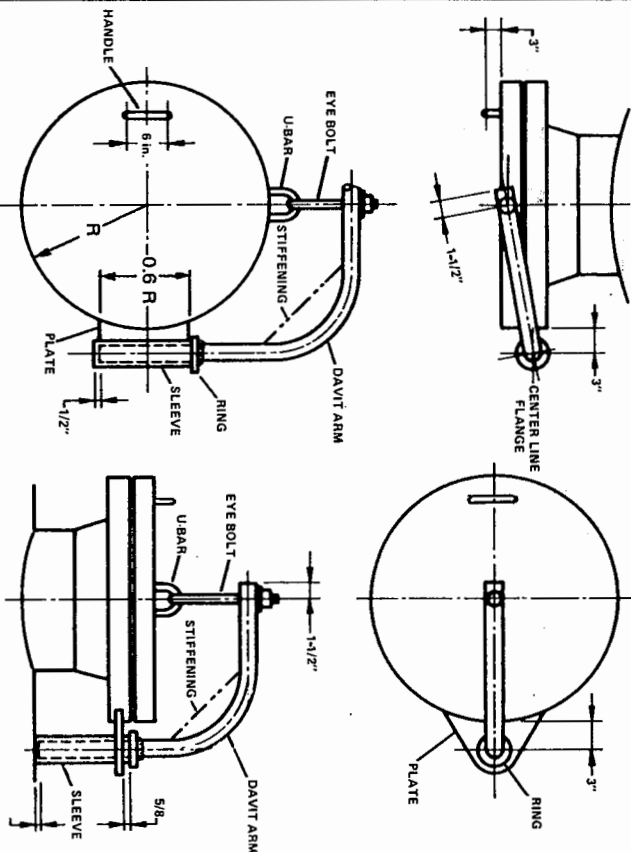
## CIRCUMFERENCES AND AREAS OF CIRCLES (continued)

Dia.	Circum.	Area	Dia.	Circum.	Area	Dia.	Circum.	Area
190.	596.90	28353	196.	615.75	30172	202.	634.60	32047
$\frac{1}{16}$	597.29	28390	$\frac{1}{16}$	616.15	30210	$\frac{1}{16}$	635.00	32086
$\frac{1}{8}$	597.68	28428	$\frac{1}{8}$	616.54	30249	$\frac{1}{8}$	635.40	32126
$\frac{3}{16}$	598.08	28465	$\frac{3}{16}$	616.93	30287	$\frac{3}{16}$	635.80	32166
$\frac{1}{2}$	598.47	28503	$\frac{1}{2}$	617.32	30326	$\frac{1}{2}$	636.18	32206
$\frac{5}{8}$	598.86	28540	$\frac{5}{8}$	617.72	30364	$\frac{5}{8}$	636.57	32246
$\frac{3}{4}$	599.25	28578	$\frac{3}{4}$	618.11	30403	$\frac{3}{4}$	636.97	32286
$\frac{7}{8}$	599.64	28615	$\frac{7}{8}$	618.50	30442	$\frac{7}{8}$	637.36	32326
191.	600.04	28652	197.	618.89	30481	203.	637.74	32366
$\frac{1}{16}$	600.44	28689	$\frac{1}{16}$	619.29	30519	$\frac{1}{16}$	638.15	32405
$\frac{1}{8}$	600.83	28727	$\frac{1}{8}$	619.68	30558	$\frac{1}{8}$	638.54	32445
$\frac{3}{16}$	601.22	28764	$\frac{3}{16}$	620.08	30596	$\frac{3}{16}$	638.93	32485
$\frac{1}{2}$	601.62	28802	$\frac{1}{2}$	620.47	30635	$\frac{1}{2}$	639.32	32525
$\frac{5}{8}$	602.01	28839	$\frac{5}{8}$	620.86	30674	$\frac{5}{8}$	639.72	32565
$\frac{3}{4}$	602.40	28877	$\frac{3}{4}$	621.25	30713	$\frac{3}{4}$	640.11	32605
$\frac{7}{8}$	602.79	28915	$\frac{7}{8}$	621.64	30752	$\frac{7}{8}$	640.50	32645
192.	603.19	28953	198.	622.04	30791	204.	640.88	32685
$\frac{1}{16}$	603.58	28990	$\frac{1}{16}$	622.44	30830	$\frac{1}{16}$	641.28	32725
$\frac{1}{8}$	603.97	29028	$\frac{1}{8}$	622.83	30869	$\frac{1}{8}$	641.67	32766
$\frac{3}{16}$	604.36	29065	$\frac{3}{16}$	623.22	30908	$\frac{3}{16}$	642.07	32806
$\frac{1}{2}$	604.76	29103	$\frac{1}{2}$	623.62	30947	$\frac{1}{2}$	642.46	32846
$\frac{5}{8}$	605.15	29141	$\frac{5}{8}$	624.01	30986	$\frac{5}{8}$	642.85	32886
$\frac{3}{4}$	605.54	29179	$\frac{3}{4}$	624.40	31025	$\frac{3}{4}$	643.24	32926
$\frac{7}{8}$	605.94	29217	$\frac{7}{8}$	624.79	31064	$\frac{7}{8}$	643.63	32966
193.	606.33	29255	199.	625.18	31103	205.	644.03	33006
$\frac{1}{16}$	606.72	29293	$\frac{1}{16}$	625.58	31142	$\frac{1}{16}$	644.43	33046
$\frac{1}{8}$	607.11	29331	$\frac{1}{8}$	625.97	31181	$\frac{1}{8}$	644.82	33087
$\frac{3}{16}$	607.51	29369	$\frac{3}{16}$	626.36	31220	$\frac{3}{16}$	645.21	33127
$\frac{1}{2}$	607.90	29407	$\frac{1}{2}$	626.76	31260	$\frac{1}{2}$	645.61	33168
$\frac{5}{8}$	608.29	29445	$\frac{5}{8}$	627.15	31299	$\frac{5}{8}$	646.00	33208
$\frac{3}{4}$	608.68	29483	$\frac{3}{4}$	627.54	31338	$\frac{3}{4}$	646.39	33249
$\frac{7}{8}$	609.08	29521	$\frac{7}{8}$	627.94	31377	$\frac{7}{8}$	646.78	33289
194.	609.47	29559	200.	628.32	31416	206.	647.17	33329
$\frac{1}{16}$	609.86	29597	$\frac{1}{16}$	628.72	31455	$\frac{1}{16}$	647.57	33369
$\frac{1}{8}$	610.26	29636	$\frac{1}{8}$	629.11	31495	$\frac{1}{8}$	647.96	33410
$\frac{3}{16}$	610.65	29674	$\frac{3}{16}$	629.51	31534	$\frac{3}{16}$	648.35	33450
$\frac{1}{2}$	611.05	29713	$\frac{1}{2}$	629.90	31574	$\frac{1}{2}$	648.75	33491
$\frac{5}{8}$	611.43	29751	$\frac{5}{8}$	630.29	31613	$\frac{5}{8}$	649.14	33531
$\frac{3}{4}$	611.83	29789	$\frac{3}{4}$	630.68	31653	$\frac{3}{4}$	649.53	33572
$\frac{7}{8}$	612.29	29827	$\frac{7}{8}$	631.08	31692	$\frac{7}{8}$	649.93	33613
195.	612.61	29865	201.	631.46	31731	207.	650.31	33654
$\frac{1}{16}$	613.00	29903	$\frac{1}{16}$	631.86	31770	$\frac{1}{16}$	650.71	33694
$\frac{1}{8}$	613.40	29942	$\frac{1}{8}$	632.26	31810	$\frac{1}{8}$	651.10	33735
$\frac{3}{16}$	613.79	29980	$\frac{3}{16}$	632.65	31849	$\frac{3}{16}$	651.50	33775
$\frac{1}{2}$	614.18	30019	$\frac{1}{2}$	633.05	31889	$\frac{1}{2}$	651.89	33816
$\frac{5}{8}$	614.57	30057	$\frac{5}{8}$	633.43	31928	$\frac{5}{8}$	652.28	33857
$\frac{3}{4}$	614.97	30096	$\frac{3}{4}$	633.83	31968	$\frac{3}{4}$	652.67	33898
$\frac{7}{8}$	615.36	30134	$\frac{7}{8}$	634.29	32007	$\frac{7}{8}$	653.07	33939

LAYOUT



## DAVIT



## FOR HORIZONTAL OPENING

## FOR VERTICAL OPENING

- NOTES:
1. All material carbon steel
  2. All welds  $3/8$ " continuous fillet weld
  3. The davit has been tested against excessive deflection
  4. Using davit less room is required than with the use of hinge
  5. For frequently used opening, davit is preferred to hinge

FLANGE RATING	150 #					300 #					600 #					900 #										
	SIZE	12	14	16	18	20	24	12	14	16	18	20	24	12	14	16	18	20	24	12	14	16	18	20	24	
NO. OF LIST	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	2	2	2	2	2	1	1	2	2	3
					LIST # 1					LIST # 2					LIST # 3											
DAVIT ARM						1-1/2"-XH PIPE					2"-XXH PIPE					2"-XXH PIPE										
SLEEVE						2"-XH PIPE					2-1/2"-STD PIPE					2-1/2"-STD PIPE										
EYE-BOLT						5/8 $\phi$					3/4 $\phi$					1" $\phi$										
U-BAR						5/8 $\phi$					3/4 $\phi$					1" $\phi$										
RING						5/8					3/4					1"										
PLATE						5/8					3/4					1"										
HANDLE						5/8 $\phi$					3/4 $\phi$					1" $\phi$										
STIFFENER						—					—					3/8"										

## FIXED STAIR

Conforms to the requirements of  
OCCUPATIONAL SAFETY AND HEALTH (OSHA) STANDARDS

Fixed stairs will be provided where operations necessitate regular travel between levels. Fixed stairways shall be designed to carry a load of five times the normal live load anticipated but never less than to carry a moving concentrated load of 1,000 pounds.

Minimum width: 22 inches

Angle of stairway rise to the horizontal: 30 to 50 degrees.

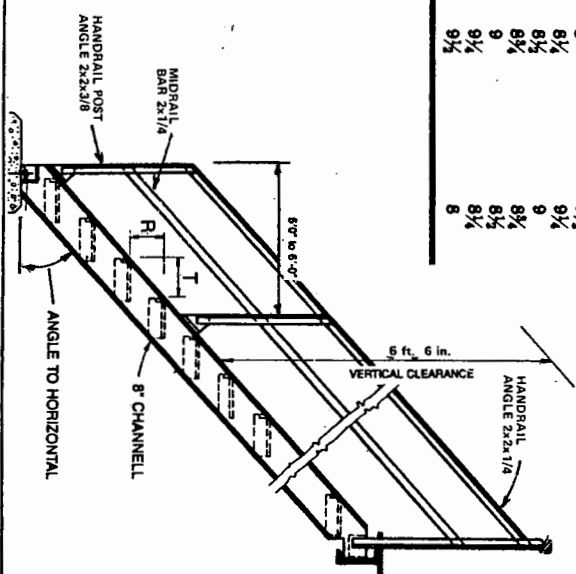
Railings shall be provided on the open sides of all exposed stairways. Handrails shall be provided on at least once side of closed stairways, preferably on the right side descending. Each tread and nosing shall be reasonably slip-resistant.

Stairs having treads of less than nine-inch width should have open risers. Open grating type treads are desirable for outside stairs.

See figure for minimum dimensions. Bolts  $1/2$   $\phi$  Bolt holes  $3/16$   $\phi$   
All burrs and sharp edges shall be removed.

Dimensions of rises (R) and tread runs (T) tabulated below:

Angle to Horizontal	Rise (in inches)	Tread Run (in inches)
30° 35'	6 1/2	11
32° 08'	8 1/2	10 1/2
33° 41'	7	10 1/2
35° 16'	7 1/2	10 1/2
36° 52'	7 1/2	10
38° 29'	7 1/2	9 1/2
40° 08'	8	9 1/2
41° 44'	8 1/2	9 1/2
43° 22'	8 1/2	9
45° 00'	8 1/2	8 1/2
46° 38'	9	8 1/2
48° 16'	9 1/2	8 1/2
49° 54'	9 1/2	8



LAYOUT

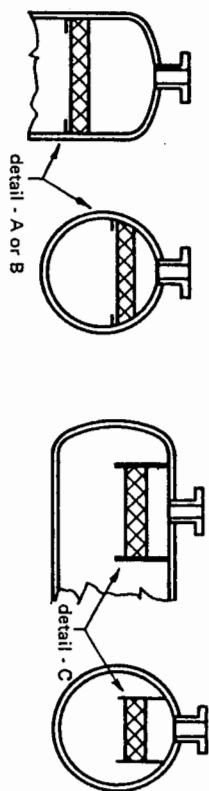




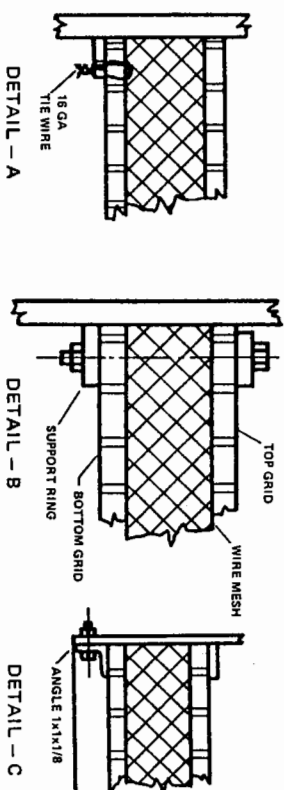


## MIST EXTRACTOR

Mist extractors by separating mist, undesirable liquids from vapor, steam, liquids, etc. improve the performance of various process equipments. They are manufactured from metal or plastic mesh and available in any required size and shape.



TYPES OF MIST EXTRACTORS



SUPPORT OF MIST EXTRACTORS

Use 6 I 12.5 beam support in center of mist extractor, when the diameter is greater than 6 ft.

## SPECIFICATION

WIRE MESH	THICKNESS OF PAD	4"	6"
	THICKNESS OF WIRE	.011"	.011"
	MATERIAL OF WIRE	TYPE 304 S.S.	TYPE 304 S.S.
	DENSITY lb./Cu. ft.	9.0	5.0
GRID	PRESSURE DROP	0.5" TO 1" WATER GAGE	
	MATERIAL CARBON STEEL		
	BEARING BAR	1"x3/16"	1"x3/16"
	CROSS BAR	1/4" $\phi$	1/4" $\phi$
	BEARING BAR SPACING	3-9/16	3-9/16
	CROSS BAR SPACING	4"	4"
	WEIGHT lb./sq. ft.	5.7	7.4
WIDTH OF ONE SECTION		12"	12"

## NAME PLATE

Pressure vessels built in accordance with the requirements of the Code may be stamped with the official symbol "U" to denote The American Society of Mechanical Engineers' standard. (Code UG-115 and 116)


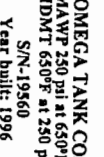
Pressure vessels stamped with the Code-symbol shall be marked with the following:

1. manufacturer's name, preceded with the words: "certified by"; maximum allowable working pressure, (MAWP) psi at temperature, °F, maximum design metal temperature at maximum allowable working pressure, psi (MDMT); manufacturer's serial number, (S/N); year built
2. Abbreviations may be used as shown in parenthesis.

as tabulated:

When inspected by a user's inspector	USER
Arc or gas welded	W
Lethal service	L
Unfired steam boiler	UB
Direct firing	DF
Fully radiographed and UW-11(a)(5) not applied	RT1
Joints A & D fully radiographed; UW-11(a)(5)(b) applied	RT2
Spot radiographed	RT3
When RT1, RT2 or RT3 are not applicable	RT4
Post weld heat treated	HT
Part of the vessel post weld heat treated	PHT
Nonstationary Pressure Vessel	NPV

1. Symbol "UM" shall be used when the vessel is exempted from inspection [Code U-1(k)].
2. For vessels made of 5%, 8% and 9% nickel sheets, the use of nameplates is mandatory for shell thickness below 1/2 in.; name plates are preferred on all thicknesses. Code U1T-115(c)

USER	CERTIFIED BY
	
W-L RT 1	HT

OMEGA TANK CO.  
MAWP 250 psi at 650°F  
MDMT 650°F at 250 psi  
S/N-19560  
Year built: 1996

## NAME PLATE EXAMPLE

(The vessel was inspected by user's inspector, arc welded, used in lethal service, fully radiographed and post weld heat treated.) Additional data shall be below the code required marking.

The name plate shall be affixed directly to the shell. If additional name plate is used on skirts, supports, etc., it shall be marked: "Duplicate."

Lettering shall be not less than 1/32 in. high. The Code-symbol and serial number shall be stamped, the other data may be stamped, etched, cast or impressed.

Commonly used material for name plate 0.32 in. stainless steel or 1/8 in carbon steel. The name plate shall be seal welded to uninsulated vessel or mounted on bracket if the vessel is insulated, and located in some conspicuous place; near manways, liquid level control, level gage, about 5 ft. above ground, etc.

## LAYOUT





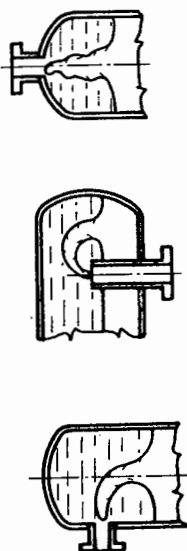


## VORTEX BREAKER

The purpose of vortex breakers is to eliminate the undesirable vortexing of liquids.

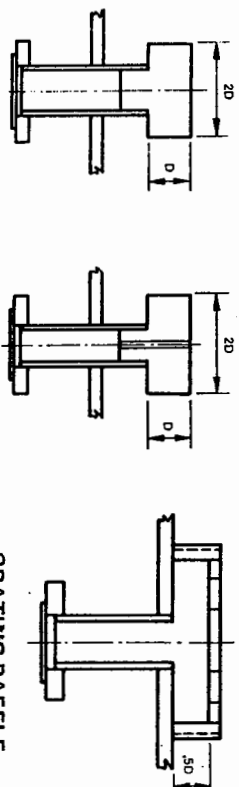
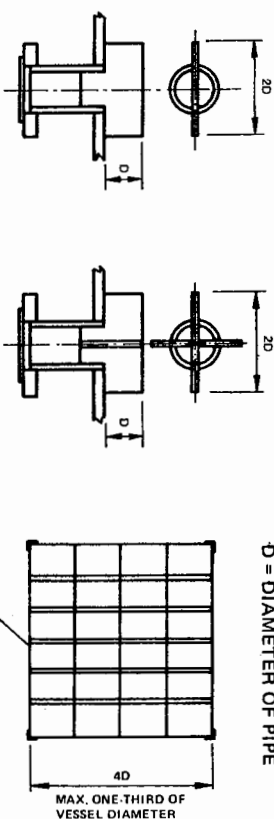
Cross and flat-plate baffles are frequently used with a width of two times the nozzle diameter.

For a high degree of effectiveness under severe swirling conditions the width of the baffle should be four times the nozzle diameter. The height above the outlet should be about half the nozzle diameter but may be several inches if required larger clearance for other reasons.



VORTEXING OF LIQUIDS

D = DIAMETER OF PIPE



FLAT AND CROSS PLATE BAFFLES

Material: 1/4 carbon steel plate or grating with 1 x 1-1/8 bars.

GRATING BAFFLE

Reference: F. M. Patterson "Vortexing can be prevented" The Oil and Gas Journal, August 4, 1969.

## PART III.

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# PROPERTIES OF PIPE

Schedule numbers and weight designations are in agreement with ANSI B36.10 for carbon and alloy steel pipe and ANSI B36.19 for stainless steel pipe.

Nom pipe size	Schedule No.		Weight designation	Out- side diam. in.	In- side diam. in.	Wall thick- ness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Trans- verse area sq. in.
	Carbon & alloy steels	Stain- less steels									
<b>1 1/8</b>	40	105	Std.	.405	.307	.049	1.86	.0320	1.06	.0804	.0740
	80	405	X-Sig.	.405	.269	.068	.244	.0246	.106	.0705	.0588
	160	805	X-Sig.	.405	.215	.095	.314	.0157	.106	.0563	.0364
<b>1 1/4</b>	40	105	Std.	.540	.410	.065	.330	.0570	1.41	.1073	.1380
	80	405	X-Sig.	.540	.364	.088	.424	.0451	1.41	.0955	.1041
	160	805	X-Sig.	.540	.302	.119	.535	.0310	1.41	.0794	.0716
<b>1 1/2</b>	40	105	Std.	.675	.545	.065	.423	.1010	1.77	1.427	.2333
	80	405	X-Sig.	.675	.493	.091	.567	.0827	1.77	1.295	.1910
	160	805	X-Sig.	.675	.423	.126	.738	.0609	1.77	1.106	.1405
<b>2</b>	40	105	Std.	.840	.670	.083	.671	.1550	.220	1.764	.3568
	80	405	X-Sig.	.840	.622	.109	.850	.1316	.220	1.637	.3040
	160	805	X-Sig.	.840	.546	.147	1.087	.1013	.220	1.433	.2240
<b>2 1/2</b>	40	105	Std.	1.050	.884	.083	.857	.2660	.275	2.314	.6138
	80	405	X-Sig.	1.050	.824	.113	1.130	.2301	.275	2.168	.5330
	160	805	X-Sig.	1.050	.742	.154	1.473	.1875	.275	1.948	.4330
<b>3</b>	40	105	Std.	1.315	1.097	.109	1.404	.4090	.344	2.872	.9448
	80	405	X-Sig.	1.315	1.049	.133	1.678	.3740	.344	2.740	.8640
	160	805	X-Sig.	1.315	.957	.179	2.171	.3112	.344	2.550	.7190
<b>4</b>	40	105	Std.	1.660	1.442	.109	1.806	.7080	.434	3.775	1.633
	80	405	X-Sig.	1.660	1.380	.140	2.272	.6471	.434	3.680	1.495
	160	805	X-Sig.	1.660	1.278	.191	2.996	.5553	.434	3.356	1.283
<b>1 1/2</b>	40	105	Std.	1.900	1.682	.109	2.085	.9630	.497	4.403	2.221
	80	405	X-Sig.	1.900	1.610	.145	2.717	.8820	.497	4.213	2.036
	160	805	X-Sig.	1.900	1.500	.200	3.631	.7648	.497	3.927	1.767
<b>2</b>	40	105	Std.	2.375	2.157	.109	2.638	1.583	.622	5.647	3.654
	80	405	X-Sig.	2.375	2.067	.154	3.652	1.452	.622	5.401	3.355
	160	805	X-Sig.	2.375	2.041	.204	4.938	1.420	.622	5.360	3.280

# PROPERTIES OF PIPE (cont.)

Nom pipe size	Schedule No.		Weight designation	Outside diam. in.	Inside diam. in.	Wall thick- ness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Trans- verse area sq. in.
	Carbon & alloy steels	Stain- less steels									
<b>2 1/2</b>	40	105	Std.	2.875	2.635	.180	3.53	2.360	.753	.6900	5.453
	80	405	X-Sig.	2.875	2.469	.203	5.79	2.072	.753	.6462	4.788
	160	805	X-Sig.	2.875	2.441	.217	6.16	2.026	.753	.6381	4.680
<b>3</b>	40	105	Std.	3.500	3.260	.180	4.33	3.62	.916	.853	8.346
	80	405	X-Sig.	3.500	3.250	.185	4.52	3.60	.916	.851	8.300
	160	805	X-Sig.	3.500	3.204	.188	5.30	3.52	.916	.840	8.100
<b>4</b>	40	105	Std.	4.500	4.260	.180	5.61	4.78	1.047	.984	11.10
	80	405	X-Sig.	4.500	4.244	.188	5.99	4.75	1.047	.978	10.95
	160	805	X-Sig.	4.500	4.232	.194	6.96	4.66	1.047	.971	10.75
<b>1 1/2</b>	40	105	Std.	5.000	4.760	.180	6.61	5.80	1.178	1.105	13.98
	80	405	X-Sig.	5.000	4.744	.188	7.64	5.92	1.178	1.093	13.67
	160	805	X-Sig.	5.000	4.724	.188	8.56	5.80	1.178	1.082	13.39



## PROPERTIES OF PIPE (cont.)

Nom- inal pipe size	Schedule No.		Weight designa- tion	Outside diam- in.	Inside diam- in.	Wall thick- ness in.	Weight per foot lb.	Wt. of water per ft. pipe lb-sq. ft.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Trans- verse area sq. in.
	Carbon & alloy steels	Stain- less steels									
4 (cont.)	40	40S	Sid.	4.500	4.090	.305	9.39	5.71	1.178	1.071	13.15
	...	...	...	4.500	4.026	.237	10.79	5.51	1.178	1.055	12.73
	...	...	...	4.500	4.000	.250	11.35	5.45	1.178	1.049	12.57
	...	...	...	4.500	3.958	.271	12.24	5.35	1.178	1.038	12.31
	...	...	...	4.500	3.938	.281	12.67	5.27	1.178	1.031	12.17
	...	...	...	4.500	3.900	.300	13.42	5.19	1.178	1.023	11.96
	...	...	...	4.500	3.876	.312	14.00	5.12	1.178	1.013	11.80
	80	80S	X-Sig.	4.500	3.826	.337	14.98	4.98	1.178	1.002	11.50
	...	...	...	4.500	3.750	.375	16.52	4.78	1.178	.982	11.04
	150	...	...	4.500	3.624	.438	19.00	4.47	1.178	.949	10.32
	...	...	...	4.500	3.500	.500	21.36	4.16	1.178	.916	9.62
	160	...	...	4.500	3.438	.531	22.60	4.02	1.178	.900	9.28
	...	...	...	4.500	3.152	.674	27.54	3.38	1.178	.826	7.80
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
5	...	10S	Sid.	5.563	5.295	.134	7.770	9.54	1.456	1.386	22.02
	40	40S	Sid.	5.563	5.047	.258	14.62	8.66	1.456	1.321	20.01
	...	...	...	5.563	4.859	.352	19.59	8.06	1.456	1.272	18.60
	80	80S	X-Sig.	5.563	4.813	.375	20.78	7.87	1.456	1.260	18.19
	...	...	...	5.563	4.688	.437	23.95	7.47	1.456	1.227	17.26
	120	...	...	5.563	4.563	.500	27.10	7.08	1.456	1.195	16.35
	160	...	...	5.563	4.313	.625	32.96	6.32	1.456	1.129	14.61
	...	...	...	5.563	4.063	.750	38.55	5.62	1.456	1.064	12.97
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
6	...	10S	Sid.	6.625	6.357	.134	9.29	13.70	1.735	1.660	31.75
	...	...	...	6.625	6.287	.169	11.56	13.45	1.735	1.650	31.00
	...	...	...	6.625	6.255	.180	12.50	13.38	1.735	1.640	30.81
	...	...	...	6.625	6.249	.188	12.93	13.31	1.735	1.639	30.70
	...	...	...	6.625	6.187	.219	15.02	13.05	1.735	1.620	30.10
	...	...	...	6.625	6.125	.250	17.02	12.80	1.735	1.606	29.50
	...	...	...	6.625	6.071	.277	18.86	12.55	1.735	1.591	28.95
	40	40S	Sid.	6.625	6.065	.280	18.97	12.51	1.735	1.587	28.99
	...	...	...	6.625	5.875	.375	25.10	11.75	1.735	1.540	27.10
	80	80S	X-Sig.	6.625	5.761	.432	28.57	11.29	1.735	1.510	26.07
8	...	...	...	6.625	5.625	.500	32.79	10.85	1.735	1.475	24.85
	...	...	...	6.625	5.501	.562	36.40	10.30	1.735	1.470	23.77
	120	...	...	6.625	5.189	.718	45.30	9.16	1.735	1.359	21.15
	160	...	...	6.625	4.897	.864	53.16	8.14	1.735	1.280	18.83
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...

## PROPERTIES OF PIPE (cont.)

Nom- inal pipe size	Schedule No.		Weight designa- tion	Outside diam- in.	Inside diam- in.	Wall thick- ness in.	Weight per foot lb.	Wt. of water per ft. pipe lb-sq. ft.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Trans- verse area sq. in.
	Carbon & alloy steels	Stain- less steels									
8	...	...	...	8.625	8.149	.238	21.43	22.7	2.26	2.136	52.2
	20	...	...	8.625	8.125	.250	22.40	22.5	2.26	2.127	51.8
	30	...	...	8.625	8.071	.277	24.70	22.2	2.26	2.115	51.2
	40	40S	Sid.	8.625	7.981	.322	28.55	21.6	2.26	2.090	50.0
	...	...	...	8.625	7.937	.344	30.40	21.4	2.26	2.078	49.5
	...	...	...	8.625	7.921	.352	31.00	21.3	2.26	2.072	49.3
	...	...	...	8.625	7.875	.375	33.10	21.1	2.26	2.062	48.7
	60	...	...	8.625	7.813	.406	35.70	20.8	2.26	2.045	47.9
	...	...	...	8.625	7.687	.469	40.83	20.1	2.26	2.013	46.4
	80	80S	X-Sig.	8.625	7.625	.500	43.39	19.8	2.26	2.006	45.6
10	...	...	...	8.625	7.439	.593	50.90	18.8	2.26	1.947	43.5
	100	...	...	8.625	7.375	.625	53.40	18.5	2.26	1.931	42.7
	...	...	...	8.625	7.189	.718	60.70	17.6	2.26	1.882	40.6
	...	...	...	8.625	7.001	.812	67.80	16.7	2.26	1.833	38.5
	...	...	...	8.625	6.875	.875	72.42	16.1	2.26	1.800	37.1
	160	...	...	8.625	6.813	.906	74.70	15.8	2.26	1.784	36.4
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
12	...	...	...	10.750	10.480	.165	18.65	36.9	2.81	2.73	85.3
	20	...	...	10.750	10.374	.188	21.12	36.7	2.81	2.72	84.5
	30	...	...	10.750	10.344	.203	22.86	36.5	2.81	2.71	84.0
	40	40S	Sid.	10.750	10.136	.307	34.24	35.0	2.81	2.65	80.7
	...	...	...	10.750	10.054	.348	38.66	34.4	2.81	2.64	79.3
	...	...	...	10.750	10.020	.365	40.48	34.1	2.81	2.62	78.9
	...	...	...	10.750	9.960	.395	43.68	33.7	2.81	2.61	77.9
	60	80S	X-Sig.	10.750	9.750	.500	54.74	32.3	2.81	2.55	74.7
	...	...	...	10.750	9.687	.531	57.98	31.9	2.81	2.54	73.7
	80	...	...	10.750	9.564	.593	64.40	31.1	2.81	2.50	71.8
16	...	...	...	10.750	9.314	.718	77.00	29.5	2.81	2.44	68.1
	100	...	...	10.750	9.250	.750	80.10	29.1	2.81	2.42	67.2
	120	...	...	10.750	9.064	.843	89.20	27.9	2.81	2.37	64.5
	140	...	...	10.750	8.750	1.000	104.20	26.1	2.81	2.29	60.1
	160	...	...	10.750	8.625	1.063	109.90	25.3	2.81	2.26	58.4
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...
	...	...	...	...	...	...	...	...	...	...	...

MEASURES



## PROPERTIES OF PIPE (cont.)

Nom- inal pipe size	Schedule No.		Weight designa- tion	Outside diam- in.	Inside diam- in.	Wall thick- ness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Trans- verse area sq. in.
	Carbon & alloy steels	Stain- less steels									
<b>12</b> (CONT.)	...	...	...	12.750	12.192	.279	37.2	50.7	3.34	3.19	116.9
	...	...	...	12.750	12.150	.300	40.0	50.5	3.34	3.18	116.1
	30	...	...	12.750	12.090	.330	43.8	49.7	3.34	3.16	114.8
	...	...	...	12.750	12.062	.344	45.5	49.7	3.34	3.16	114.5
	...	40S	Sid.	12.750	12.000	.375	49.6	48.9	3.34	3.14	113.1
	40	...	...	12.750	11.938	.406	53.6	48.5	3.34	3.13	111.9
	...	...	...	12.750	11.874	.438	57.5	48.2	3.34	3.11	111.0
	...	...	...	12.750	11.750	.500	65.4	46.9	3.34	3.08	108.4
	...	...	...	12.750	11.626	.562	73.2	46.0	3.34	3.04	106.2
	...	80S	X-Sig.	12.750	11.500	.625	80.9	44.9	3.34	3.01	103.8
<b>14</b>	...	...	...	12.750	11.376	.687	88.6	44.0	3.34	2.98	101.6
	80	...	...	12.750	11.064	.843	108.0	41.6	3.34	2.90	96.1
	100	...	...	12.750	11.000	.875	110.9	41.1	3.34	2.88	95.0
	...	...	...	12.750	10.750	1.000	125.5	39.3	3.34	2.81	90.8
	120	...	...	12.750	10.500	1.125	140.0	37.5	3.34	2.75	86.6
	140	...	...	12.750	10.313	1.219	150.1	36.3	3.34	2.70	83.8
	160	...	...	12.750	10.126	1.312	161.0	34.9	3.34	2.65	80.5
	...	...	...	14.000	13.624	.188	28	63.4	3.67	3.57	146.0
	...	...	...	14.000	13.560	.220	32	63.0	3.67	3.55	145.0
	...	...	...	14.000	13.524	.238	35	62.5	3.67	3.54	144.0
<b>16</b>	...	...	...	14.000	13.500	.250	37	62.1	3.67	3.54	143.0
	10	...	...	14.000	13.375	.312	46	60.8	3.67	3.50	140.5
	20	...	Sid.	14.000	13.250	.375	55	59.7	3.67	3.47	137.9
	30	...	...	14.000	13.188	.406	58	59.5	3.67	3.45	137.0
	40	...	...	14.000	13.124	.438	63	58.5	3.67	3.44	135.3
	...	...	...	14.000	13.062	.469	68	58.1	3.67	3.42	134.0
	...	...	...	14.000	13.000	.500	72	57.4	3.67	3.40	132.7
	60	...	X-Sig.	14.000	12.814	.593	85	55.9	3.67	3.35	129.0
	...	...	...	14.000	12.750	.625	89	55.3	3.67	3.34	127.7
	...	...	...	14.000	12.688	.656	94	54.7	3.67	3.32	126.4
<b>18</b>	...	...	...	14.000	12.500	.750	107	51.2	3.67	3.27	122.7
	80	...	...	14.000	12.125	.937	131	50.0	3.67	3.17	115.5
	100	...	...	14.000	11.814	1.093	151	47.5	3.67	3.09	109.6
	120	...	...	14.000	11.500	1.250	171	45.0	3.67	3.01	103.9
	140	...	...	14.000	11.313	1.344	182	43.5	3.67	2.96	100.5
	160	...	...	14.000	11.188	1.406	190	42.6	3.67	2.93	98.3

## PROPERTIES OF PIPE (cont.)

Nom- inal pipe size	Schedule No.		Weight designa- tion	Outside diam- in.	Inside diam- in.	Wall thick- ness in.	Weight per foot lb.	Wt. of water per ft. pipe lb.	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Trans- verse area sq. in.
	Carbon & alloy steels	Stain- less steels									
<b>16</b>	...	...	...	16.000	15.624	.188	32	83.3	4.20	4.09	192.0
	...	...	...	16.000	15.524	.238	40	82.5	4.20	4.06	190.0
	10	...	...	16.000	15.500	.250	42	82.1	4.20	4.06	189.0
	...	...	...	16.000	15.438	.281	47	81.2	4.20	4.04	187.0
	...	...	...	16.000	15.375	.312	52	80.1	4.20	4.03	185.6
	20	...	...	16.000	15.312	.344	57	80.0	4.20	4.01	184.1
	30	...	Sid.	16.000	15.250	.375	63	79.1	4.20	4.00	182.6
	...	...	...	16.000	15.188	.406	68	78.6	4.20	3.98	181.0
	...	...	...	16.000	15.124	.438	73	78.2	4.20	3.96	180.0
	...	...	...	16.000	15.062	.469	78	77.5	4.20	3.94	178.5
<b>18</b>	...	...	...	16.000	15.000	.500	83	76.5	4.20	3.93	176.7
	40	...	X-Sig.	16.000	14.938	.531	88	75.8	4.20	3.91	175.2
	...	...	...	16.000	14.868	.556	108	73.4	4.20	3.85	169.4
	60	...	...	16.000	14.655	.687	112	72.7	4.20	3.83	168.0
	...	...	...	16.000	14.500	.750	122	71.5	4.20	3.80	165.1
	80	...	...	16.000	14.314	.843	137	69.7	4.20	3.75	160.9
	100	...	...	16.000	13.938	1.031	165	66.0	4.20	3.65	152.6
	120	...	...	16.000	13.564	1.218	193	62.6	4.20	3.55	144.5
	...	...	...	16.000	13.124	1.438	224	58.6	4.20	3.44	135.3
	140	...	...	16.000	13.000	1.500	232	57.4	4.20	3.40	132.7
<b>20</b>	160	...	...	16.000	12.814	1.593	245	55.9	4.20	3.35	129.0
	...	...	...	18.000	17.500	.250	47	104.6	4.71	4.58	241.0
	10	...	...	18.000	17.375	.312	59	102.5	4.71	4.55	237.1
	20	...	Sid.	18.000	17.250	.375	71	101.2	4.71	4.51	233.7
	30	...	...	18.000	17.124	.438	82	99.5	4.71	4.48	229.5
	40	...	...	18.000	17.000	.500	93	98.2	4.71	4.45	227.0
	...	...	...	18.000	16.876	.562	105	97.2	4.71	4.42	224.0
	...	...	...	18.000	16.813	.594	110	96.1	4.71	4.40	222.0
	...	...	...	18.000	16.750	.625	116	95.8	4.71	4.39	220.5
	60	...	X-Sig.	18.000	16.500	.750	138	92.5	4.71	4.32	213.8
<b>24</b>	...	...	...	18.000	16.375	.812	149	91.2	4.71	4.29	210.6
	...	...	...	18.000	16.126	.937	171	88.5	4.71	4.22	204.2
	80	...	...	18.000	15.688	1.156	208	83.7	4.71	4.11	193.3
	100	...	...	18.000	15.250	1.375	244	79.2	4.71	3.99	182.7
	120	...	...	18.000	14.876	1.562	275	75.3	4.71	3.89	173.8
	140	...	...	18.000	14.625	1.687	294	72.7	4.71	3.83	168.0
	160	...	...	18.000	14.438	1.781	309	71.0	4.71	3.78	163.7

MEASURES



PROPERTIES OF PIPE (cont.)

Nom- inal pipe size	Schedule No.	Stain- less steels	Weight designa- tion	Outside diam. in.	Inside diam. in.	Wall thick- ness in.	Weight per foot lb.	Wt. of water per ft. pipe lb	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Trans- verse area sq. in.
20	10	...	...	20.000	19.500	.250	53	130.0	5.24	5.11	299.0
	...	...	...	20.000	19.374	.313	66	128.1	5.24	5.08	295.0
	20	...	Std.	20.000	19.250	.375	79	126.0	5.24	5.04	291.1
	...	...	...	20.000	19.124	.438	92	125.1	5.24	5.01	288.0
	30	...	X-Sig.	20.000	19.000	.500	105	122.8	5.24	4.97	283.5
	...	...	...	20.000	18.875	.562	117	121.1	5.24	4.94	279.8
	40	...	...	20.000	18.814	.593	123	120.4	5.24	4.93	278.0
	60	...	...	20.000	18.750	.625	129	119.5	5.24	4.91	276.1
	...	...	...	20.000	18.376	.812	167	114.9	5.24	4.81	265.2
	...	...	...	20.000	18.250	.875	179	113.2	5.24	4.78	261.6
22	...	...	...	20.000	18.188	.906	185	112.7	5.24	4.76	256.8
	80	...	...	20.000	17.938	1.031	209	109.4	5.24	4.80	252.7
	100	...	...	20.000	17.438	1.281	256	103.4	5.24	4.56	238.8
	120	...	...	20.000	17.000	1.500	297	98.3	5.24	4.45	227.0
	140	...	...	20.000	16.500	1.750	342	92.6	5.24	4.32	213.8
	...	...	...	20.000	16.313	1.844	357	90.5	5.24	4.27	209.0
	160	...	...	20.000	16.064	1.968	379	87.9	5.24	4.21	202.7
	...	...	...	22.000	21.500	.250	58	157.4	5.76	5.63	363.1
	...	...	...	22.000	21.376	.312	72	155.6	5.76	5.60	358.9
	...	...	...	22.000	21.250	.375	87	153.7	5.76	5.56	354.7
24	...	...	...	22.000	21.126	.437	103	152.0	5.76	5.53	350.5
	...	...	...	22.000	21.000	.500	115	150.2	5.76	5.50	346.4
	...	...	...	22.000	20.876	.562	129	148.4	5.76	5.47	342.3
	...	...	...	22.000	20.750	.625	143	146.6	5.76	5.43	338.2
	...	...	...	22.000	20.624	.688	157	144.8	5.76	5.40	334.1
	...	...	...	22.000	20.500	.750	170	143.1	5.76	5.37	330.1
	10	...	...	24.000	23.500	.250	63	189.0	6.28	6.15	435.0
	...	...	...	24.000	23.376	.312	79	186.9	6.28	6.12	430.0
	20	...	Std.	24.000	23.250	.375	95	183.8	6.28	6.09	424.6
	...	...	X-Sig.	24.000	23.125	.437	110	181.8	6.28	6.05	420.0

PROPERTIES OF PIPE (cont.)

Nom- inal pipe size	Schedule No.	Stain- less steels	Weight designa- tion	Outside diam. in.	Inside diam. in.	Wall thick- ness in.	Weight per foot lb.	Wt. of water per ft. pipe lb	Outside surface per ft. sq. ft.	Inside surface per ft. sq. ft.	Trans- verse area sq. in.
24	120	...	...	24.000	20.376	1.812	429	141.4	6.28	5.33	326.1
	140	...	...	24.000	19.876	2.062	484	134.4	6.28	5.20	310.3
	160	...	...	24.000	19.625	2.187	510	130.9	6.28	5.14	302.0
	...	...	...	24.000	19.314	2.343	542	127.0	6.28	5.06	293.1
	...	...	...	26.000	25.500	.250	67	221.4	6.81	6.68	510.7
	...	...	...	26.000	25.376	.312	84	219.2	6.81	6.64	505.8
	...	...	...	26.000	25.250	.375	103	217.1	6.81	6.61	500.7
	...	...	...	26.000	25.126	.437	119	215.0	6.81	6.58	495.8
	...	...	...	26.000	25.000	.500	136	212.8	6.81	6.54	490.9
	...	...	...	26.000	24.876	.562	153	210.7	6.81	6.51	486.0
26	...	...	...	26.000	24.750	.625	169	208.6	6.81	6.48	481.1
	...	...	...	26.000	24.624	.688	186	206.4	6.81	6.45	476.2
	...	...	...	26.000	24.500	.750	202	204.4	6.81	6.41	471.4
	10	...	...	30.000	29.376	.312	99	293.7	7.85	7.69	677.8
	...	...	...	30.000	29.250	.375	119	291.2	7.85	7.66	672.0
	20	...	...	30.000	29.125	.437	138	288.7	7.85	7.62	666.2
	...	...	...	30.000	29.000	.500	158	286.2	7.85	7.59	660.5
	...	...	...	30.000	28.875	.562	177	283.7	7.85	7.56	654.8
	...	...	...	30.000	28.750	.625	196	281.3	7.85	7.53	649.2
	...	...	...	...	...	...	...	...	...	...	...

MEASURES



## DIMENSIONS OF PIPE

ANSI B 36.10

1. All Dimensions are in inches
2. The Nominal Wall Thicknesses shown are subject to a 12.5% Mill Tolerance
3. Not included in standard ANSI B 36.10

Nominal Pipe Size	Outside Diameter	NOMINAL WALL THICKNESS													Nominal Pipe Size
		Sched. 10	Sched. 20	Sched. 30	Std. Weight	Sched. 40	Sched. 60	Extra Strong	Sched. 80	Sched. 100	Sched. 120	Sched. 140	Sched. 160	XX Strong	
1/8	0.405	--	--	--	0.068	0.068	--	0.095	0.095	--	--	--	--	--	1/8
1/4	0.540	--	--	--	0.088	0.088	--	0.119	0.119	--	--	--	--	--	1/4
3/8	0.675	--	--	--	0.091	0.091	--	0.126	0.126	--	--	--	--	--	3/8
1/2	0.840	--	--	--	0.109	0.109	--	0.147	0.147	--	--	--	0.187	0.294	1/2
3/4	1.050	--	--	--	0.113	0.113	--	0.154	0.154	--	--	--	0.218	0.308	3/4
1	1.315	--	--	--	0.133	0.133	--	0.179	0.179	--	--	--	0.250	0.358	1
1 1/4	1.660	--	--	--	0.140	0.140	--	0.191	0.191	--	--	--	0.250	0.382	1 1/4
1 1/2	1.900	--	--	--	0.145	0.145	--	0.200	0.200	--	--	--	0.281	0.400	1 1/2
2	2.375	--	--	--	0.154	0.154	--	0.218	0.218	--	--	--	0.343	0.436	2
2 1/2	2.875	--	--	--	0.203	0.203	--	0.276	0.276	--	--	--	0.375	0.552	2 1/2
3	3.500	--	--	--	0.216	0.216	--	0.300	0.300	--	--	--	0.438	0.600	3
3 1/2	4.000	--	--	--	0.226	0.226	--	0.318	0.318	--	--	--	--	0.636 <sup>3</sup>	3 1/2
4	4.500	--	--	--	0.237	0.237	--	0.337	0.337	--	0.438	--	0.531	0.674	4
5	5.563	--	--	--	0.258	0.258	--	0.375	0.375	--	0.500	--	0.625	0.750	5
6	6.625	--	--	--	0.280	0.280	--	0.432	0.432	--	0.562	--	0.718	0.864	6
8	8.625	--	0.250	0.277	0.322	0.322	0.406	0.500	0.500	0.593	0.718	0.812	0.906	0.875	8
10	10.750	--	0.250	0.307	0.365	0.365	0.500	0.500	0.593	0.718	0.843	1.000	1.125	--	10
12	12.750	--	0.250	0.330	0.375	0.406	0.562	0.500	0.687	0.843	1.000	1.125	1.312	--	12
14	14.000	0.250	0.312	0.375	0.375	0.438	0.593	0.500	0.750	0.937	1.093	1.250	1.406	--	14
16	16.000	0.250	0.312	0.375	0.375	0.500	0.656	0.500	0.843	1.031	1.218	1.438	1.593	--	16
18	18.000	0.250	0.312	0.438	0.375	0.562	0.750	0.500	0.937	1.156	1.375	1.562	1.781	--	18
20	20.000	0.250	0.375	0.500	0.375	0.593	0.812	0.500	1.031	1.281	1.500	1.750	1.968	--	20
24	24.000	0.250	0.375	0.562	0.375	0.687	0.968	0.500	1.218	1.531	1.812	2.062	2.343	--	24
30 <sup>3</sup>	30.000	0.312	0.500	0.675	0.375 <sup>3</sup>	--	--	0.500 <sup>3</sup>	--	--	--	--	--	--	30

NOTES

MEASURES



## PROPERTIES OF STEEL TUBING

O.D. of Tubing Inches	Wall Thickness Inches	Internal Area Sq. In.	External Surface Per Ft. Length	Internal Surface Per Ft. Length	Theoretical Weight Per Ft. Length	Constant C*	O.D. I.D.	Metal Area (Transverse Metal Area) Sq. In.
5/8	.125	.1104	.1636	.0982	.668	.375	.172	1.667
5/8	.110	.1288	.1636	.1060	.605	.405	.201	1.543
5/8	.105	.1353	.1636	.1086	.583	.415	.211	1.506
5/8	.095	.1486	.1636	.1139	.538	.435	.232	1.382
5/8	.085	.1626	.1636	.1191	.490	.455	.254	1.264
5/8	.075	.1772	.1636	.1244	.441	.475	.276	1.144
5/8	.065	.1924	.1636	.1296	.389	.495	.300	1.023
5/8	.060	.2003	.1636	.1322	.362	.505	.312	1.065
5/8	.055	.2083	.1636	.1348	.335	.515	.325	1.0985
5/8	.050	.2165	.1636	.1374	.307	.525	.338	1.190
3/4	.150	.1590	.1963	.1178	.961	.430	.248	1.667
3/4	.135	.1810	.1963	.1257	.887	.480	.282	1.563
3/4	.125	.1964	.1963	.1309	.834	.500	.306	1.500
3/4	.110	.2206	.1963	.1388	.752	.530	.344	1.415
3/4	.105	.2290	.1963	.1414	.723	.540	.357	1.389
3/4	.095	.2463	.1963	.1466	.665	.560	.384	1.339
3/4	.085	.2642	.1963	.1518	.604	.580	.412	1.293
3/4	.075	.2827	.1963	.1571	.541	.600	.441	1.250
3/4	.065	.3019	.1963	.1623	.476	.620	.471	1.210
3/4	.060	.3117	.1963	.1649	.442	.630	.486	1.190
3/4	.055	.3217	.1963	.1676	.408	.640	.502	1.172
3/4	.050	.3318	.1963	.1702	.374	.650	.518	1.154
7/8	.150	.2297	.2291	.1505	1.161	.575	.405	1.522
7/8	.135	.2875	.2291	.1584	1.067	.605	.448	1.446
7/8	.125	.3068	.2291	.1636	1.001	.625	.478	1.400
7/8	.110	.3370	.2291	.1715	.899	.655	.526	1.336
7/8	.105	.3473	.2291	.1741	.863	.665	.542	1.316
7/8	.095	.3685	.2291	.1793	.791	.685	.575	1.277
7/8	.085	.3904	.2291	.1846	.717	.705	.609	1.241
7/8	.075	.4128	.2291	.1898	.641	.725	.644	1.207
7/8	.065	.4359	.2291	.1950	.562	.745	.680	1.174
7/8	.060	.4477	.2291	.1977	.522	.755	.698	1.159
7/8	.055	.4596	.2291	.2003	.482	.765	.717	1.144
7/8	.050	.4717	.2291	.2029	.441	.775	.736	1.129
1	.150	.3848	.2618	.1833	1.362	.700	.600	1.429
1	.135	.4185	.2618	.1911	1.247	.730	.653	1.370
1	.125	.4418	.2618	.1964	1.168	.750	.689	1.333
1	.110	.4778	.2618	.2042	1.046	.780	.745	1.282
1	.105	.4902	.2618	.2068	1.004	.790	.764	1.266
1	.095	.5153	.2618	.2121	.918	.810	.804	1.235
1	.085	.5411	.2618	.2173	.831	.830	.844	1.205
1	.075	.5675	.2618	.2225	.741	.850	.885	1.176
1	.065	.5945	.2618	.2278	.649	.870	.927	1.149
1	.060	.6082	.2618	.2304	.602	.880	.949	1.136
1	.055	.6221	.2618	.2330	.555	.890	.970	1.124
1	.050	.6362	.2618	.2356	.507	.900	.992	1.111

\* Liquid velocity in feet/second = pounds per tube per hour

C x specific gravity of liquid

Specific gravity of water at 60 deg. F = 1.0

Courtesy of HEAT EXCHANGE INSTITUTE

## PROPERTIES OF TUBING

W.C. Tube Size	Thick- ness Inches	Internal Area Sq. In.	External Surface Per Ft. Length	Internal Surface Per Ft. Length	Weight per Ft. Lbs.	Weight per Ft. Copper Lbs.	Weight per Ft. Steel Lbs.	I.D. Inches	Constant C*	O.D. I.D.	Metal Area (Transverse Metal Area) Sq. In.
10	.134	.1001	.1636	.0935	.766	.801	.703	.357	156	1.751	.2067
11	.120	.1164	.1636	.1008	.705	.738	.647	.385	163	1.623	.1904
12	.109	.1301	.1636	.1066	.655	.685	.601	.407	203	1.536	.1767
13	.095	.1486	.1636	.1139	.586	.613	.538	.435	232	1.437	.1582
14	.083	.1655	.1636	.1202	.524	.548	.480	.459	238	1.362	.1413
15	.072	.1817	.1636	.1259	.464	.485	.425	.481	283	1.299	.1251
16	.065	.1924	.1636	.1296	.424	.443	.389	.495	300	1.263	.1144
18	.058	.2035	.1636	.1333	.383	.400	.351	.509	317	1.228	.1033
19	.049	.2181	.1636	.1380	.329	.344	.301	.527	340	1.186	.0887
20	.042	.2299	.1636	.1416	.285	.298	.262	.541	359	1.155	.0769
21	.038	.2419	.1636	.1453	.240	.251	.221	.555	377	1.126	.0649
22	.028	.2543	.1636	.1490	.195	.204	.179	.569	397	1.098	.0525
24	.134	.1825	.1963	.1262	.961	1.005	.882	.482	285	1.556	.2593
26	.120	.2043	.1963	.1335	.880	.920	.807	.510	319	1.471	.2375
28	.109	.2223	.1963	.1393	.813	.851	.746	.532	347	1.410	.2195
30	.095	.2463	.1963	.1466	.724	.758	.665	.560	384	1.339	.1955
32	.083	.2679	.1963	.1529	.644	.674	.591	.584	418	1.284	.1739
34	.072	.2884	.1963	.1587	.568	.594	.521	.606	450	1.238	.1534
36	.065	.3019	.1963	.1633	.518	.542	.476	.620	471	1.210	.1399
38	.058	.3157	.1963	.1660	.467	.489	.429	.634	492	1.183	.1261
40	.049	.3349	.1963	.1707	.400	.418	.368	.652	521	1.150	.1079
42	.042	.3484	.1963	.1744	.346	.362	.318	.666	543	1.126	.0934
44	.035	.3632	.1963	.1780	.291	.305	.267	.680	566	1.103	.0786
46	.028	.3783	.1963	.1817	.235	.246	.216	.694	590	1.081	.0635
48	.134	.2884	.2291	.1589	1.156	1.209	1.060	.607	451	1.442	.3119
50	.120	.3167	.2291	.1662	1.035	1.103	.968	.635	494	1.378	.2846
52	.109	.3390	.2291	.1720	.932	1.017	.892	.657	529	1.332	.2623
54	.095	.3685	.2291	.1793	.863	.902	.791	.685	575	1.277	.2328
56	.083	.3948	.2291	.1856	.765	.800	.702	.709	616	1.234	.2065
58	.072	.4197	.2291	.1914	.673	.704	.617	.731	655	1.197	.1816
60	.065	.4359	.2291	.1950	.613	.641	.562	.745	680	1.174	.1654
62	.058	.4525	.2291	.1987	.552	.577	.509	.759	709	1.153	.1489
64	.049	.4742	.2291	.2034	.471	.493	.432	.777	740	1.126	.1272
66	.042	.4914	.2291	.2071	.407	.426	.374	.791	766	1.106	.1099
68	.035	.5090	.2291	.2107	.342	.358	.314	.805	794	1.087	.0924
70	.028	.5268	.2291	.2144	.276	.289	.253	.819	822	1.068	.0745
72	.134	.4208	.2618	.1916	1.351	1.413	1.239	.732	656	1.366	.3646
74	.120	.4556	.2618	.1990	1.229	1.286	1.128	.760	707	1.316	.3318
76	.109	.4803	.2618	.2047	1.131	1.182	1.037	.782	749	1.279	.3051
78	.095	.5133	.2618	.2121	1.001	1.047	.918	.810	804	1.235	.2701
80	.083	.5463	.2618	.2183	.886	.927	.813	.834	852	1.199	.2391
82	.072	.5755	.2618	.2241	.778	.814	.714	.856	898	1.168	.2099
84	.065	.5945	.2618	.2278	.708	.740	.649	.870	927	1.149	.1909
86	.058	.6138	.2618	.2314	.636	.665	.584	.884	957	1.131	.1716
88	.049	.6390	.2618	.2361	.542	.567	.498	.902	997	1.109	.1464
90	.042	.6590	.2618	.2398	.468	.490	.430	.916	1028	1.092	.1264
92	.038	.6793	.2618	.2435	.393	.411	.361	.930	1059	1.075	.1061
94	.028	.6999	.2618	.2471	.317	.331	.291	.944	1092	1.059	.0855

Weights of other materials — Multiply carbon

steel weights by the following factors:

90-10 Cu. Ni. Alloy 706 - 1.140

70-30 Cu. Ni. Alloy 715 - 1.140

70-30 Ni. Cu. Alloy 400 - 1.126

TP304 Stainless Steel - 1.013

C x specific gravity of liquid

Specific gravity of water at 60 deg. F = 1.0

Courtesy of HEAT EXCHANGE INSTITUTE



## HEADS

For vessels of small and medium diameters ellipsoidal heads are used most commonly, while large diameter vessels are usually built with hemispherical or flanged and dished heads.

Heads may be of seamless or welded construction.

### STRAIGHT FLANGE

Formed heads butt-welded to the shell need not have straight flange when the head is not thicker than the shell according to the Code Par. UG-32 & 33, but in practice heads except hemisphericals are used with straight flanges. The usual length of straight flanges: 2 inches for ellipsoidal, 1 1/2 inches for flanged and dished and 0 inches for hemispherical heads.

Formed heads thicker than the shell and butt-welded to it shall have straight flange.

On the following pages the data of the most commonly used heads are listed. The dimensions of flanged and dished heads meet the requirements of ASME Code.

WEIGHT OF HEADS See tables beginning on page 374

VOLUME OF HEADS See page 416

SURFACE OF HEADS See page 425

## DIMENSIONS OF HEADS

### SYMBOLS USED IN THE TABLES

$D$  = inside diameter of hemispherical and ellipsoidal heads, outside diameter of ASME flanged & dished heads.

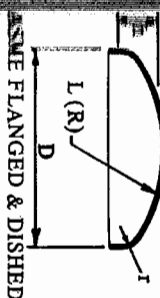
$h$  = inside depth of dish of F & D heads

$L(R)$  = inside radius of dish of ASME flanged & dished heads as used in formulas for internal or external pressure.

$M$  = factor used in formulas for internal pressure.

$r$  = inside knuckle radius of ASME flanged & dished heads.

$t$  = wall thickness, nominal or minimum.



ASME FLANGED & DISHED

ALL DIMENSIONS IN INCHES

HEAD TYPE	D	WALL THICKNESS							
		3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
14	L (R)	12	12	12					
	r	1.125	1.500	1.875					
	h	2.625	2.750	2.938					
16	L (R)	15	15	14	14				
	r	1.125	1.500	1.875	2.250				
	h	2.750	2.875	3.188	3.375				
18	L (R)	18	16	15	15	18			
	r	1.125	1.500	1.875	2.250	2.625			
	h	2.875	3.313	3.563	3.750	3.625			
20	L (R)	18	18	18	18	18	18		
	r	1.250	1.500	1.875	2.250	2.625	3.000		
	h	3.500	3.563	3.750	3.875	4.063	4.250		
22	L (R)	21	20	20	20	20	20	20	
	r	1.375	1.500	1.875	2.250	2.625	3.000	3.375	
	h	3.688	3.813	4.000	4.188	4.313	4.500	4.688	
24	L (R)	24	24	24	24	24	24	24	24
	r	1.500	1.500	1.875	2.250	2.625	3.000	3.375	3.750
	h	3.875	3.813	4.000	4.188	4.375	4.563	4.813	5.000
26	L (R)	24	24	24	24	24	24	24	24
	r	1.500	1.500	1.875	2.250	2.625	3.000	3.375	3.750
	h	3.875	3.813	4.000	4.188	4.375	4.563	4.813	5.000

MEASURES



## DIMENSIONS OF HEADS

**ALL DIMENSIONS IN INCHES**

[illegible]

## DIMENSIONS OF HEADS

**ALL DIMENSIONS IN INCHES**

WALL THICKNESS									
	1½	15⁄8	1¾	17⁄8	2	2¼	2½	2¾	3
L(R)									
15									
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### DIMENSIONS OF HEADS

ALL DIMENSIONS IN INCHES

DIAM ETER D	WALL THICKNESS										
	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$		
66	L (R)	66	66	60	60	60	60	60	60		
	r	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.125		
	h	11.000	10.938	11.750	11.625	11.563	11.500	11.438	11.375		
72	L (R)	72	72	72	66	66	66	66	66		
	r	4.375	4.375	4.375	4.375	4.375	4.375	4.375	4.375		
	h	12.000	11.938	11.875	12.625	12.500	12.438	12.375	12.313		
78	L (R)	78	72	72	72	72	72	72	72		
	r	4.750	4.750	4.750	4.750	4.750	4.750	4.750	4.750		
	h	13.000	13.813	13.750	13.688	13.563	13.500	13.438	13.313		
84	L (R)	84	84	84	84	84	84	84	84		
	r	5.125	5.125	5.125	5.125	5.125	5.125	5.125	5.125		
	h	14.000	13.938	13.875	13.813	13.750	13.688	14.438	14.375		
90	L (R)	90	84	84	84	84	84	84	84		
	r	5.500	5.500	5.500	5.500	5.500	5.500	5.500	5.500		
	h	15.125	15.813	15.750	15.688	15.625	15.563	15.500	15.438		
96	L (R)	96	90	90	90	90	90	90	84		
	r	5.875	5.875	5.875	5.875	5.875	5.875	5.875	5.875		
	h	16.125	16.875	16.813	16.750	16.625	16.563	16.500	16.438		
102	L (R)	96	96	96	96	96	90	90	90		
	r	6.125	6.125	6.125	6.125	6.125	6.125	6.125	6.125		
	h	17.938	17.875	17.750	17.688	17.625	17.563	18.500	18.375		
108	L (R)	102	102	102	102	102	96	96	96		
	r	6.500	6.500	6.500	6.500	6.500	6.500	6.500	6.500		
	h	18.938	18.875	18.750	18.688	18.563	19.438	19.375	19.313		
114	L (R)	108	108	108	108	108	108	108	108		
	r	6.875	6.875	6.875	6.875	6.875	6.875	6.875	6.875		
	h	19.875	19.813	19.750	19.685	19.625	19.563	19.500	19.438		
120	L (R)	114	114	114	114	114	108	108	108		
	r	7.250	7.250	7.250	7.250	7.250	7.250	7.250	7.250		
	h	20.875	20.813	20.750	20.688	20.625	21.500	21.438	21.375		
126	L (R)	120	120	120	120	120	120	120	114		
	r	7.625	7.625	7.625	7.625	7.625	7.625	7.625	7.625		
	h	21.875	21.813	21.750	21.688	21.625	21.563	21.500	22.313		
132	L (R)	126	126	126	120	120	120	120	120		
	r	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000		
	h	22.875	22.813	23.688	23.563	23.500	23.438	23.375	23.750		

### DIMENSIONS OF HEADS

ALL DIMENSIONS IN INCHES

	WALL THICKNESS										
	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{3}{4}$	3		
66	L (R)	60	60	60	60	60	60	60	60		
	r	4.500	4.875	5.250	5.625	6.000	6.375	6.750	7.125		
	h	11.500	11.688	11.813	12.000	12.125	12.438	12.813	13.125		
72	L (R)	66	66	66	66	66	66	66	66		
	r	4.500	4.875	5.250	5.625	6.000	6.375	6.750	7.125		
	h	12.313	12.500	12.625	12.750	12.938	13.250	13.563	13.938		
78	L (R)	72	72	72	72	72	72	72	72		
	r	4.75	4.875	5.250	5.625	6.000	6.375	6.750	7.125		
	h	13.250	13.250	13.438	13.563	13.750	14.063	14.375	14.750		
84	L (R)	78	78	78	78	78	78	78	78		
	r	5.125	5.125	5.250	5.625	6.000	6.375	6.750	7.125		
	h	14.250	14.188	14.250	14.375	14.500	14.875	15.188	15.500		
90	L (R)	84	84	84	84	84	84	84	84		
	r	5.500	5.500	5.500	5.625	6.000	6.375	6.750	7.125		
	h	15.250	15.188	15.125	15.188	15.313	15.625	16.000	16.313		
96	L (R)	84	84	84	84	84	84	84	84		
	r	5.875	5.875	5.875	5.875	6.000	6.375	6.750	7.125		
	h	17.250	17.125	17.063	17.000	17.063	17.313	17.625	18.188		
102	L (R)	90	90	90	90	90	90	90	90		
	r	6.125	6.125	6.125	6.125	6.125	6.125	6.125	6.125		
	h	18.125	18.125	18.063	18.000	17.938	18.125	18.375	18.688		
108	L (R)	96	96	96	96	96	96	96	96		
	r	6.500	6.500	6.500	6.500	6.500	6.500	6.500	6.500		
	h	19.250	19.125	19.063	19.000	18.938	19.188	19.500	19.813		
114	L (R)	102	102	102	102	102	102	102	102		
	r	6.875	6.875	6.875	6.875	6.875	6.875	6.875	6.875		
	h	20.313	20.125	20.063	20.000	19.938	19.813	20.000	20.312		
120	L (R)	108	108	108	108	108	108	108	108		
	r	7.250	7.250	7.250	7.250	7.250	7.250	7.250	7.250		
	h	21.313	21.250	21.188	21.063	20.938	20.813	20.813	21.125		
126	L (R)	114	114	114	114	114	114	114	114		
	r	7.625	7.625	7.625	7.625	7.625	7.625	7.625	7.625		
	h	22.250	22.188	22.125	22.063	21.938	21.813	21.625	21.938		
132	L (R)	120	120	120	120	120	120	120	120		
	r	8.000	8.000	8.000	8.000	8.000	8.000	8.000	8.000		
	h	23.313	23.250	23.125	23.063	23.000	22.875	22.750	23.000		



## DIMENSIONS OF HEADS

ALL DIMENSIONS IN INCHES

DIAMETER D		WALL THICKNESS							
		5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
138	L (R)	132	132	132	132	132	132	132	132
	r	8.375	8.375	8.375	8.375	8.375	8.375	8.375	8.375
	h	23.938	23.875	23.813	23.750	23.688	23.625	23.563	23.500
144	M	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.75
	L (R)	132	132	132	132	132	132	132	132
	r	8.750	8.750	8.750	8.750	8.750	8.750	8.750	8.750
	h	25.875	25.813	25.750	25.625	25.563	25.500	25.438	25.375
	M	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72
DIAMETER D	SEE PAGE 325	WALL THICKNESS							
		1 5/8	1 3/4	1 7/8	2	2 1/4	2 1/2	2 3/4	3
138	L (R)	132	132	132	130	130	130	130	130
	r	8.375	8.375	8.375	8.375	8.375	8.375	8.375	9.000
	h	23.438	23.375	23.313	23.500	23.375	23.250	23.125	23.250
144	M	1.75	1.75	1.75	1.72	1.72	1.72	1.72	1.69
	L (R)	132	132	132	132	132	132	132	132
	r	8.750	8.750	8.750	8.750	8.750	8.750	8.750	9.000
	h	25.250	25.188	25.125	25.063	24.938	24.813	24.625	24.625
	M	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72

## TOLERANCES

### WALL THICKNESS (APPROXIMATION) \*

MINIMUM REQ'D. THICKNESS	HEMISPHERICAL	OTHER TYPES	
		UP TO 150" I.D. incl.	OVER 150" I.D.
To 1" excl.	0.1875	0.0625	0.1250
1" To 2"	0.3750	0.1250	0.1250
2" To 3"	0.6250	0.2500	0.2500
3" To 3.5"	0.7500	0.3750	0.3750
3.5" To 4"	1.1250	0.500	0.5000
4" To 4.5"	1.5000	0.6250	0.6250
4.5" To 5"	1.7500	0.7500	0.7500
5" To 5.5"	2.0000	0.8750	0.8750
5.5" & Over	2.0000	1.0000	1.0000

\* Specify minimum thickness (if required) when ordering.

### INSIDE DEPTH OF DISH (n)

48" O.D. and under plus 0.5" minus 0"

Over 48" O.D. to 96" O.D. incl. plus 0.75", minus 0" Over 96" O.D. plus 1", minus 0"

### OUT OF ROUNDNESS

Within the limits permitted by the Code.

## FLANGES

### FLANGE FACING FINISH

The pressure vessel construction only gasket seats of flanges, studded openings, etc. require special finish beyond that afforded by turning, grinding or milling.

The surface finish for flange facing shall have certain roughness regulated by Standard ANSI B16.5. The roughness is repetitive deviation from the nominal surface having specified depth and width.

Raised faced flange shall have serrated finish having 24 to 40 grooves per inch. The cutting tool shall have an approximate 0.06 in. or larger radius resulting 500 microinch approximate roughness /ANSI B16.5, 6.3.4.1/

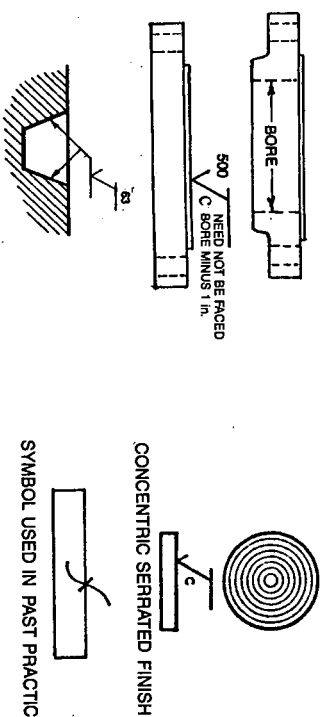
The side wall surface of gasket groove of ring joint flange shall not exceed 63 microinch roughness. /ANSI B16.5-6.3.4.3./

Other finishes may be furnished by agreement between user and manufacturer.

The finish of contact faces shall be judged by visual comparison with Standard ANSI B46-1.

The center part of blind flanges need not to be finished within a diameter which equals or less than the bore minus one inch of the joining flange. /ANSI B16.5-6.3.3/

Surface symbol used to designate roughness  $\sqrt{}$  is placed either on the line indicating the surface or on a leader pointing to the surface as shown below. The numbers: 500 and 63 indicate the height of roughness; letter "c" the direction of surface pattern: "concentric-serrated".



## MEASURES

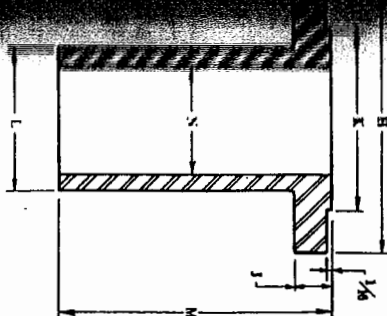
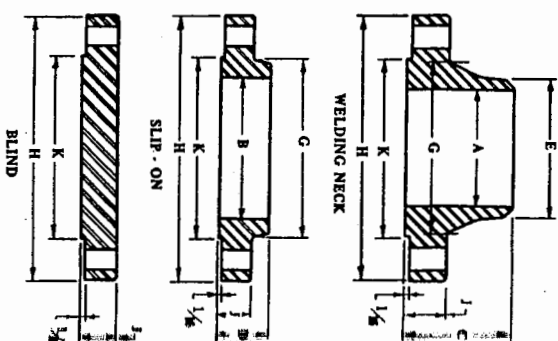


## 150 lb. FLANGES

## STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/16 in. raised face is included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 22, 26, 28 and 30 are not covered by ANSI B16.5.

SEE FACING PAGE FOR DIMENSION K  
AND DATA ON BOLTING.

150 lb.  
LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/16 in. raised face is included in dimensions J and M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

Nominal Pipe Size	Diameter of Bore				Length of Hub		Diameter of Hub at Point of Welding		Diameter of Hub at Base		Outside Diameter of Flange		Thickness of Flange
	A	B	C	D	E	F	G	H	I	J	K	L	
1/2	.62	.88	1 1/4	3/4	.84	1 1/4	3 1/2	7/4	4	1 1/2	1 1/2	2 1/2	1 1/2
3/4	.82	1.09	1 3/4	5/8	1.05	1 1/2	3 3/4	1 1/2	4	1 3/4	1 3/4	2 3/4	1 3/4
1	1.05	1.36	2 1/4	3/4	1.32	1 3/4	4 1/4	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
1 1/4	1.38	1.70	2 3/4	1 1/4	1.66	2 1/4	4 3/4	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
1 1/2	1.61	1.95	2 3/4	1 1/4	1.90	2 1/4	4 3/4	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
2	2.07	2.44	2 1/2	1	2.38	3 1/4	6	3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
2 1/2	2.47	2.94	2 3/4	1 1/4	2.88	3 3/4	7	7/4	4	1 3/4	1 3/4	2 3/4	1 3/4
3	3.07	3.57	2 3/4	1 1/4	3.50	4 1/4	7 1/2	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
3 1/2	3.55	4.07	2 3/4	1 1/4	4.00	4 3/4	8 1/2	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
4	4.03	4.57	3	1 1/4	4.50	5 1/4	9	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
5	5.05	5.66	3 1/2	1 1/4	5.56	6 1/4	10	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
6	6.07	6.72	3 1/2	1 1/4	6.63	7 1/4	11	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
8	7.98	8.72	4	1 1/4	8.63	9 1/4	13 1/2	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
10	10.02	10.88	4 1/2	1 1/4	10.75	12	16	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
12	12.00	12.88	4 1/2	1 1/4	12.75	14 3/4	19	1 1/4	4	1 3/4	1 3/4	2 3/4	1 3/4
14	13.25	14.14	5	2 1/4	14.00	15 3/4	21	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
16	15.25	16.16	5	2 1/4	16.00	18	23 1/2	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
18	17.25	18.18	5 1/2	2 1/4	18.00	19 1/4	25	1 3/4	4	1 3/4	1 3/4	2 3/4	1 3/4
20	19.25	20.20	5 1/4	2 1/4	20.00	22	27 1/2	1 1/4	4	1 3/4	1 3/4	2 3/4	1 3/4
22	21.25	22.22	5 1/2	2 1/4	22.00	24 1/4	29 1/2	1 1/4	4	1 3/4	1 3/4	2 3/4	1 3/4
24	23.25	24.25	6	3 1/4	24.00	26 1/4	32	1 1/4	4	1 3/4	1 3/4	2 3/4	1 3/4
26	To be specified	26.25	5	3 3/4	26.00	28 1/2	34 1/4	2	4	1 3/4	1 3/4	2 3/4	1 3/4
28		28.25	5 1/4	3 3/4	28.00	30 3/4	36 1/2	2 1/4	4	1 3/4	1 3/4	2 3/4	1 3/4
30		30.25	5 1/4	3 1/2	30.00	32 3/4	38 3/4	2 1/4	4	1 3/4	1 3/4	2 3/4	1 3/4

## MEASURES

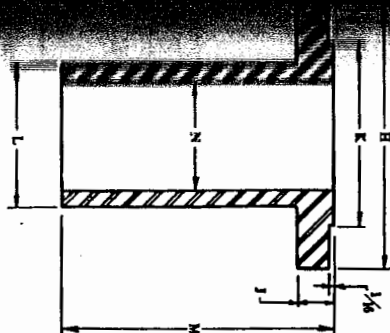
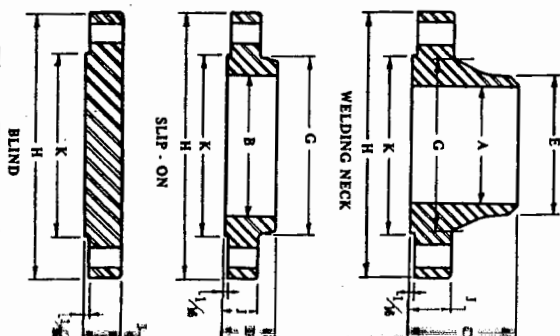


## 300 lb. FLANGES

STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/16 in. raised face is included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 22, 26, 28 and 30 are not covered by ANSI B16.5.

SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.

300 lb.  
LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/16 in. raised face is included in dimensions J and M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange	No. of Bolts	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
	A	B	C	D	E	G	H	J				1/2 Raised Face	Ring Joint	L	M	N	
1/2	.62	.88	2 1/2	7/8	.84	1 1/2	3 3/4	5/8	4	1/2	2 5/8	2 3/4	3	2 1/8			1/2
3/4	.82	1.09	2 1/4	1 1/8	1.05	1 7/8	4 7/8	5/8	4	5/8	3 1/4	3 1/4	3 1/2	2 1/8			3/4
1	1.05	1.36	2 1/4	1 1/8	1.32	2 1/8	4 7/8	1 1/2	4	3/4	3 3/4	3 3/4	3 3/4	2 1/8			1
1 1/4	1.38	1.70	2 3/8	1 1/4	1.66	2 3/4	5 1/4	1 3/8	4	3/4	3 3/4	3 3/4	3 3/4	2 1/8			1 1/4
1 1/2	1.61	1.95	2 1/4	1 1/4	1.90	2 3/4	6 1/4	1 3/8	4	3/4	4 1/2	3 3/4	4 1/4	2 1/8			1 1/2
2	2.07	2.44	2 3/4	1 3/4	2.38	3 3/8	6 1/2	1 3/4	8	3/4	5	3 1/2	4 1/4	3 3/8	9		2
2 1/2	2.47	2.94	3	1 1/2	2.88	3 1/2	7 1/2	1 3/4	8	3/4	5 1/8	4	4 3/4	3 1/2			2 1/2
3	3.07	3.57	3 1/4	1 5/8	3.50	4 1/4	8 1/4	1 3/4	8	3/4	6 3/8	4 1/4	5	4 3/8			3
3 1/2	3.55	4.07	3 3/8	1 3/4	4.00	5 1/4	9	1 3/4	8	3/4	7 1/4	4 1/4	5 1/4	5 1/4			3 1/2
4	4.03	4.57	3 3/4	1 3/4	4.50	5 3/4	10	1 3/4	8	3/4	7 7/8	4 1/2	5 1/2	5 1/2			4
5	5.05	5.66	3 3/4	2	5.56	7	11	1 3/4	8	3/4	9 1/4	4 1/2	5 1/2	5 1/2			5
6	6.07	6.72	3 3/4	2 1/8	6.63	8 1/4	12 1/2	1 3/4	12	3/4	10 3/4	5	5 3/4	8 1/8	12		6
8	7.98	8.72	4 1/4	2 3/8	8.63	10 1/4	15	1 3/4	12	1 1/4	13	5 1/2	6 1/4	10 1/4			8
10	10.02	10.88	4 3/4	2 3/4	10.75	12 3/4	17 1/2	1 3/4	16	1 1/4	15 1/4	6 1/4	7	12 3/8			10
12	12.00	12.88	5 1/4	2 3/4	12.75	14 3/4	20 1/2	2	16	1 1/4	17 3/4	6 3/4	7 1/4	14 3/4			12
14	13.25	14.14	5 3/4	3	14.00	16 3/4	23	2 1/4	20	1 1/4	20 1/4	7	7 3/4	16 3/4			14
16	15.25	16.16	5 3/4	3 1/4	16.00	19	25 1/2	2 1/4	24	1 1/4	22 1/4	7 1/2	8 1/4	19			16
18	17.25	18.18	6 1/4	3 1/2	18.00	21	28	2 3/4	24	1 1/4	24 3/4	7 3/4	8 1/2	21			18
20	19.25	20.20	6 3/4	3 3/4	20.00	23 1/4	30 1/2	2 1/2	24	1 1/4	27	8 1/4	9	23 1/4			20
22	21.25	22.22	6 1/2	4	22.00	25 1/4	33	2 3/4	24	1 1/2	29 1/4	8 3/4	9 3/4				22
24	23.25	24.25	6 3/4	4 3/8	24.00	27 3/4	36	2 3/4	24	1 1/2	32	9 1/4	10 1/4	27 3/4	10-14		24
26	To be specified	26.25	7 1/4	7 1/4	26 1/4	28 3/4	38 1/4	3 1/8	26	1 5/8	34 1/4	10	11	29 1/2			26
28		28.25	7 3/4	7 3/4	28 1/4	30 1/2	40 3/4	3 3/8	28	1 3/4	37	10 1/2	11 1/2	31 1/2			28
30		30.25	8 1/4	8 1/4	30 1/4	32 1/4	43	3 3/4	28	1 3/4	39 1/4	11 1/4	12 1/4	33 3/4			30

Same as nominal pipe size

MEASURES

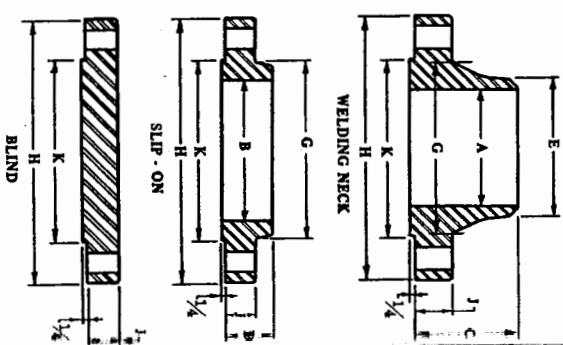


## 400 lb. FLANGES

## STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 22, 26, 28 and 30 are not covered by ANSI B16.5.

SEE FACING PAGE FOR DIMENSION K  
AND DATA ON BOLTING.



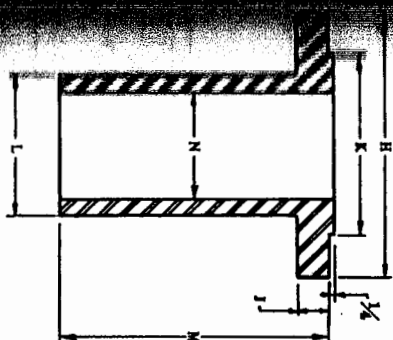
Nominal Pipe Size	Diameter of Bore		Length Through Hub	Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B					
1/2		.88	2 1/8	1.05	1 1/2	3 3/4	5/8
3/4		1.09	2 1/4	1.32	1 7/8	4 1/4	5/8
1		1.36	2 3/4	1.66	2 1/2	5 1/4	1 1/8
1 1/4		1.70	2 3/4	1.90	2 3/4	6 1/4	1 1/8
1 1/2		2.44	2 3/4	2.38	3 3/8	7 1/2	1 1/8
2		2.94	3 1/4	2.88	4 3/8	8 1/4	1 1/8
2 1/2		3.57	3 3/4	3.50	5 1/4	9	1 1/8
3		4.07	3 3/4	4.00	5 3/4	10	1 1/8
3 1/2		4.57	3 1/2	4.50	5 3/4	10	1 1/8
4		5.66	4 1/4	5.66	7	11	1 1/8
5		6.72	4 1/4	6.63	8 1/4	12 1/2	1 1/8
6		8.72	4 3/4	8.63	10 1/4	15	1 1/8
8		10.88	4 3/4	10.75	12 3/4	17 1/2	1 1/8
10		12.88	5 3/4	12.75	14 3/4	20 1/2	2 1/8
12		14.14	5 3/4	14.00	16 3/4	23	2 1/8
14		16.16	6	16.00	19	25 1/2	2 1/8
16		18.18	6 1/2	18.00	21	28	2 1/8
18		20.20	6 3/4	20.00	23 3/8	30 1/2	2 3/8
20		22.22	6 3/4	22.00	25 1/4	33	2 3/8
22		24.25	6 3/4	24.00	27 3/8	36	2 3/8
24		26.25	7 3/4	26 3/8	28 3/8	40 3/4	3 1/8
26		28.25	8 3/4	28 3/8	30 3/8	43	3 1/8
28		30.25	8 3/4	30 3/8	32 3/8		3 1/8
30							4

To be specified by purchaser

400 lb.  
LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.



Nominal Pipe Size	No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
				1/4" Raised Face	Ring Joint				
1/2	4	1/2	2 3/8	3 3/4	3 1/2	2 1/8			1/2
3/4	4	5/8	3 1/4	3 3/4	3 3/4	2 1/8			3/4
1	4	3/4	3 3/4	4	4	2 1/8			1
1 1/4	4	3/4	4 1/2	4 1/4	4 1/4	2 1/8			1 1/4
1 1/2	4	3/4	5	4 1/4	4 1/4	2 1/8			1 1/2
2	8	3/4	5 7/8	4 3/4	5	3 1/8	9		2
2 1/2	8	3/4	6 3/8	5	5 1/4	4 3/8			2 1/2
3	8	3/4	7 1/4	5 1/2	5 3/4	5 1/4			3
3 1/2	8	7/8	7 7/8	5 3/4	5 3/4	5 3/4			3 1/2
4	8	7/8	9 1/4	5 3/4	6	7			4
5	12	7/8	10 5/8	6	6 1/4	8 1/8	12		5
6	12	1	13	6 3/4	7	10 1/4			6
8	16	1 1/4	15 1/4	7 1/2	7 3/4	12 3/8			8
10	16	1 1/4	17 3/4	8	8 1/4	14 3/8			10
12	20	1 1/4	20 1/4	8 1/4	8 1/2	16 3/8			12
14	20	1 3/8	22 1/2	9	9	19			14
16	24	1 3/8	24 3/4	9	9 1/4	21			16
18	24	1 1/2	27	9 3/4	10	23 3/8	10-14		18
20	24	1 3/4	29 1/4	10	10 1/2				20
22	24	1 3/4	32	10 3/4	11 1/4				22
24	28	1 3/4	34 1/2	11 1/2	12				24
26	28	1 3/4	37	12 1/4	12 3/4				26
28	28	1 3/4	39 1/4	12 3/4	13 1/2				28
30	28	2		13					30

Same as nominal pipe size

MEASURES

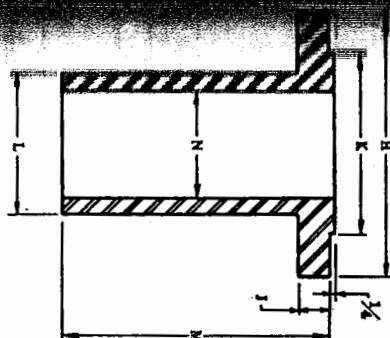
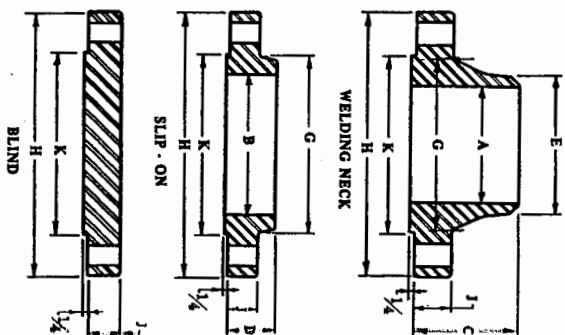


## 600 lb. FLANGES

### STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 22, 26, 28 and 30 are not covered by ANSI B16.5.

SEE FACING PAGE FOR DIMENSION K  
AND DATA ON BOLTING.



## 600 lb.

### LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.

Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
1/2		.88	2 1/4	7/8	.84	1 1/2	3 3/4	5/8
3/4		1.09	2 1/4	1	1.05	1 7/8	4 5/8	5/8
1		1.36	2 3/4	1 1/8	1.32	2 1/8	4 7/8	1 1/8
1 1/4		1.70	2 3/4	1 1/4	1.66	2 3/4	5 1/4	1 3/8
1 1/2		1.95	2 3/4	1 1/4	1.90	2 3/4	5 1/4	1 3/8
2		2.44	2 3/4	1 3/4	2.38	3 3/8	6 1/2	1 3/4
2 1/2		2.94	3 3/4	1 3/4	2.88	3 3/8	7 1/2	1 3/4
3		3.57	3 3/4	1 3/4	3.50	4 1/4	8 1/4	1 3/4
3 1/2		4.07	3 3/4	1 3/4	4.00	5 1/4	9	1 3/4
4		4.57	4 1/4	2 1/8	4.50	6	10 3/4	1 3/4
5		5.66	4 1/4	2 1/8	5.56	7 7/8	13	1 3/4
6		6.72	4 3/4	2 1/8	6.63	8 3/4	14	1 3/4
8		8.72	5 1/4	3	8.63	10 3/4	16 1/2	2 1/8
10		10.88	6	3 3/8	10.75	13 1/2	20	2 1/8
12		12.88	6 1/4	3 3/8	12.75	15 3/4	22	2 1/8
14		14.14	6 1/2	3 1/2	14.00	17	23 3/4	2 3/4
16		16.16	7	4 3/8	16.00	19 1/2	27	3
18		18.18	7 1/4	4 3/8	18.00	21 1/2	29 1/4	3 1/4
20		20.20	7 1/2	5	20.00	24	32	3 1/2
22		22.22	7 3/4	5 1/4	22.00	26 1/4	34 1/4	3 3/4
24		24.25	8	5 1/2	24.00	28 1/4	37	4
26		26.25	8 3/4	8 3/4	26 3/4	29 3/4	40	4 1/4
28		28.25	9 1/4	9 1/4	28 1/4	31 3/4	42 1/4	4 3/4
30		30.25	9 3/4	9 3/4	30 1/2	33 1/4	44 1/2	4 1/2

To be specified by purchaser

No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
			1/4" Raised Face	Ring Joint				
4	1/2	2 5/8	3 1/4	3	2 1/8			1/2
4	5/8	3 1/4	3 3/4	3 3/4	2 1/2			3/4
4	3/4	3 1/2	3 3/4	3 3/4	2 3/4			1
4	7/8	3 3/4	4 1/4	4 1/4	2 3/4			1 1/4
4	1	4 1/2	4 1/4	4 1/2	3 3/4			1 1/2
8	1	5	4 1/4	5	3 3/4	9		2
8	1 1/8	5 1/2	4 3/4	5 1/2	3 3/4			2 1/2
8	1 1/4	5 3/4	5 1/2	5 3/4	4 3/8			3
8	1 1/2	6 1/8	5 3/4	5 3/4	4 3/8			3 1/2
8	1 3/4	6 3/4	5 3/4	5 3/4	4 3/8			4
8	2	7 1/4	5 3/4	5 3/4	4 3/8			4 1/2
8	2 1/8	8 1/2	5 3/4	5 3/4	4 3/8			5
8	2 1/4	8 3/4	5 3/4	5 3/4	4 3/8			5 1/2
8	2 1/2	9	5 3/4	5 3/4	4 3/8			6
12	2 3/4	10 1/2	5 3/4	5 3/4	4 3/8	12		6 1/2
12	3	11 1/2	5 3/4	5 3/4	4 3/8			7
12	3 1/4	12 1/2	5 3/4	5 3/4	4 3/8			7 1/2
12	3 1/2	13 1/4	5 3/4	5 3/4	4 3/8			8
16	3 3/4	17	5 3/4	5 3/4	4 3/8			8 1/2
20	4	19 1/4	5 3/4	5 3/4	4 3/8			9
20	4 1/4	20 3/4	5 3/4	5 3/4	4 3/8			9 1/2
20	4 1/2	23 3/4	5 3/4	5 3/4	4 3/8			10
20	4 3/4	25 3/4	5 3/4	5 3/4	4 3/8			10 1/2
20	5	28 1/2	5 3/4	5 3/4	4 3/8			11
24	5 1/4	30 3/4	5 3/4	5 3/4	4 3/8			11 1/2
24	5 1/2	33	5 3/4	5 3/4	4 3/8			12
24	5 3/4	36	5 3/4	5 3/4	4 3/8			12 1/2
28	6	38	5 3/4	5 3/4	4 3/8			13 1/4
28	6 1/4	40 1/4	5 3/4	5 3/4	4 3/8			13 1/2
28	6 1/2		5 3/4	5 3/4	4 3/8			14

Same as nominal pipe size

MEASURES

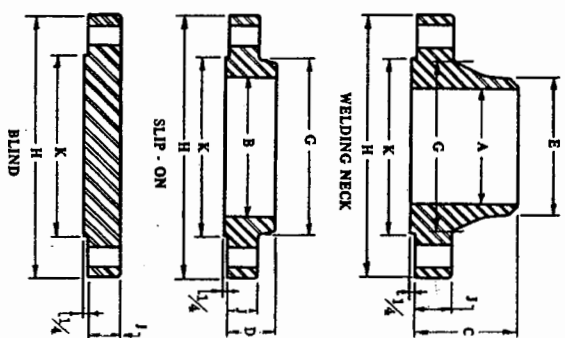


## 900 lb. FLANGES

## STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.
7. Flanges for pipe sizes 26, 28 and 30 are not covered by ANSI B16.5.

SEE FACING PAGE FOR DIMENSION K  
AND DATA ON BOLTING.



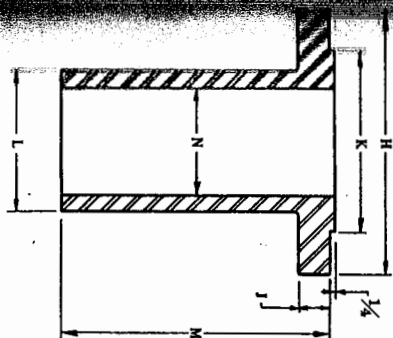
Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D	E	G	H	J
1/2		.88	2 3/4	1 1/4	.84	1 1/2	4 3/4	3/8
3/4		1.09	2 3/4	1 3/8	1.05	1 3/4	5 1/8	1 1/8
1		1.36	2 3/4	1 5/8	1.32	2 1/8	5 3/4	1 1/4
1 1/4		1.70	2 3/4	1 5/8	1.66	2 1/2	6 1/4	1 1/4
1 1/2		1.95	3 1/4	1 5/8	1.90	2 3/4	7	1 1/4
2		2.44	4	2 1/4	2.38	4 1/8	8 1/2	1 1/2
2 1/2		2.94	4 1/4	2 1/2	2.88	4 3/8	9 5/8	1 5/8
3		3.57	4 1/4	2 3/4	3.50	5	11 1/2	1 3/4
4		4.57	5	3 3/8	4.50	6 1/4	13 3/4	2
5		5.66	5 1/2	3 3/4	5.56	7 1/2	15	2 1/4
6		6.72	6 3/4	4	6.63	8 1/4	18 1/2	2 1/2
8		8.72	7 1/4	4 1/4	8.63	10 1/2	21 1/2	2 3/4
10		10.88	7 3/4	4 5/8	10.75	12 1/2	24	3 1/8
12		12.88	8 3/4	5 1/8	12.75	14 1/2	25 1/4	3 3/4
14		14.14	8 3/4	5 1/8	14.00	16 1/2	27 3/4	3 3/4
16		16.16	8 1/2	5 1/4	16.00	20	31	4
18		18.18	9 3/4	6 1/4	18.00	22 1/4	33 3/4	4 1/4
20		20.20	11 1/2	8	20.00	24 1/2	41	5 1/4
24		24.25	11 1/4	11 1/4	24.00	29 1/2	42 3/4	5 3/4
26		26.25	11 1/4	11 1/4	26 1/4	30 1/2	46	5 3/4
28		28.25	11 1/4	11 1/4	28 1/4	32 3/4	48 1/2	5 3/4
30		30.25	12 1/4	12 1/4	30 3/4	35		5 3/4

To be specified by purchaser

900 lb.  
LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.



Nominal Pipe Size	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
	1/4" Raised Face	Ring Joint				
1/2	4 1/4	4 1/4	2 1/8	9		1/2
3/4	4 1/2	4 1/2	2 1/8	9		3/4
1	5	5	2 1/8	9		1
1 1/4	5 1/2	5 1/2	2 3/4	9		1 1/4
1 1/2	5 3/4	5 3/4	2 3/4	9		1 1/2
2	6 1/4	6 1/4	4 3/8	12		2
2 1/2	6 3/4	6 3/4	5	12		2 1/2
3	7 1/4	7 3/4	6 1/4	12		3
4	7 3/4	7 3/4	7 1/2	12		4
5	8 3/4	8 3/4	8 1/4	12		5
6	9 3/4	9 3/4	9 1/4	12		6
8	10 3/4	10 3/4	11 1/4	12		8
10	11 3/4	11 3/4	12 1/4	12		10
12	12 3/4	12 3/4	13 1/4	12		12
14	13 3/4	13 3/4	14 1/4	12		14
16	14 3/4	14 3/4	15 1/4	12		16
18	15 3/4	15 3/4	16 1/4	12		18
20	16 3/4	16 3/4	17 1/4	12		20
24	17 3/4	17 3/4	18 1/4	12		24
26	18 3/4	18 3/4	19 1/4	12		26
28	19 3/4	19 3/4	20 1/4	12		28
30	20 3/4	20 3/4	21 1/4	12		30

Same as nominal pipe size

MEASURES

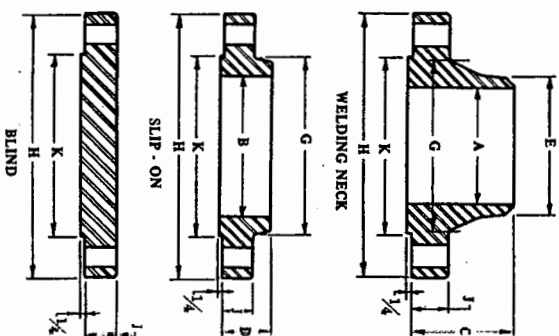


## 1500 lb. FLANGES

STANDARD ANSI B16.5

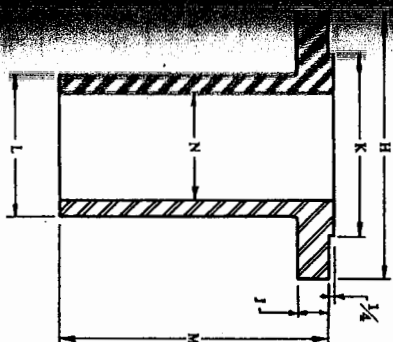
1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.

SEE FACING PAGE FOR DIMENSION K AND DATA ON BOLTING.

1500 lb.  
LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.



Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter of Hub at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D				
1/2		.88	2 3/4	1 1/4	.84	1 1/2	4 3/4	3/8
3/4		1.09	2 3/4	1 3/8	1.05	1 3/4	5 1/8	1
1		1.36	2 7/8	1 3/8	1.32	2 1/8	5 7/8	1 1/4
1 1/4		1.70	2 7/8	1 3/8	1.66	2 1/2	6 1/4	1 1/8
1 1/2		1.95	3 1/4	1 3/4	1.90	2 3/4	7	1 1/4
2		2.44	4	2 1/4	2.38	4 1/8	8 1/2	1 1/2
2 1/2		2.94	4 1/8	2 1/2	2.88	4 3/8	9 3/8	1 3/4
3		3.57	4 5/8	2 5/8	3.50	5 1/4	10 1/2	1 7/8
4		4.57	4 7/8	3 3/8	4.50	6 3/8	12 1/4	2 1/8
5		5.66	6 1/8	4 1/8	5.56	7 3/4	14 3/4	2 3/8
6		6.72	6 3/4	4 11/16	6.63	9	15 1/2	3 3/8
8		8.72	8 3/4	5 5/8	8.63	11 1/2	19	3 3/4
10		10.88	10	6 1/4	10.75	14 1/2	23	4 1/4
12		12.88	11 1/8	7 1/8	12.75	17 3/4	26 1/2	4 3/4
14		--	11 3/4	--	14.00	19 1/2	29 1/2	5 1/4
16		--	12 1/4	--	16.00	21 3/4	32 1/2	5 3/4
18		--	12 7/8	--	18.00	23 1/2	36	6 3/4
20		--	14	--	20.00	25 1/4	38 3/4	7
24		--	16	--	24.00	30	46	8

To be specified by purchaser

No. of Flanges	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
			1/2"	Ring Joint				
4	3/4	3 1/4	4 1/4	4 1/4	2 1/8	9		1 1/4
4	3/4	3 1/2	4 1/2	5	2 1/8	9		1 1/2
4	7/8	4	5	5 1/4	4 1/8	9		2
4	7/8	4 3/8	5	5 1/4	4 1/8	9		2 1/2
4	1	4 7/8	5 1/2	5 3/4	4 1/8	9		3
4	1 1/8	5 1/2	5 3/4	5 3/4	4 1/8	9		3 1/2
8	1 1/4	6 1/2	6 1/4	6 1/4	4 3/8	12		4
8	1 1/2	7 1/2	7	7 3/4	4 3/8	12		5
8	1 3/8	8 1/2	7 3/4	7 3/4	4 3/8	12		6
8	1 1/2	9 1/2	8 1/4	8 1/4	4 3/8	12		8
12	1 5/8	11 1/2	9 3/4	9 3/4	4 3/8	12		10
12	1 3/4	12 1/2	10 1/4	10 1/4	4 3/8	12		12
12	1 7/8	13 1/2	11 1/4	11 1/4	4 3/8	12		14
16	2 1/4	15 1/2	13 1/4	13 3/4	4 3/8	12		16
16	2 1/2	16 1/2	14 3/4	14 3/4	4 3/8	12		18
16	2 3/4	17 1/2	15 3/4	15 3/4	4 3/8	12		20
16	3	18 1/2	16 3/4	16 3/4	4 3/8	12		24
16	3 1/2	19 1/2	17 3/4	17 3/4	4 3/8	12		24

Same as nominal pipe size

MEASURES

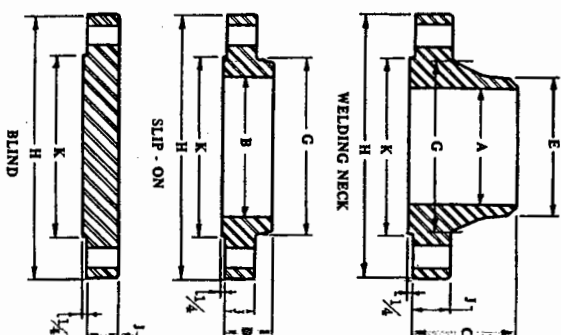


## 2500 lb. FLANGES

STANDARD ANSI B16.5

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in dimensions C, D and J.
4. The lengths of stud bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Flanges bored to dimensions shown unless otherwise specified.

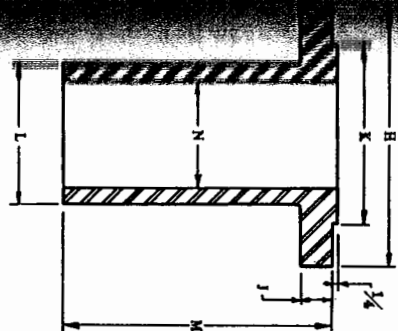
SEE FACING PAGE FOR DIMENSION K  
AND DATA ON BOLTING.



## 2500 lb. LONG WELDING NECK

1. All dimensions are in inches.
2. Material most commonly used, forged steel SA 105. Available also in stainless steel, alloy steel and non-ferrous metal.
3. The 1/4 in. raised face is not included in thickness J but is included in length M.
4. The length of bolts do not include the height of crown.
5. Bolt holes are 1/8 in. larger than bolt diameters.
6. Dimensions, M (length of welding necks) are based on data of major manufacturers. Long welding necks with necks longer than listed are available on special order.

SEE FACING PAGE FOR DIMENSION J.



Nominal Pipe Size	Diameter of Bore		Length Through Hub		Diameter at Point of Welding	Diameter of Hub at Base	Outside Diameter of Flange	Thickness of Flange
	A	B	C	D				
1/2		.88	2 1/4	1 1/4	.84	1 1/4	5 1/4	1 1/4
3/4		1.09	3 1/4	1 1/4	1.05	2	5 1/2	1 1/4
1		1.36	3 1/2	1 1/4	1.32	2 1/4	6 1/4	1 1/4
1 1/4		1.70	3 3/4	2 1/4	1.66	2 3/4	7 1/4	1 1/4
1 1/2		1.95	4 3/4	2 3/4	1.90	3 3/4	8	1 3/4
2		2.44	5	2 3/4	2.38	3 3/4	9 1/4	2
2 1/2		2.94	5 3/4	3 1/4	2.88	4 1/2	10 1/2	2 1/4
3		3.57	6 3/4	3 3/4	3.50	5 1/4	12	2 3/4
4		4.57	7 1/4	4 1/4	4.50	6 1/2	14	3
5		5.66	9	5 1/4	5.56	8	16 1/2	3 3/4
6		6.72	10 3/4	6	6.63	9 1/4	19	4 1/4
8		8.72	12 1/2	7	8.63	12	21 3/4	5
10		10.88	16 1/4	9	10.75	14 3/4	26 1/2	6 1/4
12		12.88	18 1/4	10	12.75	17 3/4	30	7 1/4

To be specified by purchaser

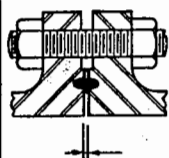
No. of Holes	Diam. of Bolts	Bolt Circle	Length of Bolts		Outside Diameter	Length	Diameter of Bore	Nominal Pipe Size
			1/4" Raised Face	Ring Joint				
4	3/4	3 1/2	5 1/4	5 1/4	2 1/4	9		1/2
4	3/4	3 3/4	5 1/4	5 1/4				3/4
4	7/8	4 1/4	5 3/4	5 3/4				1
4	1	5 1/8	6 1/4	6 1/4	2 3/4			1 1/4
4	1 1/8	5 3/4	7 1/4	7 1/4	3 3/4			1 1/2
8	1	6 3/4	7 1/4	7 1/4				2
8	1 1/4	7 3/4	8	8 1/4	4 1/2	12		2 1/2
8	1 1/4	9	9	9 1/4	5 1/4			3
8	1 1/2	10 3/4	10 1/4	10 3/4	6 1/2			4
8	1 3/4	12 3/4	12	12 3/4	8			5
8	2	14 1/2	13 3/4	14 1/2	9 1/4			6
12	2	17 1/4	15 1/4	16	12			8
12	2 1/2	21 1/4	19 1/2	20 1/2	14 3/4			10
12	2 3/4	24 3/4	21 1/2	22 1/2	17 3/4	12-20		12

Same as nominal pipe size

MEASURES



## RING JOINT FLANGES



APPROXIMATE DISTANCE BETWEEN FLANGES

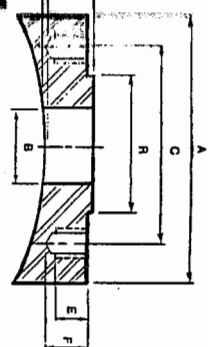
Nominal Pipe Size	Pressure Rating lb.						
	150	300	400	600	900	1500	2500
	Distance, inches						
1/2	1/8	1/8	1/8	1/8	—	—	1 1/2
3/4	5/32	5/32	5/32	5/32	5/32	5/32	1 1/2
1	5/32	5/32	5/32	5/32	5/32	5/32	1 1/2
1 1/4	5/32	5/32	5/32	5/32	5/32	5/32	1 1/2
1 1/2	5/32	5/32	5/32	5/32	5/32	5/32	1 1/2
2	5/32	5/32	5/6	3/4	1/8	1/8	1 1/2
2 1/2	5/32	5/32	5/6	3/4	1/8	1/8	1 1/2
3	5/32	5/32	5/6	3/4	1/8	1/8	1 1/2
4	5/32	5/32	5/6	3/4	5/32	1/8	1 1/2
5	5/32	5/32	5/6	3/4	5/32	1/8	1 1/2
6	5/32	5/32	5/6	3/4	5/32	1/8	1 1/2
8	5/32	5/32	5/6	3/4	5/32	1/8	1 1/2
10	5/32	5/32	5/6	3/4	5/32	1/8	1 1/2
12	5/32	5/32	5/6	3/4	5/32	1/8	1 1/2
14	5/32	5/32	5/6	3/4	5/32	1/8	1 1/2
16	5/8	5/32	5/6	3/4	5/32	1/8	1 1/2
18	1/2	5/32	5/6	3/4	5/6	3/8	1 1/2
20	1/2	5/32	5/6	3/4	5/6	3/8	1 1/2
22	1/2	1/4	5/6	3/4	—	—	1 1/2
24	1/2	1/4	5/6	3/4	—	—	1 1/2

RING NUMBERS												
Nominal Pipe Size		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	5
150	...	...	...	R15	R17	R19	R22	R25	R29	R33	R37	R41
300, 400, 600	R11	R13	R16	R18	R18	R20	R23	R26	R31	R34	R38	R42
900	...	...	...	...	...	...	...	...	R31	...	...	...
1500	R12	R14	R16	R18	R18	R20	R24	R27	R35	...	...	...
2500	R13	R16	R18	R21	R23	R26	R28	R32	...	...	...	...

Pressure Class lb.	Nominal Pipe Size											
	5	6	8	10	12	14	16	18	20	24	30	36
Pressure Class lb.	R40	R43	R48	R52	R56	R59	R64	R68	R72	R77	R82	R87
	R41	R45	R49	R53	R57	R61	R65	R69	R73	R78	R83	R88
	R41	R45	R49	R53	R57	R62	R66	R70	R74	R79	R84	R89
	R44	R46	R50	R54	R58	R63	R67	R71	R75	R80	R85	R90
	R42	R47	R51	R55	R60	...	...	...	...	...	...	...

## RING NUMBERS

Nominal Pipe Size	Ring Numbers															
	1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2	4	5	6	8	10	12	14
150	...	...	R15	R17	R19	R22	R25	R29	R33	R37	R41	R45	R49	R53	R57	R61
300, 400, 600	...	...	R16	R18	R20	R23	R26	R31	R34	R38	R42	R46	R50	R54	R58	R62
900	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1500	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2500	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

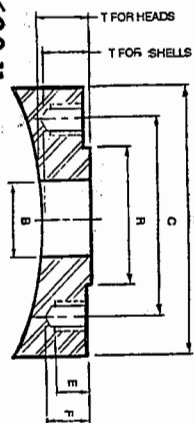


## STUD WELDING OUTLETS

All dimensions are in inches.  
Material most commonly used,  
forged steel SA-105.

THICK	OD	RF	STUD	STUDS	TPI	TAP	HOLE
T	A	R	C	J	M	E	F
1.50	3.50	1.38	2.38	4	1/2	0.75	1.25
1.50	3.88	1.69	2.75	4	1/2	0.75	1.25
1.50	4.25	2.00	3.12	4	1/2	0.75	1.25
1.50	4.62	2.50	3.50	4	1/2	0.75	1.25
1.50	5.00	2.88	3.88	4	1/2	0.75	1.25
1.50	5.38	3.25	4.25	4	1/2	0.75	1.25
1.50	5.75	3.62	4.62	4	1/2	0.75	1.25
1.50	6.12	4.00	5.00	4	1/2	0.75	1.25
1.50	6.50	4.38	5.38	4	1/2	0.75	1.25
1.50	6.88	4.75	5.75	4	1/2	0.75	1.25
1.50	7.25	5.12	6.12	4	1/2	0.75	1.25
1.50	7.62	5.50	6.50	4	1/2	0.75	1.25
1.50	8.00	5.88	6.88	4	1/2	0.75	1.25
1.50	8.38	6.25	7.25	4	1/2	0.75	1.25
1.50	8.75	6.62	7.62	4	1/2	0.75	1.25
1.50	9.12	7.00	8.00	4	1/2	0.75	1.25
1.50	9.50	7.38	8.38	4	1/2	0.75	1.25
1.50	9.88	7.75	8.75	4	1/2	0.75	1.25
1.50	10.25	8.12	9.12	4	1/2	0.75	1.25
1.50	10.62	8.50	9.50	4	1/2	0.75	1.25
1.50	11.00	8.88	9.88	4	1/2	0.75	1.25
1.50	11.38	9.25	10.25	4	1/2	0.75	1.25
1.50	11.75	9.62	10.62	4	1/2	0.75	1.25
1.50	12.12	10.00	11.00	4	1/2	0.75	1.25
1.50	12.50	10.38	11.38	4	1/2	0.75	1.25
1.50	12.88	10.75	11.75	4	1/2	0.75	1.25
1.50	13.25	11.12	12.12	4	1/2	0.75	1.25
1.50	13.62	11.50	12.50	4	1/2	0.75	1.25
1.50	14.00	11.88	12.88	4	1/2	0.75	1.25
1.50	14.38	12.25	13.25	4	1/2	0.75	1.25
1.50	14.75	12.62	13.62	4	1/2	0.75	1.25
1.50	15.12	13.00	14.00	4	1/2	0.75	1.25
1.50	15.50	13.38	14.38	4	1/2	0.75	1.25
1.50	15.88	13.75	14.75	4	1/2	0.75	1.25
1.50	16.25	14.12	15.12	4	1/2	0.75	1.25
1.50	16.62	14.50	15.50	4	1/2	0.75	1.25
1.50	17.00	14.88	15.88	4	1/2	0.75	1.25
1.50	17.38	15.25	16.25	4	1/2	0.75	1.25
1.50	17.75	15.62	16.62	4	1/2	0.75	1.25
1.50	18.12	16.00	17.00	4	1/2	0.75	1.25
1.50	18.50	16.38	17.38	4	1/2	0.75	1.25
1.50	18.88	16.75	17.75	4	1/2	0.75	1.25
1.50	19.25	17.12	18.12	4	1/2	0.75	1.25
1.50	19.62	17.50	18.50	4	1/2	0.75	1.25
1.50	20.00	17.88	18.88	4	1/2	0.75	1.25
1.50	20.38	18.25	19.25	4	1/2	0.75	1.25
1.50	20.75	18.62	19.62	4	1/2	0.75	1.25
1.50	21.12	19.00	20.00	4	1/2	0.75	1.25
1.50	21.50	19.38	20.38	4	1/2	0.75	1.25
1.50	21.88	19.75	20.75	4	1/2	0.75	1.25
1.50	22.25	20.12	21.12	4	1/2	0.75	1.25
1.50	22.62	20.50	21.50	4	1/2	0.75	1.25
1.50	23.00	20.88	21.88	4	1/2	0.75	1.25
1.50	23.38	21.25	22.25	4	1/2	0.75	1.25
1.50	23.75	21.62	22.62	4	1/2	0.75	1.25
1.50	24.12	22.00	23.00	4	1/2	0.75	1.25
1.50	24.50	22.38	23.38	4	1/2	0.75	1.25
1.50	24.88	22.75	23.75	4	1/2	0.75	1.25
1.50	25.25	23.12	24.12	4	1/2	0.75	1.25
1.50	25.62	23.50	24.50	4	1/2	0.75	1.25
1.50	26.00	23.88	24.88	4	1/2	0.75	1.25
1.50	26.38	24.25	25.25	4	1/2	0.75	1.25
1.50	26.75	24.62	25.62	4	1/2	0.75	1.25
1.50	27.12	25.00	26.00	4	1/2	0.75	1.25
1.50	27.50	25.38	26.38	4	1/2	0.75	1.25
1.50	27.88	25.75	26.75	4	1/2	0.75	1.25
1.50	28.25	26.12	27.12	4	1/2	0.75	1.25
1.50	28.62	26.50	27.50	4	1/2	0.75	1.25
1.50	29.00	26.88	27.88	4	1/2	0.75	1.25
1.50	29.38	27.25	28.25	4	1/2	0.75	1.25
1.50	29.75	27.62	28.62	4	1/2	0.75	1.25
1.50	30.12	28.00	29.00	4	1/2	0.75	1.25
1.50	30.50	28.38	29.38	4	1/2	0.75	1.25
1.50	30.88	28.75	29.75	4	1/2	0.75	1.25
1.50	31.25	29.12	30.12	4	1/2	0.75	1.25
1.50	31.62	29.50	30.50	4	1/2	0.75	1.25
1.50	32.00	29.88	30.88	4	1/2	0.75	1.25
1.50	32.38	30.25	31.25	4	1/2	0.75	1.25
1.50	32.75	30.62	31.62	4	1/2	0.75	1.25
1.50	33.12	31.00	32.00	4	1/2	0.75	1.25
1.50	33.50	31.38	32.38	4	1/2	0.75	1.25
1.50	33.88	31.75	32.75	4	1/2	0.75	1.25
1.50	34.25	32.12	33.12	4	1/2	0.75	1.25
1.50	34.62	32.50	33.50	4	1/2	0.75	1.25
1.50	35.00	32.88	33.88	4	1/2	0.75	1.25
1.50	35.38	33.25	34.25	4	1/2	0.75	1.25
1.50	35.75	33.62	34.62	4	1/2	0.75	1.25
1.50	36.12	34.00	35.00	4	1/2	0.75	1.25
1.50	36.50	34.38	35.38	4	1/2	0.75	1.25
1.50	36.88	34.75	35.75	4	1/2	0.75	1.25
1.50	37.25	35.12	36.12	4	1/2	0.75	1.25
1.50	37.62	35.50	36.50	4	1/2	0.75	1.25
1.50	38.00	35.88	36.88	4	1/2	0.75	1.25
1.50	38.38	36.25	37.25	4	1/2	0.75	1.25
1.50	38.75	36.62	37.62	4	1/2	0.75	1.25
1.50	39.12	37.00	38.00	4	1/2	0.75	1.25
1.50	39.50	37.38	38.38	4	1/2	0.75	1.25
1.50	39.88	37.75	38.75	4	1/2	0.75	1.25
1.50	40.25	38.12	39.12	4	1/2	0.75	1.25
1.50	40.62	38.50	39.50	4	1/2	0.75	1.25
1.50	41.00	38.88	39.88	4	1/2	0.75	1.25
1.50	41.38	39.25	40.25	4	1/2	0.75	1.25
1.50	41.75	39.62	40.62	4	1/2	0.75	1.25
1.50	42.12	40.00	41.00	4	1/2	0.75	1.25
1.50	42.50	40.38	41.38	4	1/2	0.75	1.25
1.50	42.88	40.75	41.75	4	1/2	0.75	1.25
1.50	43.25	41.12	42.12	4	1/2	0.75	1.25
1.50	43.62	41.50	42.50	4	1/2	0.75	1.25
1.50	44.00	41.88	42.88	4	1/2	0.75	1.25
1.50	44.38	42.25	43.25	4	1/2	0.75	1.25
1.50	44.75	42.62	43.62	4	1/2	0.75	1.25
1.50	45.12	43.00	44.00	4	1/2	0.75	1.25
1.50	45.50	43.38	44.38	4	1/2	0.75	1.25
1.50	45.88	43.75	44.75	4	1/2	0.75	1.25
1.50	46.25	44.12	45.12	4	1/2	0.75	1.25
1.50	46.62	44.50	45.50	4	1/2	0.75	1.25
1.50	47.00	44.88	45.88	4	1/2	0.75	1.25
1.50	47.38	45.25	46.25	4	1/2	0.75	1.25
1.50	47.75	45.62	46.62	4	1/2	0.75	1.





**STUDING OUTLETS**

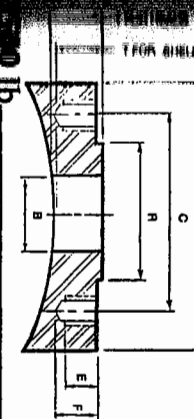
All dimensions are in inches.  
Material most commonly used,  
forged steel SA-105.

600 lb

SIZE (BORE)	THICK	OD	RF OD	STUD CIRCLE NO.	STUDS SIZE	TPI	TAP DEPTH	HOLE DEPTH
B	T	A	R	C	J	M	I	F
1/2	1.69	3.75	1.38	2.62	4	1/2	13	1.25
3/4	1.94	4.62	1.69	3.25	4	5/8	11	1.50
1	1.94	4.88	2.00	3.50	4	5/8	11	1.50
1 1/4	1.94	5.25	2.50	3.88	4	5/8	11	1.50
1 1/2	2.19	6.12	2.88	4.50	4	3/4	10	1.75
2	1.94	6.50	3.62	5.00	8	5/8	11	1.50
2 1/2	2.19	7.50	4.121	5.88	8	3/4	10	1.75
3	2.19	8.25	5.00	6.62	8	3/4	10	1.75
3 1/2	2.44	9.00	5.50	7.25	8	7/8	9	2.00
4	2.44	10.75	6.19	8.50	8	7/8	9	2.00
5	2.75	13.00	7.31	10.50	8	1	8	2.31
6	2.75	14.00	8.50	11.50	12	1 1/8	8	2.50
8	2.94	16.50	10.62	13.75	12	1 1/4	8	2.75
10	3.19	20.00	12.75	17.00	16	1 1/4	8	2.75
12	3.19	22.00	15.00	19.25	20	1 1/4	8	3.00
14	3.44	23.75	16.25	20.75	20	1 3/8	8	3.19
16	3.62	27.00	18.50	23.75	20	1 1/2	8	3.44
18	3.88	29.25	21.00	25.75	20	1 5/8	8	3.44
20	3.88	32.00	23.00	28.50	24	1 5/8	8	3.88
24	4.31	37.00	27.25	33.00	24	1 7/8	8	3.88

900 lb

SIZE (BORE)	THICK	OD	RF OD	STUD CIRCLE NO.	STUDS SIZE	TPI	TAP DEPTH	HOLE DEPTH
B	T	A	R	C	J	M	I	F
1/2	2.19	4.75	1.38	3.25	4	3/4	10	1.75
3/4	2.19	5.12	1.69	3.50	4	3/4	10	1.75
1	2.44	5.88	2.00	4.00	4	7/8	9	2.00
1 1/4	2.44	6.25	2.50	4.38	4	7/8	9	2.00
1 1/2	2.75	7.00	2.88	4.88	4	1	8	2.31
2	2.44	8.50	3.62	6.50	8	7/8	9	2.00
2 1/2	2.75	9.62	4.12	7.50	8	1	8	2.31
3	2.44	9.50	5.00	7.50	8	7/8	9	2.00
4	2.94	11.50	6.19	9.25	8	1 1/8	8	2.50
5	3.19	13.75	7.31	11.00	8	1 1/4	8	2.75
6	2.94	15.00	8.50	12.50	12	1 1/8	8	3.00
8	3.44	18.50	10.62	15.50	12	1 3/8	8	3.00
10	3.44	21.50	12.75	18.50	16	1 3/8	8	3.00
12	3.44	24.00	15.00	21.00	20	1 3/8	8	3.19
14	3.62	25.25	16.25	22.00	20	1 1/2	8	3.44
16	3.88	27.75	18.50	24.25	20	1 5/8	8	3.88
18	4.31	31.00	21.00	27.00	20	1 7/8	8	3.88
20	4.56	33.75	23.00	29.50	20	2	8	4.12
24	5.50	41.00	27.25	35.50	20	2 1/2	8	5.06



**STUDING OUTLETS**

All dimensions are in inches.  
Material most commonly used,  
forged steel SA-105.

900 lb

SIZE (BORE)	THICK	OD	RF OD	STUD CIRCLE NO.	STUDS SIZE	TPI	TAP DEPTH	HOLE DEPTH
B	T	A	R	C	J	M	I	F
1/2	2.19	4.75	1.38	3.25	4	3/4	10	1.75
3/4	2.19	5.12	1.69	3.50	4	3/4	10	1.75
1	2.44	5.88	2.00	4.00	4	7/8	9	2.00
1 1/4	2.44	6.25	2.50	4.38	4	7/8	9	2.00
1 1/2	2.75	7.00	2.88	4.88	4	1	8	2.31
2	2.44	8.50	3.62	6.50	8	7/8	9	2.00
2 1/2	2.75	9.62	4.12	7.50	8	1	8	2.31
3	2.94	10.50	5.00	8.00	8	1 1/8	8	2.50
3 1/2	3.19	12.25	6.19	9.50	8	1 1/4	8	2.75
4	3.62	14.75	7.31	11.50	8	1 1/2	8	3.19
5	3.44	15.00	8.50	12.50	12	1 3/8	8	3.00
6	3.88	19.50	10.62	15.50	12	1 5/8	8	3.44
8	4.31	23.00	12.75	19.00	12	1 7/8	8	3.88
10	4.56	26.50	15.00	22.50	16	2	8	4.12
12	5.00	29.50	16.25	25.00	16	2 1/4	8	4.56
14	5.50	32.50	18.50	27.75	16	2 1/2	8	5.06
16	5.94	36.00	21.00	30.50	16	2 3/4	8	5.50
18	6.38	38.75	23.00	32.75	16	3	8	5.94
20	7.31	46.00	27.25	39.00	16	3 1/2	8	6.88

900 lb

SIZE (BORE)	THICK	OD	RF OD	STUD CIRCLE NO.	STUDS SIZE	TPI	TAP DEPTH	HOLE DEPTH
B	T	A	R	C	J	M	I	F
1/2	2.19	5.25	1.38	3.50	4	3/4	10	1.75
3/4	2.19	5.50	1.69	3.75	4	3/4	10	1.75
1	2.44	6.25	2.00	4.25	4	7/8	9	2.00
1 1/4	2.75	7.25	2.50	5.12	4	1	8	2.31
1 1/2	2.94	8.00	2.88	5.75	4	1 1/8	8	2.50
2	2.75	9.25	3.62	6.75	8	1	8	2.31
2 1/2	2.94	10.50	4.12	7.75	8	1 1/8	8	2.50
3	3.19	12.00	5.00	9.00	8	1 1/4	8	2.75
4	3.62	14.00	6.19	10.75	8	1 1/2	8	3.19
5	4.12	16.50	7.31	12.75	8	1 3/4	8	3.69
6	4.56	19.00	8.50	14.50	8	2	8	4.12
8	5.50	26.50	12.75	21.25	12	2 1/2	8	5.06
10	5.94	30.00	15.00	24.38	12	2 3/4	8	5.50

The stud welding outlets tabulated comply with the requirements of ASME Code Sect. VIII, Div. 1.

The tabulated dimensions of thickness, T are the minimums required.

The outlets are available also in stainless and other alloy steels. Air test holes are optional.

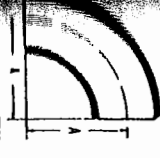





## MEASURES



## NOTES

# WELDING FITTINGS ANSI B 16.9

1. All dimensions are in inches.
2. Welding fitting material conforms to SA 234 grade WPB.
3. Sizes 22, 26 and 30 in. are not covered by ANSI B 16.9.
4. For wall thicknesses see page 322.
5. Dimension  $F_1$  applies to standard and X-STG. caps. Dimension  $F_2$  applies to heavier weight caps.

Nominal Pipe Size	Dimensions							
	Outside Diameter	A	B	C	D	E	$F_1^s$	$F_2^s$
 Long Radius Elbow	1/2	0.840	1 1/2	3/8	1 7/8	.....	.....	1
	3/4	1.050	1 1/8	7/16	1 11/16	.....	.....	1 1/2
	1	1.315	1 1/2	7/8	2 1/16	1	1 3/8	1 1/2
	1 1/4	1.660	1 7/8	1	2 3/4	1 1/4	2 1/16	1 1/2
 Radius Elbow	1/2	1.900	2 1/4	1 1/8	3 1/4	1 1/2	2 7/16	1 1/2
	2	2.375	3	1 3/8	4 3/16	2	3 3/16	1 1/2
	2 1/2	2.875	3 3/4	1 3/4	5 3/16	2 1/2	3 15/16	1 1/2
	3	3.500	4 1/2	2	6 1/4	3	4 3/4	2
 Long Elbow	3 1/4	4.000	5 1/4	2 1/4	7 1/4	3 1/2	5 1/2	2 1/2
	4	4.500	6	2 1/2	8 1/4	4	6 1/4	2 1/2
	5	5.563	7 1/2	3 1/8	10 5/16	5	7 3/4	3
	6	6.625	9	3 3/4	12 5/16	6	9 3/16	3 1/2
 Radius Elbow	8	8.625	12	5	16 1/16	8	12 3/16	4
	10	10.750	15	6 1/4	20 3/8	10	15 3/8	5
	12	12.750	18	7 1/2	24 3/8	12	18 3/8	6
	14	14.000	21	8 3/4	28	14	21	6 1/2
 Return Elbow	16	16.000	24	10	32	16	24	7
	18	18.000	27	11 1/4	36	18	27	8
	20	20.000	30	12 1/2	40	20	30	9
	22	22.000	33	13 1/2	44	....	....	10
 Cap	24	24.000	36	15	48	24	36	10 1/2
	26	26.000	39	16	52	....	....	10 1/2
	30	30.000	45	18 1/2	60	30	45	10 1/2

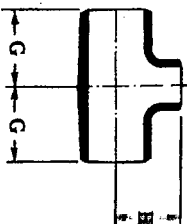

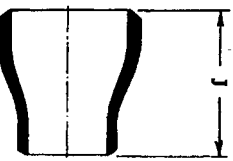
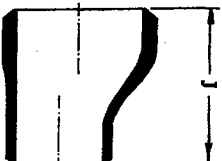
## MEASURES



## WELDING FITTINGS

## ANSI B 16.9

1. All dimensions are in inches
2. Welding fitting material conforms to SA 234 grade WPB.
3. Sizes 22, 26 and 30 in. are not covered by ANSI B 16.9.
4. For wall thicknesses see page 322.

Nominal Pipe Size	Dimensions					Tee
	Outlet	Outside Diameter	G	H	J	
1/2	1/2	.840 675	1 1	1 1	.... ....	
3/4	3/4 1/2	1.050 .840	1 1/8 1 1/8	1 1/8 1 1/8	.... 1 1/2	
1	1 3/4 1/2	1.315 1.050 .840	1 1/2 1 1/2 1 1/2	1 1/2 1 1/2 1 1/2	.... 2 2	
1 1/4	1 1/4 1 3/4 1/2	1.660 1.315 1.050 .840	1 7/8 1 7/8 1 7/8 1 7/8	1 7/8 1 7/8 1 7/8 1 7/8	.... 2 2 2	
1 1/2	1 1/2 1 1/4 1 3/4 1/2	1.900 1.660 1.315 1.050 .840	2 1/4 2 1/4 2 1/4 2 1/4 2 1/4	2 1/4 2 1/4 2 1/4 2 1/4 2 1/4	.... 2 1/2 2 1/2 2 1/2 2 1/2	
2	2 1 1/2 1 1/4 1 3/4	2.375 1.900 1.660 1.315 1.050	2 1/2 2 1/2 2 1/2 2 1/2 2 1/2	2 1/2 2 1/8 2 1/8 2 1 3/4	.... 3 3 3 3	
2 1/2	2 1/2 2 1 1/2 1 1/4 1	2.875 2.375 1.900 1.660 1.315	3 3 3 3 3	3 2 3/4 2 1/2 2 1/4 2 1/4	.... 3 1/2 3 1/2 3 1/2 3 1/2	
3	3 2 1/2 2 1 1/2 1 1/4	3.500 2.875 2.375 1.900 1.660	3 3/8 3 3/8 3 3/8 3 3/8 3 3/8	3 3/8 3 3/4 3 2 7/8 2 3/4	.... 3 1/2 3 1/2 3 1/2 3 1/2	
3 1/2	3 1/2 3 2 1/2 2 1 1/2	4.000 3.500 2.875 2.375 1.900	3 3/4 3 3/4 3 3/4 3 3/4 3 3/4	3 3/4 3 3/8 3 1/2 3 1/4 3 1/8	.... 4 4 4 4	
4	4 3 1/2 3 2 1/2 2 1 1/2	4.500 4.000 3.500 2.875 2.375 1.900	4 1/8 4 1/8 4 1/8 4 1/8 4 1/8 4 1/8	4 1/8 4 3 7/8 3 3/4 3 1/2 3 1/8	.... 4 4 4 4 4	
						
Eccentric Reducer						

Tee

Reducing Tee

Concentric Reducer

Eccentric Reducer

## WELDING FITTINGS

## ANSI B 16.9

1. All dimensions are in inches
2. Welding fitting material conforms to SA 234 grade WPB.
3. Sizes 22, 26 and 30 in. are not covered by ANSI B 16.9.
4. For wall thicknesses see page 322.

Nominal Pipe Size		Dimensions				
		Outlet	Outside Diameter	G	H	J
5	5	5.563	4 7/8	4 7/8	••••	
	4	4.500	4 7/8	4 7/8	5	
	3 1/2	4.000	4 7/8	4 3/4	5	
	3	3.500	4 7/8	4 7/8	5	
	2 1/2	2.875	4 7/8	4 1/4	5	
6	2	2.375	4 7/8	4 1/8	5	
	6	6.625	5 3/8	5 3/8	••••	
	5	5.563	5 3/8	5 3/8	5 1/2	
	4	4.500	5 3/8	5 1/8	5 1/2	
	3 1/2	4.000	5 3/8	5	5 1/2	
	3	3.500	5 3/8	4 7/8	5 1/2	
	2 1/2	2.875	5 3/8	4 3/4	5 1/2	
	8	8.625	7	7	••••	
	6	6.625	7	6 3/8	6	
	5	5.563	7	6 1/8	6	
4	4	4.500	7	6 1/8	6	
	3 1/2	4.000	7	6	6	
	10	10.750	8 1/2	8 1/2	••••	
	8	8.625	8 1/2	8	7 7/8	
	6	6.625	8 1/2	7 1/2	7 7/8	
	5	5.563	8 1/2	7 1/4	7 7/8	
	4	4.500	8 1/2	7 1/4	7 7/8	
	12	12.750	10	10	••••	
	10	10.750	10	9 1/2	8	
	8	8.625	10	9	8	
	6	6.625	10	8 3/8	8	
	5	5.563	10	8 1/2	8	
	14	14.000	11	11	••••	
	12	12.750	11	10 3/8	13	
	10	10.750	11	10 1/8	13	
	8	8.625	11	9 3/4	13	
	6	6.625	11	9 1/8	13	
	16	16.000	12	12	••••	
	14	14.000	12	12	14	
	12	12.750	12	11 3/8	14	
	10	10.750	12	11 1/8	14	
	8	8.625	12	10 3/4	14	
	6	6.625	12	10 1/8	14	
	18	18.000	13 1/2	13 1/2	••••	
	16	16.000	13 1/2	13	15	
	14	14.000	13 1/2	13	15	

Tee

Reducing Tee

Concentric Reducer

Eccentric Reducer

## MEASURES

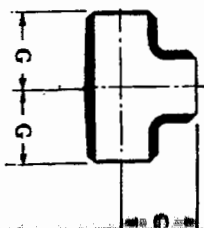


# WELDING FITTINGS

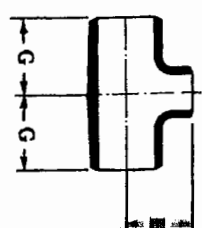
ANSI B 16.9

1. All dimensions are in inches
2. Welding fitting material conforms to SA 234 grade WPB.
3. Sizes 22, 26 and 30 in. are not covered by ANSI B 16.9.
4. For wall thicknesses see page 322.

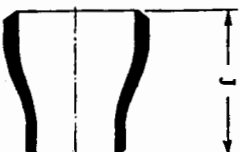
Nominal Pipe Size	Dimensions				
	Outlet	Outside Diameter	G	H	J
18	12	12.750	13 $\frac{3}{4}$	12 $\frac{3}{8}$	15
	10	10.750	13 $\frac{3}{4}$	12 $\frac{1}{8}$	15
	8	8.625	13 $\frac{3}{4}$	11 $\frac{1}{4}$	15
	8	8.625	15	12 $\frac{3}{4}$	20
20	20	20.000	15	15	...
	18	18.000	15	14 $\frac{1}{2}$	20
	16	16.000	15	14	20
	14	14.000	15	14	20
	12	12.750	15	13 $\frac{3}{8}$	20
	10	10.750	15	13 $\frac{1}{8}$	20
	8	8.625	15	12 $\frac{3}{4}$	20
	8	8.625	16 $\frac{1}{2}$	16 $\frac{1}{2}$	...
22	22	22.000	16 $\frac{1}{2}$	16	20
	20	20.000	16 $\frac{1}{2}$	15 $\frac{1}{2}$	20
	18	18.000	16 $\frac{1}{2}$	15	20
	16	16.000	16 $\frac{1}{2}$	15	20
	14	14.000	16 $\frac{1}{2}$	15	20
	12	12.750	16 $\frac{1}{2}$	14 $\frac{3}{8}$	...
	10	10.750	16 $\frac{1}{2}$	14 $\frac{1}{8}$	...
	10	10.750	17	17	...
24	24	24.000	17	17	...
	22	22.000	17	17	20
	20	20.000	17	17	20
	18	18.000	17	16 $\frac{1}{2}$	20
	16	16.000	17	16	20
	14	14.000	17	16	20
	12	12.750	17	15 $\frac{3}{8}$	20
	10	10.750	17	15 $\frac{1}{8}$	20
30	30	30.000	22	22	...
	24	24.000	22	21	24
	22	22.000	22	20 $\frac{3}{4}$	24
	20	20.000	22	20	24
	18	18.000	22	19 $\frac{1}{4}$	...
	16	16.000	22	19	...
	16	16.000	22	19	...
	16	16.000	22	19	...



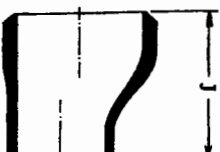
Tee



Reducing Tee

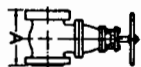


Concentric Reducer



Eccentric Reducer

## FACE-TO-FACE DIMENSIONS OF FLANGED STEEL GATE VALVES (WEDGE AND DOUBLE DISC)

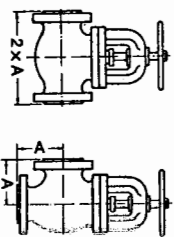


Pressure, lb. per Sq. In.				Nominal Size, Inches	Pressure, lb. per Sq. In.				
150	300	400	600		900	1500	2500		
Dimension A, Inches					Dimension A, Inches				
1	—	—	8½	8½	1	10	10	12½	
1½	—	—	9	9	1½	11	11	13½	
2	—	7½	9½	9½	2	12	12	15½	
2½	7	8½	11½	11½	2½	14½	14½	17½	
3	7½	9½	13	13	3	16½	16½	20	
3½	8	11½	14	14	3½	15	18½	22½	
4	8½	11½	—	—	4	18	21½	26½	
5	9	12	16	17	5	22	26½	31½	
6	10	15	18	20	6	24	27½	36	
8	10½	15½	19½	22	8	29	32½	40½	
10	11½	16½	23½	26	10	33	39	50	
12	13	18	26½	31	12	38	44½	56	
14	14	19½	30	33	14	40½	49½	—	
15	15	30	32½	35	16	44½	54½	—	
16	33	35½	39	—	18	48	60½	—	
17	36	38½	43	—	20	52	65½	—	
18	39	41½	47	—	24	61	76½	—	
20	45	48½	55	—					
Pressure, lb. per Sq. In.					Pressure, lb. per Sq. In.				
Dimension A, Inches					Dimension A, Inches				
150	300	400	600	Nominal Size, Inches	900	1500	2500		
5½	—	8½	8½	1	10	10	12½		
6	—	9	9	1½	11	11	13½		
7	8	9½	9½	2	12	12	15½		
7½	9½	11½	11½	2½	14½	14½	17½		
8	10½	13½	13½	3	16½	16½	20½		
8½	11½	14½	14½	3½	15½	18½	23		
9½	12½	16½	17½	4	18½	21½	26½		
10½	15½	18½	20½	5	22½	26½	31½		
11	16½	19½	22½	6	24½	28	36½		
12	17½	23½	26½	8	29½	33½	40½		
13½	18½	26½	31½	10	33½	39½	50½		
14½	20½	30½	33½	12	38½	45½	56½		
15½	30½	32½	35½	14	40½	50½	—		
16½	33½	35½	39½	16	44½	55½	—		
17½	36½	38½	43½	18	48½	61½	—		
18½	39½	41½	47½	20	52½	66½	—		
20½	45½	48½	55½	24	61½	77½	—		

## MEASURES



# FACE-TO-FACE DIMENSIONS OF FLANGED STEEL GLOBE AND ANGLE VALVES



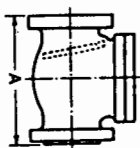
## Raised Face

Nominal Size, Inches	Class, lb			Nominal Size, Inches	Pressure, lb. per Sq. In.		
	150	300	400	600	900	1500	2500
Dimension 2 x A, inches					Dimension 2 x A, inches		
1/2	—	—	—	—	—	—	10 3/4
3/4	—	—	7 1/2	7 1/2	9	9	10 3/4
1	—	—	8 1/2	8 1/2	10	10	12 1/4
1 1/4	—	—	9	9	11	11	13 3/4
1 1/2	—	—	9 1/4	9 1/4	12	12	15 1/4
2	8	10 1/4	11 1/4	11 1/4	14 1/4	14 1/4	17 3/4
2 1/4	8 1/2	11 1/4	13	13	16 1/4	16 1/4	20
3	9 1/4	12 1/4	14	14	18 1/4	18 1/4	22 3/4
3 1/2	10 1/2	13 1/4	—	—	21 1/4	21 1/4	26 1/2
4	11 1/2	14	16	17	22	26 1/4	31 1/4
5	14	15 1/4	18	20	24	27 3/4	36
6	16	17 1/4	19 1/4	22	29	32 1/4	40 1/4
8	19 1/4	22	23 1/4	26	33	39	50
12	—	—	—	—	38	44 1/4	56
14	—	—	—	—	40 1/4	49 1/4	—

## Ring Type Joint

Nominal Size, Inches	Pressure, lb. per Sq. In.			Nominal Size, Inches	Pressure, lb. per Sq. In.		
	150	300	400	600	900	1500	2500
Dimension 2 x A, inches					Dimension 2 x A, inches		
1/2	—	6 1/4	6 1/4	6 1/4	—	—	10 3/4
3/4	—	7 1/4	7 1/4	7 1/4	9	9	10 3/4
1	—	8 1/4	8 1/4	8 1/4	10	10	12 1/4
1 1/4	—	9	9	9	11	11	13 3/4
1 1/2	7	9 1/4	9 1/4	9 1/4	12	12	15 1/4
2	8 1/2	11 1/4	11 1/4	11 1/4	14 1/4	14 1/4	17 3/4
2 1/4	9	12 1/4	13 1/4	13 1/4	16 1/4	16 1/4	20
3	—	13 1/4	14 1/4	14 1/4	18 1/4	18 1/4	23
4	12	14 1/4	16 1/4	17 1/4	21 1/4	21 1/4	26 1/2
5	14 1/4	16 1/4	18 1/4	20 1/4	24 1/4	24 1/4	31 1/4
6	16 1/4	18 1/4	19 1/4	22 1/4	28	28	36 1/2
8	20	22 1/4	23 1/4	26 1/4	33 1/4	33 1/4	40 1/4
10	25	25 1/4	26 1/4	31 1/4	39 1/4	39 1/4	50 1/4
12	28	28 1/4	30 1/4	33 1/4	45 1/4	45 1/4	56 1/4
14	31 1/2	—	—	—	50 1/4	—	—
16	36 1/4	—	—	—	—	—	—

# FACE-TO-FACE DIMENSIONS OF FLANGED STEEL SWING CHECK VALVES



## Raised Face

Nominal Size, Inches	Pressure, lb. per Sq. In.			Nominal Size, Inches	Pressure, lb. per Sq. In.		
	150	300	400	600	900	1500	2500
Dimension A, inches					Dimension A, inches		
3	10 1/2	11 1/2	11 1/2	11 1/2	—	—	10 3/4
3 1/2	11 1/2	13	13	13	9	9	10 3/4
4	12 1/2	14	14	14	10	10	12 1/4
4 1/2	13 1/4	—	—	—	11	11	13 3/4
5	14	16	17	17	12	12	15 1/4
6	15 1/4	—	—	—	14 1/4	14 1/4	17 3/4
8	17 1/4	19 1/4	22	22	16 1/4	16 1/4	20
10	21	23 1/4	26	26	18 1/4	18 1/4	22 3/4
12	24 1/2	26 1/2	31	31	21 1/4	21 1/4	26 1/2
14	—	30	33	33	24	26 1/4	31 1/4
16	—	—	—	—	27 1/4	27 1/4	36
18	—	—	—	—	32 1/4	32 1/4	40 1/4
20	—	—	—	—	39	39	50
24	—	—	—	—	44 1/4	44 1/4	56
28	—	—	—	—	49 1/4	—	—

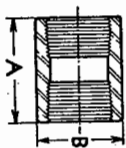
## Ring Type Joint

Nominal Size, Inches	Pressure, lb. per Sq. In.			Nominal Size, Inches	Pressure, lb. per Sq. In.		
	150	300	400	600	900	1500	2500
Dimension A, inches					Dimension A, inches		
4 1/4	—	—	6 1/4	6 1/4	—	—	10 3/4
5 1/4	—	7 1/4	7 1/4	7 1/4	9	9	10 3/4
6 1/4	9	8 1/4	8 1/4	8 1/4	10	10	12 1/4
7 1/4	9 1/4	9	9	9	11	11	13 3/4
8 1/4	10	9 1/4	9 1/4	9 1/4	12	12	15 1/4
9 1/4	11 1/4	11 1/4	11 1/4	11 1/4	14 1/4	14 1/4	17 3/4
10 1/4	12 1/4	13 1/4	13 1/4	13 1/4	16 1/4	16 1/4	20
11 1/4	13 1/4	14 1/4	14 1/4	14 1/4	18 1/4	18 1/4	23
12 1/4	14 1/4	16 1/4	17 1/4	17 1/4	21 1/4	21 1/4	26 1/2
13 1/4	16 1/4	18 1/4	20 1/4	20 1/4	24 1/4	24 1/4	31 1/4
14 1/4	18 1/4	19 1/4	22 1/4	22 1/4	28	28	36 1/2
16 1/4	21 1/4	23 1/4	26 1/4	26 1/4	33 1/4	33 1/4	40 1/4
18 1/4	25 1/4	26 1/4	31 1/4	31 1/4	39 1/4	39 1/4	50 1/4
20 1/4	28 1/4	30 1/4	33 1/4	33 1/4	45 1/4	45 1/4	56 1/4
24 1/4	—	—	—	—	50 1/4	—	—

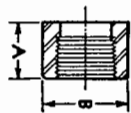
Face-to-Face and End-to-End Dimensions of Ferrous Valves  
American National Standard ANSI B16.10-1973

MEASURES





Full Coupling



Half Coupling

## SCREWED COUPLINGS

1. All dimensions are in inches.
2. Material forged carbon steel conforms the requirements of Specification SA-105.
3. Threads comply with ANSI Standard B7.1-1968.

Nominal Pipe Size	Full Coupling				Half Coupling			
	3000 lb		6000 lb		3000 lb		6000 lb	
	Length A	Diameter B	Length A	Diameter B	Length A	Diameter B	Length A	Diameter B
1/8	1 1/4	3/4	1 1/4	7/8	5/8	3/4	5/8	7/8
1/4	1 3/8	3/4	1 3/8	1	11/16	3/4	11/16	1
3/8	1 1/2	7/8	1 1/2	1 1/4	3/4	7/8	3/4	1 1/4
1/2	1 7/8	1 1/8	1 7/8	1 1/2	15/16	1 1/8	15/16	1 1/2
3/4	2	1 3/8	2	1 3/4	1	1 3/8	1	1 3/4
1	2 3/8	1 3/4	2 3/8	2 1/4	1 3/16	1 3/4	1 3/16	2 1/4
1 1/4	2 5/8	2 1/4	2 5/8	2 1/2	1 5/16	2 1/4	1 5/16	2 1/2
1 1/2	3 1/8	2 1/2	3 1/8	3	1 9/16	2 1/2	1 9/16	3
2	3 3/8	3	3 3/8	3 5/8	1 11/16	3	1 11/16	3 5/8
2 1/2	3 5/8	3 5/8	3 5/8	4 1/4	1 13/16	3 5/8	1 13/16	4 1/4
3	4 1/4	4 1/4	4 1/4	5	2 1/8	4 1/4	2 1/8	5
3 1/2	4 1/2	4 3/4	4 1/2	5 3/4	2 1/4	4 3/4	2 1/4	5 3/4
4	4 3/4	5 1/2	4 3/4	6 1/4	2 3/8	5 1/2	2 3/8	6 1/4

SYMBOLS FOR PIPE FITTINGS  
American Standard: ANSI Z32.2.3

	Flanged	Screwed	Bell and Spigot	Welded	Soldered
Reducer					
Elbow					
Tee					
Cross					
Tee - Degree					
Tee - Down					
Tee - Up					
Tee - Branch					
Tee - Radius					
Tee - Outlet (Outlet Down)					
Tee - Outlet (Outlet Up)					

## MEASURES



















































## SYMBOLS FOR PIPE FITTINGS

## NOTES

	Flanged	Screwed	Bell and Spigot	Welded	Soldered
Diaphragm Valve					
Float Valve					
Gate Valve					
Motor-Operated					
Globe Valve					
Motor-Operated					
Hose Valve, also Hose Globe Angle, also Hose Angle Gate Globe					
Lockshield Valve					
Plug Valve					
Quick Opening or Butterfly Valve					
Safety Valve					

## MEASURES



## WEIGHTS

1. The tables on the following pages show the weights of different vessel components made of steel.
2. All weights are calculated with the theoretical weight of steel: 1 cubic inch = 0.28333 pounds.
3. To obtain the actual weight of a vessel, add 6% to the total weight. This will cover the overweights of material which comes from the manufacturing tolerances and the weight of the weldings.
4. The weights of shells shown in the tables refer to one lineal foot of shell length. The weights tabulated in columns headed by "I.S." and "O.S." are the weights of shell when the given diameter signifies inside or outside diameter.
5. The weights of the heads include:
  - A. For ellipsoidal heads: 2 inch straight flange or the wall thickness, whichever is greater.
  - B. For ASME flanged and dished heads: 1½ inch straight flange.
  - C. For hemispherical heads: 0 inch straight flange.
6. The weights of pipe fittings made by different manufacturers show in many cases considerable deviations, which reflect manufacturing differences. The weights of pipe fittings shown in these tables refer to the products of Lashin Company.
7. All dimensions in inches.  
All weights in pounds.

### WEIGHT OF SHELLS & HEADS

DIAMETER	WALL THICKNESS									
	1/4"					5/16"				
	SHELL		HEAD			SHELL		HEAD		
	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	33	31	22	14	20	41	39	28	19	26
14	38	36	28	19	28	48	46	35	24	35
16	44	42	33	23	36	54	52	41	29	46
18	49	49	41	28	46	61	59	51	35	58
20	54	52	47	35	56	68	66	58	43	71
22	60	58	55	41	68	74	72	69	51	85
24	65	63	62	47	81	81	79	78	58	101
26	70	68	70	55	95	88	86	87	69	119
28	76	74	78	62	110	94	92	100	78	138
30	81	79	89	70	126	101	99	114	87	158
32	86	84	100	80	143	108	106	129	100	179
34	92	90	113	89	161	114	112	144	111	202
36	97	95	128	98	180	121	119	160	123	226
38	102	100	139	110	201	128	126	177	138	256
40	108	106	156	120	222	134	133	195	150	279
42	113	111	165	131	245	141	139	214	163	307
44	129	127	215	168	320	161	159	285	210	400
46	145	143	270	210	404	182	179	351	263	506
48	161	159	330	257	498	202	199	434	322	624
50	177	175	398	309	602	222	219	520	386	755
52	193	191	453	365	717	243	239	598	456	897
54	209	207	543	421	840	263	259	695	532	1052
56	225	223	624	492	974	283	279	806	614	1220
58	241	239	723	556	1118	303	299	925	702	1399
60	257	255	820	637	1272	324	319	1050	796	1592
62	273	271	922	710	1435	344	339	1180	896	1796
64	289	287	1031	801	1608	364	359	1320	1001	2013
66	305	303	1150	883	1792	385	379	1468	1104	2242
68	321	319	1255	984	1985	405	399	1622	1230	2484
70	337	335	1445	1075	2188	425	419	1820	1344	2738
72	353	351	1590	1186	2401	446	439	1990	1482	3004
74	369	367	1730	1286	2624	466	459	2160	1607	3282
76	385	383	1880	1406	2856	486	480	2350	1758	3573

ME



## WEIGHT OF SHELLS &amp; HEADS

DIAM.	WALL THICKNESS									
	3/8"					7/16"				
	SHELL		HEAD			SHELL		HEAD		
VESSEL	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	50	47	33	22	32	58	54	41	26	57
14	58	55	42	28	43	67	63	49	33	59
16	66	63	50	35	55	77	73	61	41	65
18	74	71	61	42	70	86	82	71	52	72
20	82	79	70	52	85	95	91	85	61	80
22	90	87	82	61	103	105	101	97	71	87
24	98	95	94	70	122	114	110	109	82	105
26	106	103	105	82	143	123	119	122	97	124
28	114	111	121	94	166	133	129	141	109	142
30	122	119	137	105	190	142	138	160	122	170
32	130	127	154	121	216	151	148	180	141	195
34	138	135	173	134	243	161	157	191	156	225
36	146	143	192	147	272	170	166	224	172	255
38	154	151	213	165	303	179	176	248	192	285
40	162	159	234	180	336	189	185	273	210	315
42	170	167	257	196	370	198	194	300	229	345
48	194	191	331	252	482	226	222	386	295	464
54	218	215	415	316	609	254	250	484	368	583
60	242	239	508	386	751	282	278	592	450	702
66	266	263	610	463	907	310	306	711	540	820
72	290	287	718	547	1079	338	334	842	639	938
78	314	311	836	638	1265	366	362	983	745	1056
84	338	335	965	737	1466	394	391	1136	860	1174
90	362	359	1110	842	1682	422	419	1298	983	1292
96	386	383	1260	955	1912	450	447	1473	1115	1410
102	410	407	1419	1075	2158	478	475	1658	1254	1528
108	434	431	1582	1202	2418	506	503	1854	1402	1646
114	458	455	1760	1335	2694	534	531	2061	1558	1764
120	482	479	1950	1476	2984	562	559	2249	1722	1882
126	506	503	2170	1624	3288	591	587	2530	1894	2000
132	530	527	2490	1779	3608	619	615	2790	2075	2118
138	554	551	2595	1928	3942	647	643	3025	2264	2236
144	579	576	2820	2110	4292	675	671	3300	2461	2354

## WEIGHT OF SHELLS &amp; HEADS

DIAM.	WALL THICKNESS									
	1/2"					9/16"				
	SHELL		HEAD			SHELL		HEAD		
VESSEL	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	67	61	47	30	43	76	69	52	35	49
14	78	72	56	38	58	88	81	63	44	65
16	88	82	70	47	75	100	93	78	54	85
18	99	93	81	59	94	112	105	91	67	106
20	110	104	97	70	115	124	117	109	78	131
22	120	114	110	81	139	136	129	124	91	157
24	131	125	125	94	165	148	141	143	107	186
26	142	136	140	110	193	160	153	162	124	218
28	152	146	161	125	223	172	165	181	140	252
30	163	157	182	140	255	184	177	205	157	288
32	174	168	206	161	290	196	189	231	181	327
34	184	178	230	178	327	208	201	259	200	369
36	195	189	256	196	366	220	213	288	220	413
38	206	200	283	220	407	232	225	319	247	459
40	217	211	313	240	450	244	237	352	270	508
42	227	221	343	261	496	256	249	386	294	560
48	259	253	442	337	646	292	285	497	379	728
54	291	285	553	421	815	328	321	622	473	919
60	323	317	677	514	1005	364	357	762	578	1133
66	355	349	813	617	1214	400	393	915	694	1368
72	387	381	962	730	1443	436	429	1083	821	1626
78	419	413	1124	852	1692	472	465	1264	958	1906
84	451	445	1298	983	1960	508	501	1460	1106	2209
90	483	477	1484	1124	2248	544	537	1669	1264	2533
96	515	509	1683	1274	2557	580	573	1894	1433	2880
102	547	541	1894	1433	2884	617	610	2131	1612	3249
108	579	573	2119	1602	3232	653	646	2384	1802	3640
114	611	605	2355	1780	3599	689	682	2650	2002	4054
120	647	638	2571	1968	3986	725	718	2892	2214	4489
126	676	670	2890	2165	4393	761	754	3234	2435	4947
132	708	702	3340	2372	4820	797	790	3660	2668	5427
138	740	734	3460	2588	5266	833	826	3897	2911	5930
144	777	766	3760	2813	5732	869	862	4240	3165	6454

WEIGHTS

MEASURES



## WEIGHT OF SHELLS &amp; HEADS

DIAM.	WALL THICKNESS									
	5/8"					11/16"				
	SHELL		HEAD			SHELL		HEAD		
VESSEL	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	84	76	58	40	55	93	83	64	44	63
14	97	89	70	50	73	108	98	79	55	81
16	111	103	87	61	95	122	112	95	67	105
18	124	116	101	74	119	137	127	113	83	132
20	137	129	121	86	146	152	142	133	97	162
22	151	143	138	101	176	166	156	154	113	194
24	164	156	161	121	208	181	171	177	133	230
26	177	169	180	138	243	196	186	198	151	264
28	191	183	201	156	281	211	201	221	171	311
30	204	196	228	175	322	225	215	251	195	355
32	218	210	257	201	365	240	230	283	221	403
34	231	223	288	223	411	255	245	317	245	452
36	244	236	326	245	460	269	259	353	270	503
38	258	250	355	275	512	284	274	390	302	565
40	271	263	391	300	566	299	289	430	330	625
42	284	276	428	327	623	313	303	471	360	685
48	324	316	552	421	811	357	347	607	458	895
54	364	356	691	526	1024	401	391	760	579	1129
60	404	396	846	643	1261	445	435	931	707	1390
66	444	436	1017	772	1523	489	479	1118	849	1677
72	484	476	1203	912	1810	533	523	1323	1003	1992
78	524	516	1405	1065	2121	577	567	1545	1171	2357
84	564	556	1622	1229	2458	621	611	1784	1352	2707
90	604	596	1855	1405	2818	665	655	2041	1545	3104
96	644	636	2104	1592	3204	710	700	2315	1751	3529
102	685	677	2368	1791	3614	754	744	2605	1970	3985
108	725	717	2648	2003	4049	798	788	2913	2203	4459
114	765	757	2944	2225	4509	842	832	3239	2448	4965
120	805	797	3213	2460	4993	886	876	3535	2706	5495
126	848	837	3578	2706	5502	930	920	3910	2977	6058
132	885	877	3980	2965	6036	974	964	4317	3261	6646
138	925	917	4325	3234	6595	1018	1008	4703	3557	7261
144	965	957	4720	3516	7178	1062	1052	5185	3868	7902

## WEIGHT OF SHELLS &amp; HEADS

DIAM.	WALL THICKNESS									
	3/4"					13/16"				
	SHELL		HEAD			SHELL		HEAD		
VESSEL	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	102	90	70	48	67	111	97	76	53	73
14	118	106	88	60	90	128	114	95	67	98
16	134	122	104	74	116	146	132	113	82	126
18	150	138	126	92	145	163	149	136	100	158
20	166	154	145	108	177	180	166	157	117	193
22	182	170	171	126	213	198	184	185	137	232
24	198	186	193	145	252	215	201	209	160	275
26	214	202	216	165	295	233	219	234	182	321
28	230	218	241	187	340	250	236	261	412	370
30	246	234	274	216	389	267	253	304	234	423
32	262	250	309	241	442	285	271	335	261	480
34	278	266	345	267	497	302	288	378	289	541
36	294	282	393	294	556	319	305	425	323	605
38	310	298	425	330	618	337	323	470	357	672
40	326	314	469	361	684	354	340	508	391	743
42	342	330	514	393	753	371	357	567	425	818
48	390	378	662	505	979	423	409	729	547	1063
54	438	426	829	631	1234	475	461	911	683	1340
60	486	474	1015	772	1520	527	513	1107	836	1650
66	534	522	1220	926	1835	579	565	1337	1003	1991
72	582	570	1443	1095	2179	631	617	1564	1186	2365
78	630	618	1685	1277	2554	683	669	1835	1384	2771
84	678	666	1947	1475	2958	735	721	2120	1597	3209
90	726	714	2226	1685	3391	788	774	2433	1825	3679
96	775	763	2525	1911	3855	840	826	2757	2070	4181
102	823	811	2842	2150	4348	892	878	3103	2329	4716
108	871	859	3178	2403	4870	944	930	3457	2603	5282
114	919	907	3533	2671	5422	996	982	3854	2893	5881
120	967	955	3856	2952	6004	1048	1034	4204	3198	6511
126	1015	1003	4243	3248	6616	1100	1086	4614	3518	7174
132	1063	1051	4655	3558	7257	1152	1138	5059	3854	7869
138	1111	1099	5082	3881	7928	1204	1190	5522	4205	8596
144	1159	1147	5550	4219	8628	1256	1242	6067	4571	9356

MEASURES



DIAM.	WALL THICKNESS									
	7/8"					15/16"				
	SHELL		HEAD			SHELL		HEAD		
VESSEL	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	120	104	82	59	80	130	111	90	67	86
14	139	123	103	74	106	150	131	110	83	115
16	157	141	122	90	137	170	151	135	101	148
18	176	160	147	107	171	190	171	157	123	185
20	195	179	170	127	209	210	191	185	144	226
22	213	197	199	147	251	230	211	213	167	271
24	232	216	225	175	297	250	231	241	194	320
26	251	235	252	199	347	270	251	271	220	374
28	270	254	288	225	401	290	271	310	249	431
30	288	272	327	252	458	310	291	351	282	493
32	307	291	366	281	519	330	311	393	314	558
34	326	310	412	312	584	350	331	442	347	628
36	344	328	458	352	653	370	351	491	387	702
38	363	347	506	385	726	390	371	543	422	780
40	382	366	558	421	803	410	391	597	462	863
42	400	384	611	458	883	430	411	654	507	949
48	456	440	789	589	1148	491	471	836	643	1233
54	512	496	982	736	1447	551	531	1051	802	1554
60	568	552	1200	900	1780	611	591	1285	979	1911
66	624	608	1440	1080	2149	671	651	1543	1174	2306
72	680	664	1702	1278	2551	731	711	1823	1387	2738
78	736	720	1986	1491	2989	791	771	2128	1616	3207
84	792	776	2293	1720	3461	851	832	2456	1864	3714
90	849	833	2620	1966	3968	911	892	2807	2129	4257
96	905	889	2970	2229	4509	971	952	3182	2412	4837
102	961	945	3341	2508	5085	1031	1012	3580	2712	5454
108	1017	1001	3735	2804	5695	1091	1072	4002	3036	6109
114	1073	1057	4150	3115	6340	1151	1132	4447	3366	6800
120	1129	1113	4528	3444	7019	1212	1192	4852	3720	7529
126	1185	1169	4985	3789	7734	1272	1252	5341	4091	8294
132	1241	1225	5463	4150	8482	1332	1312	5853	4480	9097
138	1297	1281	5963	4528	9266	1392	1372	6389	4886	9937
144	1353	1337	6485	4923	10084	1452	1432	6948	5310	10813

DIAM.	WALL THICKNESS									
	1"									
	SHELL		HEAD			SHELL		HEAD		
VESSEL	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	139	117	98	76	93	148	124	104	83	100
14	160	138	118	93	124	171	147	125	102	132
16	182	160	144	113	159	193	169	153	122	170
18	203	181	168	139	198	216	192	178	150	212
20	224	202	200	162	242	239	215	212	175	259
22	246	223	228	187	290	262	238	242	202	310
24	267	245	257	214	343	284	260	277	231	366
26	289	266	288	242	400	307	283	311	261	427
28	310	287	330	273	462	330	306	350	294	493
30	331	308	374	313	528	352	328	397	338	563
32	353	330	421	347	598	375	351	448	373	638
34	374	351	471	383	673	398	374	500	412	717
36	396	372	523	421	752	420	396	562	452	801
38	417	393	579	460	835	443	419	614	495	884
40	438	415	637	502	923	466	442	677	539	968
42	459	436	698	556	1015	489	465	741	597	1052
48	523	500	897	698	1318	557	533	953	749	1484
54	587	564	1121	869	1661	625	601	1191	931	1769
60	651	628	1371	1059	2043	693	669	1457	1134	2155
66	715	692	1646	1268	2465	761	737	1749	1357	2624
72	779	756	1945	1496	2926	829	805	2067	1590	3114
78	844	821	2270	1743	3427	897	874	2412	1851	3647
84	908	885	2620	2008	3967	965	942	2783	2134	4221
90	972	949	2994	2292	4547	1033	1010	3181	2435	4838
96	1036	1013	3394	2596	5166	1101	1078	3606	2758	5496
102	1100	1077	3819	2917	5825	1169	1146	4057	3099	6197
108	1164	1141	4268	3258	6523	1237	1214	4535	3462	6939
114	1228	1205	4743	3617	7261	1306	1282	5038	3843	7724
120	1292	1269	5175	3996	8039	1374	1350	5498	4246	8550
126	1356	1333	5697	4393	8856	1442	1418	6053	4667	9419
132	1420	1397	6243	4809	9712	1510	1486	6633	5108	10329
138	1484	1461	6815	5243	10609	1578	1554	7241	5571	11282
144	1549	1526	7411	5697	11544	1646	1623	7874	6053	12276



## WEIGHT OF SHELLS &amp; HEADS

DIAM.	VESSEL	WALL THICKNESS									
		1-1/8"					1-3/16"				
		SHELL		HEAD			SHELL		HEAD		
		I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	12	158	131	110	90	106	167	137	116	97	113
14	14	182	155	133	110	141	192	162	143	120	150
16	16	206	179	163	132	181	218	188	172	143	193
18	18	230	203	189	162	226	243	213	203	171	240
20	20	254	227	225	189	276	268	238	237	200	293
22	22	278	251	256	217	330	294	264	279	230	351
24	24	302	275	298	248	390	319	289	318	266	414
26	26	326	299	333	281	454	345	315	352	301	482
28	28	350	323	371	315	524	370	340	391	337	555
30	30	374	347	421	362	598	395	365	444	382	634
32	32	398	371	474	400	678	421	391	500	423	718
34	34	422	395	530	442	762	466	416	560	466	807
36	36	446	419	601	484	851	471	441	634	517	902
38	38	470	443	651	530	946	497	467	687	565	1001
40	40	494	467	717	576	1045	522	492	756	615	1106
42	42	518	491	785	639	1149	548	518	828	674	1216
48	48	591	563	1009	800	1491	624	594	1065	852	1577
54	54	663	635	1261	994	1877	700	670	1331	1049	1986
60	60	735	707	1543	1209	2308	776	746	1628	1276	2441
66	66	807	779	1852	1446	2783	852	822	1954	1526	2943
72	72	879	852	2189	1684	3303	929	899	2310	1788	3492
78	78	951	924	2554	1960	3867	1005	975	2695	2082	4089
84	84	1023	996	2947	2260	4476	1081	1051	3108	2398	4732
90	90	1095	1068	3368	2579	5129	1157	1127	3555	2736	5422
96	96	1167	1140	3818	2920	5827	1233	1203	4030	3097	6159
102	102	1239	1212	4296	3282	6569	1309	1279	4535	3480	6942
108	108	1312	1284	4802	3666	7356	1385	1355	5069	3872	7773
114	114	1384	1356	5336	4070	8187	1461	1431	5632	4314	8651
120	120	1456	1428	5822	4496	9062	1537	1507	6145	4764	9576
126	126	1528	1500	6409	4942	9982	1613	1583	6765	5236	10547
132	132	1600	1573	7024	5410	10947	1690	1660	7414	5731	11566
138	138	1672	1645	7667	5899	11956	1766	1736	8093	6248	12632
144	144	1744	1717	8338	6408	13010	1842	1812	8801	6786	13744

## WEIGHT OF SHELLS &amp; HEADS

DIAM.	VESSEL	WALL THICKNESS									
		1-1/4"					1-5/16"				
		SHELL		HEAD			SHELL		HEAD		
		I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	12	177	144	122	105	120	187	150	129	112	127
14	14	204	171	154	129	160	215	178	161	138	169
16	16	230	197	181	154	204	243	206	193	165	216
18	18	257	224	217	181	254	271	234	228	193	269
20	20	284	251	250	210	310	299	262	267	225	327
22	22	311	278	292	242	371	327	290	307	258	392
24	24	337	304	331	284	438	355	318	347	303	462
26	26	364	331	371	322	510	383	346	390	343	538
28	28	391	358	412	360	587	411	374	439	384	619
30	30	417	384	467	402	670	439	402	497	428	707
32	32	444	411	526	446	759	467	430	559	474	800
34	34	471	438	589	490	853	495	458	625	521	899
36	36	497	464	667	551	952	523	486	700	585	1003
38	38	524	491	724	601	1057	552	515	768	638	1113
40	40	551	518	796	654	1168	580	543	844	694	1230
42	42	578	545	872	710	1284	608	571	924	753	1352
48	48	658	625	1121	904	1665	692	655	1187	958	1732
54	54	738	705	1401	1104	2095	776	739	1482	1169	2205
60	60	818	785	1714	1343	2575	860	823	1812	1421	2709
66	66	898	865	2057	1606	3104	944	907	2173	1634	3265
72	72	979	945	2432	1893	3683	1029	991	2567	1988	3873
78	78	1059	1025	2837	2204	4311	1113	1075	2994	2314	4533
84	84	1139	1105	3275	2537	4988	1197	1159	3455	2664	5245
90	90	1219	1185	3742	2894	5715	1281	1243	3947	3039	6009
96	96	1299	1265	4242	3274	6491	1365	1328	4473	3438	6824
102	102	1379	1346	4774	3678	7317	1449	1418	5032	3862	7692
108	108	1459	1426	5336	4106	8192	1533	1496	5623	4311	8611
114	114	1539	1506	5929	4558	9116	1617	1580	6248	4786	9582
120	120	1619	1586	6469	5032	10090	1701	1664	6815	5283	10606
126	126	1700	1666	7121	5530	11113	1786	1748	7501	5807	11681
132	132	1780	1746	7804	6051	12186	1870	1832	8220	6354	12808
138	138	1860	1826	8519	6596	13308	1954	1916	8971	6926	13986
144	144	1940	1906	9264	7165	14480	2038	2000	9755	7524	15217



## WEIGHT OF SHELLS &amp; HEADS

DIAM.	VESSEL	WALL THICKNESS									
		1-3/8"					1-7/16"				
		SHELL		HEAD			SHELL		HEAD		
		I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12		196	156	142	119	135	206	162	151	126	143
14		225	185	169	148	178	237	193	180	155	188
16		255	215	206	176	228	267	223	220	184	240
18		284	244	239	206	283	298	254	255	220	298
20		313	273	285	239	345	329	285	303	253	363
22		343	303	322	275	412	360	316	342	292	434
24		372	332	364	323	486	390	346	386	337	511
26		402	362	408	364	566	421	377	432	380	594
28		431	391	466	408	651	452	408	493	426	684
30		460	421	527	454	743	482	438	558	481	780
32		490	450	593	502	841	513	469	627	532	882
34		519	479	662	553	945	544	500	699	585	991
36		548	508	734	620	1054	575	531	775	648	1106
38		578	538	812	676	1170	605	561	857	707	1228
40		607	567	892	734	1293	636	592	941	768	1355
42		637	597	977	796	1420	667	623	1030	840	1489
48		725	685	1253	1012	1841	759	715	1320	1057	1929
54		813	773	1563	1234	2315	851	807	1646	1301	2426
60		901	861	1910	1500	2844	943	899	2061	1568	2979
66		989	949	2289	1768	3427	1035	991	2407	1861	3590
72		1078	1038	2703	2083	4065	1128	1083	2841	2177	4257
78		1166	1126	3152	2424	4757	1220	1175	3312	2534	4981
84		1254	1214	3635	2791	5503	1312	1267	3819	2917	5761
90		1342	1302	4152	3184	6303	1404	1360	4360	3328	6599
96		1430	1390	4704	3602	7159	1496	1452	4938	3766	7493
102		1518	1478	5291	4046	8068	1588	1544	5553	4230	8445
108		1606	1566	5911	4517	9032	1680	1636	6203	4722	9453
114		1694	1654	6567	5014	10050	1772	1728	6890	5241	10518
120		1783	1743	7162	5535	11122	1865	1820	7513	5786	11640
126		1871	1831	7882	6084	12249	1957	1912	8267	6360	12818
132		1959	1919	8636	6656	13430	2049	2004	9113	6959	14054
138		2047	2007	9424	7256	14666	2141	2097	9881	7586	15346
144		2135	2095	10246	7882	15955	2233	2189	10742	8240	16695

## WEIGHT OF SHELLS &amp; HEADS

DIAM.	VESSEL	WALL THICKNESS									
		1-1/2"					1-9/16"				
		SHELL		HEAD			SHELL		HEAD		
		I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12		216	168	162	134	150	227	174	173	144	158
14		248	200	192	162	198	260	207	204	174	208
16		280	232	234	192	252	294	241	248	206	265
18		312	264	271	234	313	327	274	287	249	328
20		344	296	321	271	381	361	308	340	287	399
22		376	328	363	310	455	394	341	384	329	476
24		408	360	409	352	536	427	374	432	374	561
26		440	392	457	397	623	461	408	483	415	652
28		472	424	521	444	717	494	441	550	470	750
30		504	456	589	508	817	527	474	621	536	855
32		536	488	661	562	924	561	508	696	592	965
34		568	520	738	618	1038	594	541	777	652	1085
36		600	552	817	676	1158	628	575	860	712	1210
38		633	585	903	738	1285	661	608	950	777	1343
40		665	617	991	802	1418	694	641	1042	844	1482
42		697	649	1084	885	1558	728	675	1140	931	1628
48		793	745	1388	1103	2018	828	775	1457	1110	2187
54		889	841	1729	1368	2537	928	875	1815	1436	2649
60		985	937	2111	1636	3115	1028	975	2212	1716	3251
66		1082	1034	2526	1954	3753	1129	1075	2647	2049	3916
72		1178	1130	2980	2272	4449	1229	1175	3122	2382	4643
78		1274	1226	3472	2644	5205	1329	1275	3635	2770	5431
84		1370	1322	4003	3044	6021	1420	1376	4189	3171	6281
90		1466	1418	4569	3472	6895	1529	1476	4781	3617	7192
96		1562	1514	5173	3930	7829	1629	1576	5411	4093	8166
102		1658	1610	5815	4414	8823	1729	1676	6081	4598	9201
108		1754	1706	6496	4928	9875	1829	1776	6792	5133	10298
114		1851	1803	7213	5468	10987	1930	1876	7540	5696	11457
120		1947	1899	7864	6038	12158	2030	1976	8219	6290	12678
126		2043	1995	8652	6636	13389	2130	2076	9041	6913	13960
132		2139	2091	9590	7262	14678	2230	2176	10020	7564	15304
138		2235	2187	10339	7916	16027	2330	2276	10738	8246	16710
144		2331	2283	11239	8599	17436	2430	2376	11741	8957	18188



## WEIGHT OF SHELLS &amp; HEADS

DIAM.	VESSEL	WALL THICKNESS									
		1-5/8"					1-11/16"				
		SHELL		HEAD			SHELL		HEAD		
		I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12		236	180	184	153	166	247	186	195	163	174
14		271	215	217	186	218	283	222	230	198	228
16		305	249	263	220	277	319	258	277	235	290
18		340	284	304	265	344	355	294	321	280	359
20		375	319	359	304	417	391	330	379	315	436
22		410	354	405	348	498	427	366	427	361	520
24		444	388	455	393	586	463	402	480	415	611
26		479	423	509	443	681	499	438	535	466	710
28		514	458	578	495	783	535	474	608	521	817
30		548	492	653	564	892	571	570	686	585	930
32		583	527	732	623	1009	608	547	770	647	1051
34		618	562	815	685	1132	644	583	856	711	1180
36		653	597	903	748	1263	680	619	948	785	1316
38		687	631	997	817	1401	716	655	1045	857	1459
40		722	666	1094	886	1546	752	691	1147	930	1610
42		757	701	1195	978	1698	788	727	1253	1015	1768
48		861	805	1527	1216	2197	896	835	1598	1275	2288
54		965	909	1900	1505	2761	1004	943	1987	1562	2873
60		1069	1013	2314	1797	3388	1112	1051	2418	1880	3526
66		1174	1117	2768	2144	4080	1221	1159	2891	2226	4245
72		1278	1221	3264	2492	4836	1329	1267	3408	2603	5031
78		1382	1325	3799	2897	5657	1437	1376	3965	3008	5884
84		1486	1430	4375	3298	6542	1545	1484	4565	3443	6803
90		1590	1534	4994	3762	7490	1653	1592	5207	3926	7789
96		1694	1638	5650	4257	8504	1761	1700	5892	4441	8842
102		1798	1742	6348	4782	9581	1869	1808	6618	4966	9961
108		1903	1846	7088	5338	10723	1978	1916	7388	5567	11148
114		2007	1950	7867	5924	11928	2086	2024	8198	6177	12401
120		2111	2054	8575	6541	13198	2194	2133	8935	6819	13720
126		2215	2159	9431	7190	14533	2302	2241	9825	7493	15107
132		2319	2263	10450	7867	15931	2410	2349	10851	8198	16560
138		2423	2367	11138	8576	17394	2518	2457	11669	8936	18079
144		2527	2471	12243	9316	18921	2626	2565	12749	9705	19666

## WEIGHT OF SHELLS &amp; HEADS

DIAM.	VESSEL	WALL THICKNESS									
		1-3/4"					1-13/16"				
		SHELL		HEAD			SHELL		HEAD		
		I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12		257	192	206	172	182	267	197	218	182	190
14		294	229	243	211	238	306	236	257	223	249
16		332	267	294	249	303	344	274	314	264	316
18		369	304	338	296	375	383	313	356	311	391
20		407	342	399	327	455	422	352	420	345	473
22		444	379	450	374	542	461	391	473	394	564
24		481	416	504	437	637	499	429	530	460	663
26		519	454	562	490	740	538	468	590	515	770
28		556	491	639	547	850	577	507	670	575	885
30		593	528	719	607	969	615	545	754	638	1007
32		631	566	807	671	1094	654	584	845	704	1138
34		668	603	898	737	1228	693	623	940	772	1276
36		706	641	993	823	1369	732	662	1040	862	1423
38		743	678	1094	897	1518	770	700	1144	939	1577
40		780	715	1200	973	1675	809	739	1254	1018	1740
42		818	753	1311	1053	1839	848	778	1370	1101	1910
48		930	865	1670	1332	2378	964	894	1743	1392	2259
54		1042	977	2074	1620	2986	1080	1010	2163	1691	3100
60		1154	1089	2523	1963	3664	1196	1126	2630	2047	3802
66		1267	1201	3015	2308	4410	1313	1243	3141	2407	4576
72		1379	1313	3552	2715	5226	1429	1359	3700	2829	5422
78		1491	1426	4132	3119	6111	1545	1475	4301	3299	6339
84		1603	1538	4756	3588	7065	1661	1591	4948	3737	7328
90		1715	1650	5421	4091	8089	1777	1707	5639	4237	8389
96		1827	1762	6134	4626	9181	1893	1823	6379	4792	9521
102		1940	1874	6888	5150	10343	2010	1940	7162	5334	10725
108		2052	1986	7688	5796	11574	2126	2056	7991	6003	12001
114		2164	2099	8529	6430	12874	2242	2172	8865	6660	13348
120		2276	2211	9295	7098	14243	2358	2288	9659	7351	14767
126		2388	2323	10220	7797	15681	2474	2404	10618	8076	16257
132		2500	2435	11252	8530	17189	2590	2520	11650	8535	17820
138		2612	2547	12201	9296	18766	2707	2637	12673	9628	19453
144		2725	2659	13256	10094	20412	2823	2753	13768	10455	21159



## WEIGHT OF SHELLS &amp; HEADS

## WALL THICKNESS

DIAM.	WALL THICKNESS									
	1-7/8"					1-15/16"				
	SHELL		HEAD			SHELL		HEAD		
VESSEL	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	278	203	231	191	198	288	208	243	201	206
14	318	243	271	235	259	329	249	285	247	270
16	358	283	326	278	329	371	291	343	293	342
18	398	323	375	327	407	412	332	394	342	423
20	438	363	441	363	493	454	374	462	382	512
22	478	403	497	414	587	495	415	521	435	610
24	518	443	556	482	689	536	456	583	498	716
26	558	483	619	540	800	578	498	648	558	830
28	598	523	701	602	929	619	539	737	622	953
30	638	563	789	668	1046	661	581	825	699	1085
32	679	604	883	736	1181	702	622	923	770	1225
34	719	644	981	808	1325	743	663	1025	845	1374
36	759	684	1086	902	1477	785	705	1134	932	1531
38	799	724	1194	981	1637	826	746	1246	1014	1697
40	839	764	1309	1063	1805	867	787	1365	1099	1871
42	879	804	1429	1150	1981	909	829	1489	1200	2054
48	999	924	1817	1452	2561	1033	953	1892	1501	2653
54	1119	1044	2253	1762	3214	1157	1077	2344	1835	3329
60	1239	1164	2737	2132	3941	1282	1202	2846	2203	4081
66	1360	1284	3268	2506	4743	1406	1326	3397	2607	4910
72	1480	1405	3846	2944	5618	1530	1450	3995	3040	5816
78	1600	1525	4470	3380	6568	1654	1574	4642	3512	6798
84	1720	1645	5141	3886	7592	1778	1698	5357	4015	7857
90	1840	1765	5858	4383	8690	1902	1822	6080	4552	8992
96	1960	1885	6624	4958	9862	2027	1947	6873	5123	10204
102	2081	2005	7436	5518	11108	2151	2071	7714	5722	11492
108	2201	2126	8295	6210	12429	2275	2195	8603	6417	12858
114	2321	2246	9201	6890	13823	2399	2319	9540	7120	14299
120	2441	2366	10024	7604	15292	2523	2443	10358	7858	15818
126	2561	2486	11017	8355	16834	2647	2567	11420	8633	17413
132	2681	2606	12058	9140	18451	2772	2692	12460	9444	19084
138	2802	2726	13146	9960	20142	2896	2816	13623	10291	20832
144	2922	2846	14280	10816	21907	3020	2940	14756	11176	22657

## WEIGHT OF SHELLS &amp; HEADS

## WALL THICKNESS

DIAM.	WALL THICKNESS									
	2"					2 1/4"				
	SHELL		HEAD			SHELL		HEAD		
VESSEL	I.S.	O.S.	ELLIP	F.&D.	HEMIS	I.S.	O.S.	ELLIP	F.&D.	HEMIS
12	299	214	256	210	215	342	216	307	248	251
14	342	257	300	259	281	391	282	358	296	326
16	384	299	361	307	356	439	330	362	349	411
18	427	342	414	358	439	487	379	425	406	506
20	470	385	484	400	531	535	427	495	467	612
22	513	428	546	456	633	583	475	578	533	726
24	555	470	610	514	742	631	523	648	603	851
26	598	513	678	576	861	679	571	723	678	986
28	641	556	767	642	988	727	619	801	757	1130
30	683	598	862	730	1124	775	667	904	840	1285
32	726	641	963	804	1269	823	715	1014	927	1449
34	769	684	1068	882	1423	871	763	1130	1019	1633
36	812	727	1181	962	1586	919	811	1277	1115	1844
38	854	769	1298	1047	1757	967	859	1380	1216	2001
40	897	812	1421	1134	1937	1015	907	1515	1321	2205
42	940	855	1550	1250	2126	1063	955	1655	1438	2409
48	1068	983	1968	1550	2745	1208	1100	2115	1802	3155
54	1196	1111	2436	1909	3444	1352	1244	2632	2181	3922
60	1325	1239	2956	2274	4221	1496	1388	3204	2632	4808
66	1453	1367	3526	2708	5078	1640	1532	3833	3085	5787
72	1581	1496	4145	3140	6013	1784	1676	4519	3618	6854
78	1709	1624	4814	3645	7028	1929	1821	5260	4146	8012
84	1837	1752	5573	4145	8122	2073	1965	6058	4760	9194
90	1965	1880	6302	4722	9295	2217	2109	6913	5364	10528
96	2094	2008	7122	5288	10546	2361	2253	7823	6058	11952
102	2222	2137	7992	5937	11877	2505	2397	8790	6737	13466
108	2350	2265	8911	6624	13287	2650	2542	9814	7513	15073
114	2478	2393	9880	7349	14776	2794	2686	10893	8332	16767
120	2606	2521	10692	8112	16345	2938	2830	11874	9193	18554
126	2734	2649	11824	8911	17992	3082	2974	13059	10096	20328
132	2863	2777	12862	9748	19718	3226	3118	14301	11041	22291
138	2991	2906	14100	10623	21523	3371	3263	15597	12029	24343
144	3119	3034	15232	11536	23408	3514	3407	16952	13059	26424



## WEIGHT OF PIPES AND FITTINGS






NOM. PIPE SIZE	DESIGNATION	NOM. WALL THK.	PIPE 1 ft.	ELBOW			RETURN		TEE
				90° L.R.	90° S.R.	45° L.R.	180° L.R.	180° S.R.	
½	STD	.109	0.9	0.2		0.1	0.4		0.4
	X STG	.147	1.1	0.3		0.2	0.5		0.5
	SCH. 160 XX STG	.187 .294	1.3 1.7				0.5 0.4		0.4
¾	STD	.113	1.1	0.2		0.1	0.4		0.5
	X STG	.154	1.5	0.3		0.2	0.7		0.6
	SCH. 160 XX STG	.218 .308	1.9 2.4				0.6 0.6		0.6
1	STD	.133	1.7	0.4	0.3	0.3	0.8	0.5	0.8
	X STG	.179	2.2	0.5	0.4	0.3	1.0	0.9	0.9
	SCH. 160 XX STG	.250 .358	2.8 3.7	0.6 0.8	0.4 0.5	0.3 0.4	1.2 1.5	0.8 1.0	1.0 1.3
1¼	STD	.140	2.3	0.6	0.4	0.4	1.3	0.8	1.3
	X STG	.191	3.0	0.9	0.7	0.5	1.8	1.6	1.6
	SCH. 160 XX STG	.250 .382	3.8 5.2	1.0 1.4	0.7 0.9	0.5 0.8	2.0 2.7	1.4 1.8	2.0 2.5
1½	STD	.145	2.7	0.9	0.6	0.4	1.9	1.1	2.0
	X STG	.200	3.6	1.2	0.8	0.7	2.4	1.5	2.3
	SCH. 160 XX STG	.281 .400	4.9 6.4	1.4 1.9	1.2 1.0	1.0 1.1	3.3 4.0	2.4 2.7	3.0 3.4
2	STD	.154	3.7	1.6	1.0	0.8	3.2	2.0	3.5
	X STG	.218	5.0	2.2	1.5	1.2	4.4	3.0	4.0
	SCH. 160 XX STG	.343 .456	7.5 9.0	3.3 3.5	2.2 2.3	1.6 2.0	6.0 7.5	4.0 5.0	5.0 6.3
2½	STD	.203	5.8	3.3	2.1	1.8	6.5	4.3	6.0
	X STG	.276	7.7	4.0	2.8	2.1	8.0	5.6	7.0
	SCH. 160 XX STG	.375 .552	10.0 13.7	5.1 7.0	3.4 5.0	3.0 3.8	12.0 14.0	6.0 9.7	8.0 10.5
3	STD	.216	7.6	5.0	3.0	2.6	10.2	6.0	7.0
	X STG	.300	10.3	6.5	4.3	3.5	13.0	8.5	8.5
	SCH. 160 XX STG	.438 .600	14.3 18.6	8.5 11.0	6.0 7.3	4.4 5.8	18.0 22.0	12.0 14.6	10.0 13.5

## WEIGHT OF PIPES AND FITTINGS






NOM. PIPE SIZE	DESIGNATION	NOM. WALL THK.	PIPE 1 Ft.	ELBOW			RETURN		TEE
				90° L.R.	90° S.R.	45° L.R.	180° L.R.	180° S.R.	
¾	STD	.226	9.1	6.8	4.5	3.5	13.0	9.0	9.0
	X STG	.318	12.5	8.4	6.0	4.5	16.8	12.0	12.0
	XX STG	.636	22.9	16.0	11.0	8.5	32.00	22.0	18.0
4	STD	.237	10.8	9.0	6.3	4.5	18.5	12.5	12.0
	X STG	.337	15.0	13.5	8.5	6.1	25.0	17.0	15.8
	SCH. 120 SCH. 160 XX STG	.438 .531 .674	19.0 22.5 27.5	15.6 18.0 20.0	10.4 12.0 13.0	7.8 8.8 10.8	31.3 40.0 40.0	20.8 24.0 27.0	23.5 25.0 25.0
5	STD	.258	14.6	15.5	9.6	7.5	30.0	19.0	22.0
	X STG	.375	20.8	22.0	14.0	10.8	44.0	28.0	26.0
	SCH. 120 SCH. 160 XX STG	.500 .625 .750	27.0 33.0 38.6	27.8 32.0 36.0	18.6 22.0 24.0	13.9 16.0 19.0	55.6 65.0 72.0	37.2 44.0 48.0	44.5 55.0 40.0
6	STD	.280	19.0	24.5	18.0	12.0	50.0	35.0	34.0
	X STG	.432	28.6	35.0	23.0	17.5	70.0	46.0	40.0
	SCH. 120 SCH. 160 XX STG	.562 .718 .864	36.4 45.3 53.2	45.2 57.0 65.0	30.0 38.0 44.0	22.6 30.0 32.0	90.3 120.0 130.0	60.0 76.0 87.0	64.0 62.0 68.0
8	STD	.250	22.4	36.5	24.4	18.2	73.0	48.8	54.0
	SCH. 30	.277	24.7	40.9	27.0	20.4	81.9	54.0	57.0
	STD	.322	28.6	50.0	34.0	23.0	95.0	68.0	55.0
10	SCH. 60	.406	35.6	58.0	39.1	29.4	117.0	78.0	76.0
	X. STG.	.500	43.4	71.0	47.5	35.0	142.0	100.0	95.0
	SCH. 100	.593	50.9	84.0	56.0	42.0	168.0	112.0	97.0
10 (cont.)	SCH. 120	.718	60.6	100.8	66.0	50.4	202.0	133.0	115.0
	SCH. 140	.812	67.8	111.0	74.0	55.0	222.0	149.0	133.0
	SCH. 160 XX STG.	.906 .875	74.7 72.4	120.0 118.0	80.0 79	62.0 60.0	230.0 236.0	160.0 158.0	152.0 148.0



## WEIGHT OF PIPES AND FITTINGS

NOM. PIPE SIZE	NOM. DESIGNATION	NOM. WALL THK.	PIPE 1 ft.	ELBOW			RETURN		TEE
				90° L.R.	90° S.R.	45° L.R.	180° L.R.	180° S.R.	
									
(cont.)	SCH. 80	.592	64.4	133	88	67	267	177	161
	SCH. 100	.718	77.0	159	106	79	318	212	180
	SCH. 120	.843	89.2	185	123	92	370	246	215
	SCH. 140	1.000	104.2	214	143	107	428	286	241
	SCH. 160	1.125	116.0	260	174	130	530	348	260
10	SCH. 20	.250	33.4	82	55	41	164	109	120
	SCH. 30	.330	43.8	108	72	54	216	145	136
	STD.	.375	49.6	125	80	62	230	155	120
	SCH. 40	.406	53.6	132	88	66	264	176	147
	X STG	.500	65.4	160	104	84	320	218	160
	SCH. 60	.562	73.2	182	121	91	364	242	226
	SCH. 80	.687	88.6	219	146	109	439	292	245
	SCH. 100	.843	108.0	268	177	134	535	354	304
	SCH. 120	1.000	125.5	311	207	155	622	414	353
	SCH. 140	1.125	140.0	347	231	174	694	462	404
12	SCH. 160	1.312	161.0	450	300	225	910	600	480
	SCH. 10	.250	37.0	106	70	53	212	140	193
	SCH. 20	.312	46.0	132	87	66	264	175	210
	STD.	.375	55.0	160	105	80	325	210	165
	SCH. 40	.438	63.0	183	122	91	366	244	252
	X STG	.500	72.0	205	140	100	400	275	230
	SCH. 60	.593	85.0	245	163	123	490	326	311
	SCH. 80	.750	107.0	310	205	154	619	410	369
	SCH. 100	.937	131.0						
	SCH. 120	1.093	151.0	425		213	850		
14	SCH. 140	1.250	171.0						
	SCH. 160	1.406	190.0	572	382	286	1092	764	
	SCH. 10	.250	42.0	139	92	69	277	184	201
	SCH. 20	.312	52.0	172	115	86	344	230	222
	SCH. 30 STD	.375	63.0	206	132	100	412	260	195
16	SCH. 40XSTG	.500	83.0	276	174	135	550	340	280
	SCH. 60	.656	108.0	355	236	178	710	472	458
	(cont.)								

## WEIGHT OF PIPES AND FITTINGS

NOM. PIPE SIZE	NOM. DESIGNATION	NOM. WALL THK.	PIPE 1 ft.	ELBOW			RETURN		TEE
				90° L.R.	90° S.R.	45° L.R.	180° L.R.	180° S.R.	
									
(cont.)	SCH. 80	.843	137	450	300	225	900	600	548
	SCH. 100	1.031	165						
	SCH. 120	1.218	193						
	SCH. 140	1.438	224						
	SCH. 160	1.593	245	809	540	405	1618	1080	
16	SCH. 10	.250	47	176	118	88	352	226	281
	SCH. 20	.312	59	219	146	110	438	292	307
	STD	.375	71	260	167	126	510	330	249
	SCH. 30	.438	82	308	205	154	616	410	399
	X STG	.500	93	340	219	167	690	430	392
	SCH. 40	.562	105	390	259	195	780	518	525
	SCH. 60	.750	138	494	340	247	989	680	682
	SCH. 80	.937	171	634	422	317	1268	844	700
	SCH. 100	1.156	208						
	SCH. 120	1.375	244						
18	SCH. 140	1.562	275						
	SCH. 160	1.781	309						
	SCH. 10	.250	53	217	144	109	434	288	439
	SCH. 20 STD	.375	79	320	210	160	640	410	342
	SCH. 30XSTG	.500	105	420	275	206	830	550	480
20	SCH. 40	.593	123	506	338	253	1012	676	706
	SCH. 60	.812	167	690	457	345	1380	914	834
	SCH. 80	1.031	209	861	573	431	1722	1146	1021
	SCH. 100	1.281	256						
	SCH. 120	1.50C	297						
	SCH. 140	1.750	342						
	SCH. 160	1.968	379						
	SCH. 10	.250	58	262	174	131	524	348	477
	SCH. 20	.312	72						
	SCH. 30	.375	87	394		197	787		414
22	SCH. 40	.437	103						
	SCH. 60	.500	115	520		260	1040		550
	(cont.)								



## WEIGHT OF PIPES AND FITTINGS

NOM. PIPE SIZE	DESIGNATION	NOM. WALL THK.	PIPE 1 FT	ELBOW			RETURN		TEE
				90° L.R.	90° S.R.	45° L.R.	180° L.R.	180° S.R.	
(cont.)		.562	129						
22		.625	143						
		.688	157						
		.750	170						
24	SCH. 10	.250	63	314	208	157	627	416	677
	SCH. 20 STD	.375	95	460	298	238	890	590	528
	X STG	.500	125	600	392	300	1200	780	610
	SCH. 30	.562	141	702	470	351	1404	940	977
	SCH. 40	.687	171	846	564	423	1692	1128	1257
	SCH. 60	.968	238	1188	783	594	2377	1566	1446
	SCH. 80	1.218	297	1470	977	735	2940	1954	1673
	SCH. 100	1.531	367						
	SCH. 120	1.812	429						
	SCH. 140	2.062	484						
	SCH. 160	2.343	542						
26		.250	67						
		.312	84						
		.375	103	550		275	1100		770
		.437	119	729		365	1458		875
		.500	136						
		.562	153						
		.625	169						
		.688	186						
		.750	202						
30		.312	99	612	464	306	1223		1058
		.375	119	734	618	367	1465	930	1060
		.500	158	975		488	1950	1235	1200

## WEIGHT OF FLANGES

NOM. PIPE SIZE	150 lbs.					300 lbs.				
	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS
1/2	1.0	2.0		2.0	1.0	1.5	2.0		2.0	1.0
3/4	1.5	2.0		2.0	1.0	2.5	3.0		3.0	2.0
1	2.0	2.5	8.0	2.0	1.0	3.0	4.0	10.0	4.0	2.0
1 1/4	2.5	2.5	10.0	3.0	1.0	4.5	5.0	14.0	6.0	2.0
1 1/2	3.0	4.0	12.0	3.0	1.0	6.5	7.0	17.0	7.0	3.5
2	5.0	6.0	16.0	4.0	1.5	7.0	8.0	19.0	8.0	4.0
2 1/2	8.0	10.0	21.0	7.0	1.5	10.0	12.0	28.0	12.0	7.0
3	9.0	11.5	24.0	9.0	1.5	13.0	16.0	36.0	16.0	7.5
3 1/2	11.0	12.0	31.0	13.0	3.5	16.0	20.0	45.0	21.0	7.5
4	12.0	16.0	47.0	17.0	4.0	21.0	25.0	54.0	27.0	7.5
5	13.0	20.0	57.0	20.0	6.0	26.0	34.0	86.0	35.0	8.0
6	18.0	24.0	77.0	26.0	6.0	35.0	45.0	108.0	50.0	11.5
8	28.0	42.0	103	45.0	6.5	54.0	70.0	150	81.0	18.9
10	37.0	55.0	150	70.0	15.0	77.0	99.0	218	127	38.0
12	60.0	85.0	215	110	15.0	110	142	289	184	49.0
14	77.0	114	221	131	22.0	164	186	342	236	62.0
16	93.0	142	254	170	31.0	220	246	426	307	83.0
18	120	155	278	209	41.0	280	305	493	390	101
20	155	170	324	272	52.0	325	378	575	492	105
22	159	224		333	69.0	433	429		594	157
24	210	260	439	411	71.0	490	545	823	754	174
26	248	270	470	498	93.6	552	615	870	950	239
30	319	375	600	681	112.0	779	858	1130	1403	307



## WEIGHT OF FLANGES

NOM. PIPE SIZE	400 lbs.					600 lbs.				
	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS
1/2	2.0	3.0		2.0	1.0	2.0	3.0		2.0	1.0
3/4	3.0	3.5		3.0	2.0	3.0	3.5		3.0	2.0
1	3.5	4.0	11.0	4.0	2.0	3.5	4.0	11.0	4.0	2.0
1 1/4	4.5	5.5	14.0	6.0	2.0	4.5	5.5	14.0	6.0	2.0
1 1/2	6.5	8.0	17.0	8.0	3.5	6.5	8.0	17.0	8.0	3.5
2	8.0	10.0	21.0	10.0	4.5	8.0	10.0	21.0	10.0	4.5
2 1/2	12.0	14.0	29.0	15.0	7.5	12.0	14.0	29.0	15.0	8.0
3	15.0	18.0	38.0	20.0	7.7	15.0	18.0	38.0	20.0	8.0
3 1/2	21.0	26.0	48.0	29.0	11.6	21.0	26.0	48.0	29.0	11.6
4	24.0	30.0	67.0	33.0	12.0	33.0	37.0	80.0	41.0	12.5
5	31.0	39.0	90.0	44.0	12.5	63.0	68.0	128	68.0	19.5
6	39.0	49.0	115.0	61.0	19.0	80.0	73.0	158	86.0	30.0
8	63.0	78.0	140	100	30.0	97.0	112.0	215	139	40.0
10	91.0	110.0	230	155	52.0	177	189	324	231	72.0
12	129	160	301	226	69.0	215	226	500	295	91.0
14	191	233	336	310	88.0	259	347	417	378	118
16	253	294	416	398	114	366	481	564	527	152
18	310	360	481	502	139	476	555	654	665	193
20	378	445	563	621	180	612	690	840	855	242
22	464	465		685	205	643	710		962	267
24	539	640	799	936	274	876	977	1100	1175	365
26	616	680	970	1111	307	898	960	1250	1490	398
30	859	940	1230	1596	453	1158	1230	1520	1972	574

## WEIGHT OF FLANGES

NOM. PIPE SIZE	900 lbs.					1500 lbs.				
	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS
1/2	6.0	7.0		4.0	3.2	6.0	7.0		4.0	3.2
3/4	6.0	7.0		6.0	3.3	6.0	7.0		6.0	3.3
1	7.5	8.5	15.0	9.0		7.5	8.5	15.0	9.0	6.0
1 1/4	10.0	10.0	18.0	10.0		10.0	10.0	18.0	10.0	6.0
1 1/2	14.0	14.0	23.0	14.0		14.0	14.0	23.0	14.0	9.0
2	25.0	24.0	44.0	25.0		25.0	24.0	44.0	25.0	12.5
2 1/2	36.0	36.0	65.0	35.0	19.0	36.0	36.0	72.0	35.0	19.0
3	31.0	29.0	72.0	32.0	12.5	48.0	48.0	84.0	48.0	25.0
3 1/2	53.0	51.0	98.0	54.0	25.0	73.0	69.0	118	73.0	34.0
4	83.0	86.0	143	87.0	33.0	132.0	132.0	195	142	60.0
5	108.0	110.0	199	113	40.0	164	164	235	159	76.0
6	172	187	310	197	69.0	258	273	366	302	121
8	245	268	385	290	95.0	436	454	610	507	184
10	326	372	667	413	124	667	690	1028	775	306
12	380	562	558	494	159		940	1030	975	425
14	459	685	670	619	199		1250	1335	1300	570
16	647	924	949	880	299		1625	1750	1750	770
18	792	1164	1040	1107	361		2050	2130	2225	1010
20						WEIGHTS ON APPLICATION				
22										
24	1480	2107	1775	2099	687		3325	3180	3625	1560
26	1450	1650	1650	2200	765		1525	1575	2200	
30	1990	2290	2200	3025	1074		2075	2150	3025	



## WEIGHT OF FLANGES

NOM. PIPE SIZE		2500 lbs.										
		SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS	SLIP ON	WELD NECK	LONG. WELD NECK	BLIND	STUDS	
1/2		7.0	8.0		7.0	3.4						
3/4		9.0	9.0		10.0	3.6						
1		12.0	13.0	20.0	12.0	6.0						
1 1/4		18.0	20.0	30.0	18.0	9.0						
1 1/2		25.0	28.0	38.0	25.0	12.0						
2		38.0	42.0	55.0	39.0	21.0						
2 1/2		55.0	52.0	85.0	56.0	27.0						
3		83.0	94.0	125.0	86.0	37.0						
3 1/2												
4		127	146	185	133	61						
5		210	244	300	223	98						
6		323	378	450	345	145						
8		485	576	600	533	232						
10		925	1068	1150	1025	445						
12		1300	1608	1560	1464	622						
14												
16												
18												
20												
22												
24												
26												
30												

Manufacturers' Standard Gauge for  
SHEET STEEL

This gage system replaces U.S. Standard Gauge for Steel Sheets. It is based on weight 41.82 pounds per square foot per inch of thickness. In ordering steel sheets, it is advisable to specify the inch equivalent of gage.

Mfgs' Standard Gage Number	Inch Equivalent	Lbs. Per Square Inch	Lbs. Per Square Foot	Mfgs' Standard Gage Number	Inch Equivalent	Lbs. Per Square Inch	Lbs. Per Square Foot
3	.2391	.069444	10.0000	21	.0329	.0095486	1.3750
4	.2242	.065104	9.3750	22	.0299	.0086806	1.2500
5	.2092	.060764	8.7500	23	.0269	.0078125	1.1250
6	.1943	.056424	8.1250	24	.0239	.0069444	1.0000
7	.1793	.052083	7.5000	25	.0209	.0060764	.87500
8	.1644	.047743	6.8750	26	.0179	.0052083	.75000
9	.1495	.043403	6.2500	27	.0164	.0047743	.68750
10	.1345	.039062	5.6250	28	.0149	.0043403	.62500
11	.1196	.034722	5.0000	29	.0135	.0039062	.56250
12	.1046	.030382	4.3750	30	.0120	.0034722	.50000
13	.0897	.026042	3.7500	31	.0105	.0030382	.43750
14	.0747	.021701	3.1250	32	.0097	.0028212	.40625
15	.0673	.019531	2.8125	33	.0090	.0026042	.37500
16	.0598	.017631	2.5000	34	.0082	.0023872	.34375
17	.0538	.015625	2.2500	35	.0075	.0021701	.31250
18	.0478	.013889	2.0000	36	.0067	.0019531	.28125
19	.0418	.012153	1.7500	37	.0064	.0018446	.26562
20	.0359	.010417	1.5000	38	.0060	.0017361	.25000

## GALVANIZED SHEET

Galv. Sheet Gage Number	Ounces Per Square Foot	Pounds Per Square Foot	Pound Per Square Inch	Thickness Equivalent for Galv. Sheet Gage No.	Galv. Sheet Gage Number	Ounces Per Square Foot	Pounds Per Square Foot	Pound Per Square Inch	Thickness Equivalent for Galv. Sheet Gage No.
8	112.5	7.03125	.048828	.1681	21	24.5	1.53125	.0106340	.0366
9	102.5	6.40625	.044488	.1532	22	22.5	1.40625	.0097656	.0336
10	92.5	5.78125	.040148	.1382	23	20.5	1.28125	.0088976	.0306
11	82.5	5.15625	.035807	.1233	24	18.5	1.15625	.0080295	.0276
12	72.5	4.53125	.031467	.1084	25	16.5	1.03125	.0071615	.0247
13	62.5	3.90625	.027127	.0934	26	14.5	.90625	.0062934	.0217
14	52.5	3.28125	.022786	.0785	27	13.5	.84375	.0058594	.0202
15	47.5	2.96875	.020616	.0710	28	12.5	.78125	.0054253	.0187
16	42.5	2.65625	.018446	.0635	29	11.5	.71875	.0049913	.0172
17	38.5	2.40625	.016710	.0575	30	10.5	.65625	.0045573	.0157
18	34.5	2.15625	.014974	.0516	31	9.5	.59375	.0041233	.0142
19	30.5	1.90625	.013238	.0456	32	9.0	.56250	.0039062	.0134
20	26.5	1.65625	.011502	.0396					



# WEIGHT OF PLATES

Pounds Per Linear Foot

Width In.	Thickness, Inches															
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$2$	$2\frac{1}{4}$
$\frac{1}{16}$	.16	.21	.27	.32	.37	.43	.48	.53	.58	.64	.69	.74	.80	.85	.90	.96
$\frac{1}{8}$	.32	.43	.53	.64	.74	.85	.96	1.06	1.17	1.28	1.38	1.49	1.59	1.70	1.80	1.91
$\frac{3}{16}$	.48	.64	.80	.96	1.12	1.28	1.43	1.59	1.75	1.91	2.07	2.23	2.39	2.55	2.71	2.87
$\frac{1}{2}$	.64	.85	1.06	1.28	1.49	1.70	1.91	2.13	2.34	2.55	2.76	2.98	3.19	3.40	3.61	3.83
$\frac{5}{8}$	.80	1.06	1.33	1.59	1.86	2.13	2.39	2.66	2.92	3.19	3.45	3.72	3.98	4.25	4.52	4.78
$1\frac{1}{8}$	.96	1.28	1.59	1.91	2.23	2.55	2.87	3.19	3.51	3.83	4.14	4.46	4.78	5.10	5.42	5.74
$1\frac{1}{4}$	1.12	1.49	1.86	2.23	2.60	2.98	3.35	3.72	4.09	4.46	4.83	5.21	5.58	5.95	6.33	6.70
$1\frac{3}{8}$	1.28	1.70	2.13	2.55	2.98	3.40	3.83	4.25	4.68	5.10	5.53	5.95	6.38	6.80	7.23	7.65
$1\frac{1}{2}$	1.43	1.91	2.39	2.87	3.35	3.83	4.30	4.78	5.26	5.74	6.22	6.69	7.17	7.65	8.13	8.61
$1\frac{5}{8}$	1.59	2.13	2.66	3.19	3.72	4.25	4.78	5.31	5.84	6.38	6.91	7.44	7.97	8.50	9.03	9.56
$1\frac{3}{4}$	1.75	2.34	2.92	3.51	4.09	4.68	5.26	5.84	6.43	7.01	7.60	8.18	8.77	9.35	9.93	10.51
$2$	1.91	2.55	3.19	3.83	4.46	5.10	5.74	6.38	7.01	7.65	8.29	8.93	9.56	10.2	10.8	11.4
$2\frac{1}{4}$	2.07	2.76	3.45	4.14	4.83	5.53	6.22	6.91	7.60	8.29	8.98	9.67	10.4	11.1	11.8	12.5
$2\frac{1}{2}$	2.23	2.98	3.72	4.46	5.21	5.95	6.69	7.44	8.18	8.93	9.67	10.4	11.2	11.9	12.7	13.4
$2\frac{3}{4}$	2.39	3.19	3.98	4.78	5.58	6.38	7.17	7.97	8.77	9.56	10.4	11.2	12.0	12.8	13.6	14.4
$3$	2.55	3.40	4.25	5.10	5.95	6.80	7.65	8.50	9.35	10.2	11.1	11.9	12.8	13.6	14.5	15.3
$3\frac{1}{4}$	2.71	3.61	4.52	5.42	6.32	7.23	8.13	9.03	9.93	10.8	11.7	12.6	13.6	14.5	15.4	16.3
$3\frac{1}{2}$	2.87	3.83	4.78	5.74	6.69	7.65	8.61	9.56	10.5	11.5	12.4	13.4	14.3	15.3	16.2	17.1
$3\frac{3}{4}$	3.03	4.04	5.05	6.06	7.07	8.08	9.08	10.1	11.1	12.1	13.1	14.1	15.1	16.2	17.1	18.0
$4$	3.19	4.25	5.31	6.38	7.44	8.50	9.56	10.6	11.7	12.8	13.8	14.9	15.9	17.0	17.9	18.8
$4\frac{1}{4}$	3.35	4.46	5.58	6.69	7.81	8.93	10.0	11.2	12.3	13.4	14.5	15.6	16.7	17.9	18.6	19.4
$4\frac{1}{2}$	3.51	4.68	5.84	7.01	8.18	9.35	10.5	11.7	12.9	14.0	15.2	16.4	17.5	18.7	19.3	20.1
$4\frac{3}{4}$	3.67	4.89	6.11	7.33	8.55	9.78	11.0	12.2	13.4	14.7	15.9	17.1	18.3	19.6	20.1	20.8
$5$	3.83	5.10	6.38	7.65	8.93	10.2	11.5	12.8	14.0	15.3	16.6	17.9	19.1	20.4	20.8	21.3
$5\frac{1}{4}$	3.98	5.31	6.64	7.97	9.30	10.6	12.0	13.3	14.6	15.9	17.3	18.6	19.9	21.3	21.6	22.1
$5\frac{1}{2}$	4.14	5.53	6.91	8.29	9.67	11.1	12.4	13.8	15.2	16.6	18.0	19.3	20.7	22.1	22.3	22.8
$5\frac{3}{4}$	4.30	5.74	7.17	8.61	10.0	11.5	12.9	14.3	15.8	17.2	18.7	20.1	21.5	23.0	23.3	23.8
$6$	4.46	5.95	7.44	8.93	10.4	11.9	13.4	14.9	16.4	17.9	19.3	20.8	22.3	23.8	24.1	24.6
$6\frac{1}{4}$	4.62	6.16	7.70	9.24	10.8	12.3	13.9	15.4	17.0	18.5	20.0	21.6	23.1	24.7	24.9	25.4
$6\frac{1}{2}$	4.78	6.38	7.97	9.56	11.2	12.8	14.3	15.9	17.5	19.1	20.7	22.3	23.9	25.5	25.7	26.2
$6\frac{3}{4}$	4.94	6.59	8.23	9.98	11.5	13.2	14.8	16.5	18.1	19.8	21.4	23.1	24.7	26.4	26.6	27.1
$7$	5.10	6.80	8.50	10.2	11.9	13.6	15.3	17.0	18.7	20.4	22.1	23.8	25.5	27.2	27.4	27.9
$7\frac{1}{4}$	5.26	7.01	8.77	10.5	12.3	14.0	15.8	17.5	19.3	21.0	22.8	24.5	26.3	28.1	28.3	28.8
$7\frac{1}{2}$	5.42	7.23	9.03	10.8	12.6	14.5	16.3	18.1	19.9	21.7	23.5	25.3	27.1	28.9	29.1	29.6
$7\frac{3}{4}$	5.58	7.44	9.30	11.2	13.0	14.9	16.7	18.6	20.5	22.3	24.2	26.0	27.9	29.8	30.0	30.5
$8$	5.74	7.65	9.56	11.5	13.4	15.3	17.2	19.1	21.0	22.9	24.9	26.8	28.7	30.6	30.8	31.3
$8\frac{1}{4}$	5.90	7.86	9.83	11.8	13.8	15.7	17.7	19.7	21.6	23.6	25.6	27.5	29.5	31.5	31.7	32.2
$8\frac{1}{2}$	6.06	8.08	10.1	12.1	14.1	16.2	18.2	20.2	22.2	24.2	26.2	28.3	30.3	32.3	32.5	33.0
$8\frac{3}{4}$	6.22	8.29	10.4	12.4	14.5	16.6	18.7	20.7	22.8	24.9	26.9	29.0	31.1	33.2	33.4	33.9
$9$	6.38	8.50	10.6	12.8	14.9	17.0	19.1	21.3	23.4	25.5	27.6	29.8	31.9	34.0	34.2	34.7
$9\frac{1}{4}$	6.54	8.71	10.9	13.2	15.4	17.6	19.8	22.0	24.2	26.4	28.6	30.8	33.0	35.2	35.4	35.9
$9\frac{1}{2}$	6.70	8.93	11.2	13.6	15.9	18.1	20.3	22.5	24.7	26.9	29.1	31.3	33.5	35.7	35.9	36.4
$9\frac{3}{4}$	6.86	9.15	11.5	13.9	16.2	18.4	20.6	22.8	25.0	27.2	29.4	31.6	33.8	36.0	36.2	36.7
$10$	7.01	9.30	11.8	14.2	16.5	18.8	21.0	23.3	25.6	27.9	30.2	32.5	34.8	37.0	37.2	37.7

# WEIGHT OF PLATES

Pounds Per Linear Foot

Thickness, Inches																
Width In.	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$2$	$2\frac{1}{4}$	1
$10\frac{1}{4}$	6.53	8.71	10.9	13.1	15.3	17.4	19.6	21.8	24.0	26.1	28.3	30.5	32.7	34.9	37.1	39.3
$10\frac{1}{8}$	6.69	8.93	11.2	13.4	15.6	17.9	20.1	22.3	24.5	26.8	29.0	31.2	33.5	35.7	37.9	40.1
$10\frac{1}{16}$	6.85	9.14	11.4	13.7	16.0	18.3	20.6	22.8	25.1	27.4	29.7	32.0	34.3	36.6	38.9	41.2
11	7.01	9.35	11.7	14.0	16.4	18.7	21.0	23.4	25.7	28.1	30.4	32.7	35.1	37.4	39.7	42.0
$11\frac{1}{16}$	7.17	9.56	12.0	14.3	16.7	19.1	21.5	23.9	26.3	28.7	31.1	33.5	35.9	38.3	40.6	43.0
$11\frac{1}{8}$	7.33	9.78	12.2	14.7	17.1	19.6	22.0	24.4	26.9	29.3	31.8	34.2	36.7	39.1	41.5	43.9
$11\frac{1}{16}$	7.49	9.99	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0
12	7.65	10.2	12.8	15.3	17.9	20.4	23.0	25.5	28.1	30.6	33.2	35.7	38.3	40.8	43.3	45.8
$12\frac{1}{16}$	7.97	10.6	13.3	15.9	18.6	21.3	23.9	26.6	29.2	31.9	34.5	37.2	39.8	42.5	45.1	47.8
$13$	8.29	11.1	13.8	16.6	19.3	22.1	24.9	27.6	30.4	33.2	35.9	38.7	41.4	44.2	46.9	49.6
$13\frac{1}{8}$	8.49	11.5	14.3	17.2	20.1	23.0	25.8	28.8	32.6	35.4	38.3	41.2	44.0	46.9	49.7	52.6
$13\frac{1}{16}$	8.61	11.9	14.9	17.9	20.8	23.8	26.8	29.8	32.7	35.7	38.7	41.7	44.6	47.6	50.5	53.5
$14$	8.93	11.9	15.3	18.3	21.7	24.7	27.7	30.8	33.9	37.0	40.1	43.1	46.2	49.2	52.2	55.2
$14\frac{1}{8}$	9.24	12.3	15.4	18.5	21.6	24.7	27.7	30.8	33.9	37.0	40.1	43.1	46.2	49.2	52.2	55.2
$15$	9.56	12.8	15.9	19.1	22.3	25.5	28.7	31.9	35.1	38.3	41.4	44.6	47.8	51.0	54.2	57.4
$15\frac{1}{8}$	9.88	13.2	16.5	19.8	23.1	26.4	29.6	32.9	36.2	39.5	42.8	46.1	49.4	52.7	56.0	59.3
$16$	10.2	13.6	17.0	20.4	23.8	27.2	30.6	34.0	37.4	40.8	44.2	47.6	51.0	54.4	57.8	61.2
$16\frac{1}{16}$	10.5	14.0	17.5	21.0	24.5	28.1	31.6	35.1	38.6	42.1	45.6	49.1	52.6	56.1	59.5	63.0
$17$	10.8	14.5	18.1	21.7	25.3	28.9	32.5	36.1	39.7	43.4	47.0	50.6	54.2	57.8	61.4	65.0
$17\frac{1}{8}$	11.2	14.9	18.6	22.3	26.0	29.8	33.5	37.2	40.9	44.6	48.3	52.1	55.8	59.5	63.2	66.9
$18$	11.5	15.3	19.1	23.0	26.8	30.6	34.4	38.3	42.1	45.9	49.7	53.6	57.4	61.2	65.0	68.8
$18\frac{1}{16}$	11.8	15.7	19.7	23.6	27.5	31.5	35.4	39.3	43.2	47.2	51.1	55.0	59.0	62.9	66.8	70.7
$19$	12.1	16.2	20.2	24.2	28.3	32.3	36.3	40.4	44.4	48.5	52.5	56.5	60.6	64.6	68.6	72.6
$19\frac{1}{8}$	12.4	16.6	20.7	24.9	29.0	33.2	37.3	41.4	45.6	49.7	53.9	58.0	62.2	66.3	70.4	74.5
$20$	12.8	17.0	21.3	25.5	29.8	34.0	38.3	42.5	46.8	51.0	55.3	59.5	63.8	68.0	72.3	76.5
$20\frac{1}{16}$	13.1	17.4	21.8	26.1	30.5	34.9	39.2	43.6	47.9	52.3	56.6	61.0	65.3	69.7	74.0	78.4
$21$	13.4	17.9	22.3	26.8	31.2	35.7	40.2	44.6	49.1	53.6	58.0	62.5	66.9	71.3	75.7	80.1
$21\frac{1}{8}$	13.7	18.3	22.8	27.4	32.0	36.6	41.1	45.7	50.3	54.8	59.4	64.0	68.5	73.1	77.6	82.1
$22$	14.0	18.7	23.4	28.1	32.7	37.4	42.1	46.8	51.4	56.1	60.8	65.5	70.1	74.8	79.5	84.2
$22\frac{1}{16}$	14.3	19.1	23.9	28.7	33.5	38.3	43.0	47.8	52.6	57.4	62.2	66.9	71.7	76.5	81.3	86.1
$23$	14.7	19.6	24.4	29.3	34.2	39.1	44.0	48.9	53.8	58.7	63.5	68.4	73.3	78.2	83.0	87.9
$23\frac{1}{8}$	15.0	20.0	25.0	30.0	35.0	40.0	44.9	49.9	54.9	59.9	64.9	69.9	74.9	79.9	84.9	89.9
$24$	15.3	20.4	25.5	30.6	35.7	40.8	45.9	51.0	56.1	61.2	66.3	71.4	76.5	81.6	86.7	91.8
$25$	15.9	21.3	26.6	31.9	37.2	42.5	47.8	53.1	58.4	63.8	69.1	74.4	79.7	85.0	90.3	95.6
$26$	16.6	22.1	27.6	33.2	38.7	44.2	49.7	55.3	60.8	66.3	71.8	77.4	82.9	88.4	93.9	99.4
$27$	17.2	23.0	28.7	34.4	40.2	45.9	51.6	57.4	63.1	68.9	74.6	80.3	86.1	91.8	97.5	103.2
$28$	17.9	23.8	29.8	35.7	41.7	47.6	53.6	59.5	65.5	71.4	77.4	83.3	89.3	95.2	101.1	107.1
$29$	18.5	24.7	30.8	37.0	43.1	49.3	55.5	61.6	67.8	74.0	80.1	86.3	92.4	98.6	104.7	110.9
$30$	19.1	25.5	31.9	38.3	44.6	51.0	57.4	63.8	70.1	76.5	82.9	89.3	95.6	102.0	108.4	114.8
$31$	19.8	26.4	32.9	39.5	46.1	52.7	59.3	65.9	72.5	79.1	85.6	92.2	98.8	105.4	112.0	118.6
$32$	20.4	27.2	34.0	40.8	47.6	54.4	61.2	68.0	74.8	81.6	88.4	95.2	102.0	108.9	115.7	122.5



## WEIGHT OF PLATES

Pounds Per Linear Foot

Width In.	Thickness, Inches.														
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{1}{2}$	$\frac{11}{16}$	$\frac{13}{16}$	$\frac{15}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1
33	21.0	28.1	35.1	42.1	49.1	56.1	63.1	70.1	77.1	84.2	91.2	98.2	105	112	119
34	21.7	28.9	36.1	43.4	50.6	57.8	65.0	72.3	79.5	86.7	93.9	101	108	116	122
35	22.3	29.8	37.2	44.6	52.1	59.5	66.9	74.4	81.8	89.3	96.1	104	112	119	126
36	23.0	30.6	38.3	45.9	53.6	61.2	68.9	76.5	84.2	91.8	99.5	107	115	122	129
37	23.6	31.5	39.3	47.2	55.0	62.9	70.8	78.6	86.5	94.4	102	110	118	126	133
38	24.2	32.3	40.4	48.5	56.5	64.6	72.7	80.8	88.8	96.9	105	113	121	129	136
39	24.9	33.2	41.4	49.7	58.0	66.3	74.6	82.9	91.2	99.5	108	116	124	133	140
40	25.5	34.0	42.5	51.0	59.5	68.0	76.5	85.0	93.5	102	111	119	128	136	144
41	26.1	34.9	43.6	52.3	61.0	69.7	78.4	87.1	95.8	105	113	122	131	139	147
42	26.8	35.7	44.6	53.6	62.5	71.4	80.3	89.3	98.2	107	116	125	134	143	151
43	27.4	36.6	45.7	54.8	64.0	73.1	82.2	91.4	101	110	119	128	137	146	155
44	28.1	37.4	46.8	56.1	65.5	74.8	84.2	93.5	103	112	122	131	140	150	159
45	28.7	38.3	47.8	57.4	66.9	76.5	86.1	95.6	105	115	124	134	143	153	162
46	29.3	39.1	48.9	58.7	68.4	78.2	88.0	97.8	108	117	127	137	147	156	166
47	30.0	40.0	49.9	59.9	69.9	79.9	89.9	99.9	110	120	130	140	150	160	170
48	30.6	40.8	51.0	61.2	71.4	81.6	91.8	102	112	122	133	143	153	163	173
49	31.2	41.7	52.1	62.5	72.9	83.3	93.7	104	115	125	135	146	156	167	177
50	31.9	42.5	53.1	63.8	74.4	85.0	95.6	106	117	128	138	149	159	170	180
51	32.5	43.4	54.2	65.0	75.9	86.7	97.5	108	119	130	141	152	163	173	184
52	33.2	44.2	55.3	66.3	77.4	88.4	99.5	111	122	133	144	155	166	177	188
53	33.8	45.1	56.3	67.6	78.8	90.1	101	113	124	135	146	158	169	180	191
54	34.4	45.9	57.4	68.9	80.3	91.8	103	115	126	138	149	161	172	184	195
55	35.1	46.8	58.4	70.1	81.8	93.5	105	117	129	140	152	164	175	187	199
56	35.7	47.6	59.5	71.4	83.3	95.2	107	119	131	143	155	167	179	190	201
57	36.3	48.5	60.6	72.7	84.8	96.9	109	121	133	145	158	170	182	194	207
58	37.0	49.3	61.6	74.0	86.3	98.6	111	123	136	148	160	173	185	197	210
59	37.6	50.2	62.7	75.2	87.8	100	113	125	138	151	163	176	188	201	214
60	38.3	51.0	63.8	76.5	89.3	102	115	128	140	153	166	179	191	204	218
61	38.9	51.9	64.8	77.8	90.7	104	117	130	143	156	169	182	194	207	221
62	39.5	52.7	65.9	79.1	92.2	105	119	132	145	158	171	185	198	211	224
63	40.2	53.6	66.9	80.3	93.7	107	121	134	147	161	174	187	201	214	228
64	40.8	54.4	68.0	81.6	95.2	109	122	136	150	163	177	190	204	218	231
65	41.4	55.3	69.1	82.9	96.7	111	124	138	152	166	180	193	207	221	235
66	42.1	56.1	70.1	84.2	98.2	112	126	140	154	168	182	196	210	224	238
67	42.7	57.0	71.2	85.4	99.7	114	128	142	157	171	185	199	214	228	241
68	43.4	57.8	72.3	86.7	101	116	130	145	159	173	188	202	217	231	245
69	44.0	58.7	73.3	88.0	103	117	132	147	161	176	191	205	220	235	249
70	44.6	59.5	74.4	89.3	104	119	134	149	164	179	193	208	223	238	252
71	45.3	60.4	75.4	90.5	106	121	136	151	166	181	196	211	226	241	255
72	45.9	61.2	76.5	91.8	107	122	138	153	168	184	199	214	230	245	259

## WEIGHTS OF PLATES

Pounds Per Linear Foot

Width In.	Thickness, Inches														
	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{1}{16}$	$\frac{1}{2}$	$\frac{11}{16}$	$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{7}{8}$	$1\frac{1}{2}$	1
73	46.5	62.1	77.6	93.1	109	124	140	155	171	186	202	217	233	248	263
74	47.2	62.9	78.6	94.4	110	126	142	157	173	189	204	220	236	252	267
75	47.8	63.8	79.7	95.6	112	128	143	159	175	191	207	223	239	255	270
76	48.5	64.6	80.8	96.9	113	129	145	162	178	194	210	226	242	258	273
77	49.1	65.5	81.8	98.2	115	131	147	164	180	196	213	229	245	262	277
78	49.7	66.3	82.9	99.5	116	133	149	166	182	199	216	232	249	265	282
79	50.4	67.2	83.9	101	118	134	151	168	185	202	218	235	252	269	285
80	51.0	68.0	85.0	102	119	136	153	170	187	204	221	238	255	272	288
81	51.6	68.9	86.1	103	121	138	155	172	189	207	224	241	258	275	291
82	52.3	69.7	87.1	105	122	139	157	174	192	209	227	244	261	279	295
83	52.9	70.6	88.2	106	124	141	159	176	194	212	229	247	265	282	299
84	53.6	71.4	89.3	107	125	143	161	179	196	214	232	250	268	286	303
85	54.2	72.3	90.3	108	126	145	163	181	199	217	235	253	271	289	309
86	54.8	73.1	91.4	110	128	146	165	183	201	219	238	256	274	292	315
87	55.5	74.0	92.4	111	129	148	166	185	203	222	240	259	277	295	321
88	56.1	74.8	93.5	112	131	150	168	187	206	224	243	262	281	299	327
89	56.7	75.7	94.6	114	132	151	170	189	208	227	246	265	284	303	333
90	57.4	76.5	95.6	115	134	153	172	191	210	230	249	268	287	306	339
91		77.4	96.7	116	135	155	174	193	213	232	251	271	290	309	345
92		78.2	97.8	117	137	156	176	196	215	235	254	274	293	313	351
93		79.1	98.8	119	138	158	178	198	217	237	257	277	296	316	357
94		79.9	99.9	120	140	160	180	200	220	240	260	280	300	320	363
95		80.8	101	121	141	162	182	202	222	242	262	283	303	323	369
96		81.6	102	122	143	163	184	204	224	245	265	286	306	326	375
97		82.5	103	123	144	164	185	205	225	246	266	287	307	327	381
98		83.3	104	125	146	167	187	208	229	250	271	292	312	333	388
99		84.2	105	126	147	168	188	209	230	251	272	293	313	334	394
100		85.0	106	128	149	170	191	213	234	255	276	298	319	340	399
101		85.9	107	129	150	171	192	214	235	256	277	299	320	341	405
102		86.7	108	130	152	173	195	217	238	260	282	304	325	347	411
103		87.6	109	131	153	174	196	218	239	261	283	305	326	348	417
104		88.4	111	133	155	177	199	221	243	265	287	309	332	354	423
105		89.3	112	134	156	178	200	222	244	266	288	310	333	355	429
106		90.1	113	135	158	180	203	225	248	270	293	315	338	360	435
107		90.9	114	136	159	181	204	226	249	271	294	316	339	361	441
108		91.8	115	138	161	184	207	230	253	275	298	321	345	370	447
109		92.6	116	139	162	185	208	231	254	276	299	322	346	371	453
110		93.5	117	140	164	187	210	234	257	281	304	327	351	376	459
111		94.3	118	141	165	188	211	235	258	282	305	328	352	377	465
112		95.2	119	143	167	190	214	238	262	286	309	333	357	381	471
113		96.0	120	144	168	191	215	239	263	287	310	334	358	382	477
114		96.9	121	145	170	194	218	242	267	291	315	339	363	388	483
115		97.8	122	146	171	195	219	243	268	292	316	340	364	389	489
116		98.6	123	148	173	197	222	247	271	296	321	345	370	394	495
117		99.5	124	150	175	199	224	250	273	298	323	347	372	396	501
118		100	125	151	176	201	226	251	276	301	326	351	376	401	507
119		101	126	153	179	204	230	255	281	306	332	357	383	408	513
120		102	128	155	182	207	234	259	285	311	337	363	389	415	519
121		103	129	156	184	209	236	261	287	313	339	365	391	417	521
122		104	130	158	187	211	238	264	290	316	343	369	395	422	527
123		105	132	160	189	213	240	266	292	318	345	371	397	424	529
124		106	133	161	190	214	241	268	294	320	348	374	399	426	531
125		107	134	163	191	215	242	269	295	321	349	375	400	428	533
126		108	135	164	192	216	243	270	296	322	350	376	401	429	535
127		109	136	165	193	217	244	271	297	323	351	377	402	430	537
128		110	137	166	194	218	245	272	298	324	352	378	403	431	539



## WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES										WEIGHTS IN POUNDS									
DIA	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 1/2	1 3/4	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2	2 5/8
1.00	.042	.055	.070	.083	.097	.111	.125	.139	.153	.167	.181	.195	.209	.223	.237	.251	.265	.279	.293
1.25	.065	.087	.109	.130	.152	.174	.196	.217	.239	.261	.282	.304	.326	.348	.369	.391	.412	.434	.455
1.50	.094	.125	.156	.188	.219	.250	.282	.313	.344	.375	.407	.438	.469	.501	.531	.562	.593	.624	.655
1.75	.128	.170	.213	.256	.298	.341	.383	.426	.468	.511	.554	.596	.639	.681	.724	.766	.809	.851	.894
2.00	.167	.223	.278	.334	.389	.445	.501	.556	.612	.668	.723	.779	.834	.890	.945	.1000	.1055	.1110	.1165
2.25	.211	.282	.352	.422	.492	.562	.632	.702	.772	.842	.912	.982	.1052	.1122	.1192	.1262	.1332	.1402	.1472
2.50	.261	.348	.435	.521	.608	.695	.782	.869	.956	.1043	.1130	.1217	.1304	.1391	.1478	.1565	.1652	.1739	.1826
2.75	.315	.421	.526	.631	.736	.841	.946	.1052	.1157	.1262	.1367	.1472	.1577	.1683	.1788	.1893	.1998	.2103	.2208
3.00	.375	.501	.626	.751	.876	.1001	.1126	.1252	.1377	.1502	.1627	.1752	.1877	.2003	.2128	.2253	.2378	.2503	.2628
3.25	.441	.588	.734	.881	.1028	.1175	.1322	.1469	.1616	.1763	.1910	.2056	.2203	.2350	.2496	.2643	.2789	.2936	.3082
3.50	.511	.681	.852	.1022	.1192	.1363	.1533	.1704	.1874	.2044	.2215	.2385	.2555	.2726	.2896	.3066	.3236	.3406	.3576
3.75	.587	.782	.978	.1173	.1369	.1564	.1760	.1956	.2151	.2347	.2542	.2738	.2933	.3129	.3324	.3519	.3714	.3909	.4104
4.00	.668	.890	.1113	.1335	.1558	.1780	.2003	.2225	.2448	.2670	.2893	.3115	.3338	.3560	.3782	.4004	.4226	.4448	.4670
4.25	.754	.1005	.1236	.1458	.1680	.1902	.2124	.2346	.2568	.2790	.3012	.3234	.3456	.3678	.3900	.4122	.4344	.4566	.4788
4.50	.845	.1126	.1369	.1601	.1833	.2065	.2297	.2529	.2761	.2993	.3225	.3457	.3689	.3921	.4153	.4385	.4617	.4849	.5081
4.75	.941	.1253	.1509	.1751	.2006	.2251	.2496	.2741	.2986	.3231	.3476	.3721	.3966	.4211	.4456	.4701	.4946	.5191	.5436
5.00	1.043	.1391	.1738	.2086	.2434	.2781	.3129	.3477	.3824	.4172	.4520	.4867	.5215	.5563	.5910	.6258	.6605	.6953	.7300
5.25	1.150	.1533	.1916	.2300	.2683	.3066	.3450	.3833	.4216	.4599	.4982	.5365	.5749	.6133	.6516	.6899	.7282	.7665	.8048
5.50	1.262	.1683	.2103	.2524	.2945	.3365	.3786	.4207	.4628	.5048	.5469	.5889	.6310	.6731	.7152	.7572	.7993	.8414	.8835
5.75	1.379	.1839	.2289	.2759	.3228	.3697	.4166	.4635	.5104	.5573	.6042	.6511	.6980	.7449	.7918	.8387	.8856	.9325	.9794
6.00	1.502	.2003	.2503	.3004	.3504	.4005	.4506	.5006	.5507	.6008	.6508	.7009	.7509	.8010	.8510	.9011	.9511	.1001	.1051
6.25	1.763	.2350	.2907	.3458	.4008	.4558	.5108	.5658	.6208	.6758	.7308	.7858	.8408	.8958	.9508	.1008	.1058	.1108	.1158
6.50	2.044	.2726	.3391	.4063	.4735	.5407	.6078	.6750	.7422	.8094	.8766	.9438	.1010	.1072	.1134	.1196	.1258	.1320	.1382
6.75	2.347	.3129	.3811	.4493	.5175	.5857	.6539	.7221	.7903	.8585	.9267	.9949	.1061	.1123	.1185	.1247	.1309	.1371	.1433
7.00	2.670	.3560	.4242	.4924	.5606	.6288	.6970	.7652	.8334	.9016	.9698	.1036	.1104	.1172	.1240	.1308	.1376	.1444	.1512
7.25	3.014	.4019	.4701	.5383	.6065	.6747	.7429	.8111	.8793	.9475	.1013	.1081	.1149	.1217	.1285	.1353	.1421	.1489	.1557
7.50	3.379	.4505	.5187	.5869	.6551	.7233	.7915	.8597	.9279	.9961	.1063	.1131	.1199	.1267	.1335	.1403	.1471	.1539	.1607
7.75	3.765	.5020	.5702	.6384	.7066	.7748	.8430	.9112	.9794	.1046	.1114	.1182	.1250	.1318	.1386	.1454	.1522	.1590	.1658
8.00	4.172	.5563	.6245	.6927	.7609	.8291	.8973	.9655	.1033	.1101	.1169	.1237	.1305	.1373	.1441	.1509	.1577	.1645	.1713
8.25	4.600	.6133	.6815	.7497	.8179	.8861	.9543	.1021	.1089	.1157	.1225	.1293	.1361	.1429	.1497	.1565	.1633	.1701	.1769
8.50	5.048	.6731	.7413	.8095	.8777	.9459	.1017	.1085	.1153	.1221	.1289	.1357	.1425	.1493	.1561	.1629	.1697	.1765	.1833
8.75	5.517	.7356	.8038	.8720	.9402	.1008	.1076	.1144	.1212	.1280	.1348	.1416	.1484	.1552	.1620	.1688	.1756	.1824	.1892
9.00	6.008	.8101	.8783	.9465	.1011	.1079	.1147	.1215	.1283	.1351	.1419	.1487	.1555	.1623	.1691	.1759	.1827	.1895	.1963
9.25	6.519	.8801	.9483	.1019	.1087	.1155	.1223	.1291	.1359	.1427	.1495	.1563	.1631	.1699	.1767	.1835	.1903	.1971	.2039
9.50	7.051	.9401	.1007	.1075	.1143	.1211	.1279	.1347	.1415	.1483	.1551	.1619	.1687	.1755	.1823	.1891	.1959	.2027	.2095
9.75	7.603	.1013	.1071	.1139	.1207	.1275	.1343	.1411	.1479	.1547	.1615	.1683	.1751	.1819	.1887	.1955	.2023	.2091	.2159
10.00	8.177	.1090	.1152	.1214	.1276	.1338	.1400	.1462	.1524	.1586	.1648	.1710	.1772	.1834	.1896	.1958	.2020	.2082	.2144
10.25	8.771	.1169	.1231	.1293	.1355	.1417	.1479	.1541	.1603	.1665	.1727	.1789	.1851	.1913	.1975	.2037	.2099	.2161	.2223
10.50	9.387	.1251	.1313	.1375	.1437	.1499	.1561	.1623	.1685	.1747	.1809	.1871	.1933	.1995	.2057	.2119	.2181	.2243	.2305
10.75	10.02	.1336	.1398	.1460	.1522	.1584	.1646	.1708	.1770	.1832	.1894	.1956	.2018	.2080	.2142	.2204	.2266	.2328	.2390
11.00	10.68	.1424	.1486	.1548	.1610	.1672	.1734	.1796	.1858	.1920	.1982	.2044	.2106	.2168	.2230	.2292	.2354	.2416	.2478
11.25	11.35	.1514	.1576	.1638	.1700	.1762	.1824	.1886	.1948	.2010	.2072	.2134	.2196	.2258	.2320	.2382	.2444	.2506	.2568
11.50	12.05	.1607	.1669	.1731	.1793	.1855	.1917	.1979	.2041	.2103	.2165	.2227	.2289	.2351	.2413	.2475	.2537	.2599	.2661
11.75	12.77	.1703	.1765	.1827	.1889	.1951	.2013	.2075	.2137	.2199	.2261	.2323	.2385	.2447	.2509	.2571	.2633	.2695	.2757
12.00	13.51	.1802	.1864	.1926	.1988	.2050	.2112	.2174	.2236	.2298	.2360	.2422	.2484	.2546	.2608	.2670	.2732	.2794	.2856
12.25	14.27	.1903	.1965	.2027	.2089	.2151	.2213	.2275	.2337	.2399	.2461	.2523	.2585	.2647	.2709	.2771	.2833	.2895	.2957
12.50	15.06	.2015	.2077	.2139	.2201	.2263	.2325	.2387	.2449	.2511	.2573	.2635	.2697	.2759	.2821	.2883	.2945	.3007	.3069
12.75	15.86	.2136	.2198	.2260	.2322	.2384	.2446	.2508	.2570	.2632	.2694	.2756	.2818	.2880	.2942	.3004	.3066	.3128	.3190
13.00	16.68	.2262	.2324	.2386	.2448	.2510	.2572	.2634	.2696	.2758	.2820	.2882	.2944	.3006	.3068	.3130	.3192	.3254	.3316
13.25	17.51	.2397	.2459	.2521	.2583	.2645	.2707	.2769	.2831	.2893	.2955	.3017	.3079	.3141	.3203	.3265	.3327	.3389	.3451
13.50	18.35	.2532	.2594	.2656	.2718	.2780	.2842	.2904	.2966	.3028	.3090	.3152	.3214	.3276	.3338	.3400	.3462	.3524	.3586
13.75	19.20	.2667	.2729	.2791	.2853	.2915	.2977	.3039	.3101	.3163	.3225	.3287	.3349	.3411	.3473	.3535	.3597	.3659	.3721
14.00	20.06	.2802	.2864	.2926	.2988	.3050	.3112	.3174	.3236	.3298	.3360	.3422	.3484	.3546	.3608	.3670	.3732	.3794	.3856
14.25	20.92	.2937	.2999	.3061	.3123	.3185	.3247	.3309	.3371	.3433	.3495	.3557	.3619	.3681	.3743	.3805	.3867	.3929	.3991
14.50	21.79	.3072	.3134	.3196	.3258	.3320	.3382	.3444	.3506	.3568	.3630	.3692	.3754	.3816	.3878	.3940	.4002	.4064	.4126
14.75	22.67	.3207	.3269	.3331	.3393	.3455	.3517	.3579	.3641	.3703	.3765	.3827	.3889	.3951	.4013	.4075	.4137	.4199	.4261
15.00	23.56	.3342	.3404	.3466	.3528	.3590	.3652	.3714	.3776	.3838	.3900	.3962	.4024	.4086	.4148	.4210	.4272	.4334	.4396
15.25	24.46	.3477	.3539	.3601	.3663	.3725	.3787	.3849	.3911	.3973	.4035	.4097	.4159	.4221	.4283	.4345	.4407	.4469	.4531
15.50	25.37	.3612	.3674	.3736	.3798	.3860	.3922	.3984	.4046	.4108	.4170	.4232	.4294	.4356	.4418	.4480	.4542	.4604	.4666
15.75	26.29	.3747	.3809	.3871	.3933	.3995	.4057	.4119	.4181	.4243	.4305	.4367	.4429	.4491	.4553	.4615	.4677	.4739	.4801
16.00	27.22	.3882	.3944	.4006	.4068	.4130	.4192	.4254	.4316	.4378	.4440	.4502	.4564	.4626	.4688	.4750	.4812	.4874	.4936
16.25	28.16	.4017	.4079	.4141	.4203	.4265	.4327	.4389	.4451	.4513	.4575	.4637	.4699	.4761	.4823	.4885	.4947	.5009	.5071
16.50	29.11	.4152	.4214	.4276	.4338	.4400	.4462	.4524	.4586	.4648	.4710	.4772	.4834	.4896	.4958	.5020	.5082	.5144	.5206
16.75	30.07	.4287	.4349	.4411	.4473	.4535	.4597	.4659	.4721	.4783	.4845	.4907	.4969	.5031	.5093	.5155	.5217	.5279	.5341
17.00	31.04	.4422	.4484	.4546	.4608	.4670	.4732	.4794	.4856	.4918	.4980	.5042	.5104</						



## WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES

WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	1/2	5/8	3/4	7/8	1
50	104	139	174	209	243	278	313	348	382
50 1/2	106	142	177	213	248	284	319	355	390
51	109	145	181	217	253	289	326	362	398
51 1/2	111	148	184	221	258	295	332	369	406
52	113	150	188	226	263	301	338	376	414
52 1/2	115	153	192	230	268	307	345	383	422
53	117	156	195	234	273	313	352	391	430
53 1/2	119	159	199	239	279	318	358	398	438
54	122	162	203	243	284	324	365	406	446
54 1/2	124	165	207	248	289	330	372	413	454
55	126	168	210	252	294	337	379	421	463
55 1/2	129	171	214	257	300	343	386	428	471
56	131	174	218	262	305	349	392	436	480
56 1/2	133	178	222	266	311	355	400	444	488
57	136	181	226	271	316	361	407	452	497
57 1/2	138	184	230	276	322	368	414	460	506
58	140	187	234	281	327	374	421	468	515
58 1/2	143	190	238	286	333	381	428	476	524
59	145	194	242	290	339	387	436	484	532
59 1/2	148	197	246	295	345	394	443	492	542
60	150	200	250	300	350	401	451	501	551
60 1/2	153	204	255	305	356	407	458	509	560
61	155	207	259	310	362	414	466	517	569
61 1/2	158	210	263	316	368	421	473	526	579
62	160	214	267	321	374	428	481	535	588
62 1/2	163	217	272	326	380	435	489	543	598
63	166	221	276	331	386	442	497	552	607
63 1/2	168	224	280	336	393	449	505	561	617
64	171	228	285	342	399	456	513	570	627
64 1/2	174	231	289	347	405	463	521	579	636
65	176	235	294	353	411	470	529	588	646
65 1/2	179	239	298	358	418	477	537	597	656
66	182	242	303	363	424	485	545	606	666
66 1/2	184	246	307	369	430	492	553	615	676
67	187	250	312	375	437	499	562	624	687
67 1/2	190	253	317	380	444	507	570	634	697
68	193	257	322	386	450	514	579	643	707
68 1/2	196	261	326	392	457	522	587	653	718
69	199	265	331	397	463	530	596	662	728
69 1/2	202	269	336	403	470	537	605	672	739
70	204	273	341	409	477	545	613	681	750
70 1/2	207	276	346	415	484	553	622	691	760
71	210	280	351	421	491	561	631	701	771
71 1/2	213	284	355	427	498	569	640	711	782
72	216	288	360	433	505	577	649	721	793
72 1/2	219	292	365	439	512	585	658	731	804
73	222	296	371	445	519	593	667	741	815
73 1/2	225	301	376	451	526	601	676	751	826
74	228	305	381	457	533	609	685	762	838
74 1/2	232	309	386	463	540	617	695	772	849
75	235	313	391	469	548	626	704	782	860
75 1/2	238	317	396	476	555	634	713	793	872
76	241	321	402	482	562	643	723	803	884
76 1/2	244	326	407	488	570	651	732	814	895
77	247	330	412	495	577	660	742	825	907
77 1/2	251	334	418	501	585	668	752	835	919

## WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES

WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	1/2	5/8	3/4	7/8	1
78	254	338	423	508	592	677	761	846	931
78 1/2	257	343	428	514	600	686	771	857	943
79	260	347	434	521	608	694	781	868	955
79 1/2	264	352	439	527	615	703	791	879	967
80	267	356	445	534	623	712	801	890	979
80 1/2	270	360	451	541	631	721	811	901	991
81	274	365	456	547	639	730	821	912	1004
81 1/2	277	369	462	554	647	739	831	924	1016
82	281	374	468	561	655	748	842	935	1029
82 1/2	284	379	473	568	663	757	852	947	1041
83	287	383	479	575	671	766	862	958	1054
83 1/2	291	388	485	582	679	776	873	970	1067
84	294	392	491	589	687	785	883	981	1079
84 1/2	298	397	496	596	695	794	894	993	1092
85	301	402	502	603	703	804	904	1005	1105
85 1/2	305	407	508	610	712	813	915	1017	1118
86	309	411	514	617	720	823	926	1029	1131
86 1/2	312	416	520	624	728	832	936	1041	1145
87	316	421	526	632	737	842	947	1053	1158
87 1/2	319	426	532	639	745	852	958	1065	1171
88	323	431	538	646	754	862	969	1077	1185
88 1/2	327	436	545	654	762	871	980	1089	1198
89	330	441	551	661	771	881	991	1102	1212
89 1/2	334	446	557	668	780	891	1003	1114	1225
90	338	451	563	676	788	901	1014	1126	1239
90 1/2	342	456	569	683	797	911	1025	1139	1253
91	345	461	576	691	806	921	1036	1152	1267
91 1/2	349	466	582	699	815	931	1048	1164	1281
92	353	471	589	706	824	942	1059	1177	1295
92 1/2	357	476	595	714	833	952	1071	1190	1309
93	361	481	601	722	842	962	1082	1203	1323
93 1/2	365	486	608	729	851	973	1094	1216	1337
94	369	492	614	737	860	983	1106	1229	1352
94 1/2	373	497	621	745	869	994	1118	1242	1366
95	377	502	628	753	879	1004	1130	1255	1381
95 1/2	380	507	634	761	888	1015	1141	1268	1395
96	384	513	641	769	897	1025	1153	1282	1410
96 1/2	389	518	648	777	907	1036	1166	1295	1425
97	393	523	654	785	916	1047	1178	1308	1439
97 1/2	397	529	661	793	925	1058	1190	1322	1454
98	401	534	668	801	935	1068	1202	1336	1469
98 1/2	405	540	675	810	944	1079	1214	1349	1484
99	409	545	681	818	954	1090	1227	1363	1499
99 1/2	413	551	688	826	964	1101	1239	1377	1514
100	417	556	695	834	973	1113	1252	1391	1530
100 1/2	421	562	702	843	983	1124	1264	1405	1545
101	426	567	709	851	993	1135	1277	1419	1560
101 1/2	430	573	716	860	1003	1146	1289	1433	1576
102	434	579	723	868	1013	1157	1302	1447	1592
102 1/2	438	584	731	877	1023	1169	1315	1461	1607
103	443	590	738	885	1033	1180	1328	1475	1623
103 1/2	447	596	745	894	1043	1192	1341	1490	1639
104	451	602	752	902	1053	1203	1354	1504	1655
104 1/2	456	607	759	911	1063	1215	1367	1519	1670
105	460	613	767	920	1073	1227	1380	1533	1687
105 1/2	464	619	774	929	1083	1238	1393	1548	1703



## WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES

WEIGHTS IN POUNDS

DIA	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2	2 5/8	2 3/4	2 7/8	3	3 1/8	3 1/4	3 3/8	3 1/2	3 5/8	3 3/4	3 7/8	4	4 1/8	4 1/4	4 3/8	4 1/2	4 5/8	4 3/4	4 7/8	5	5 1/8	5 1/4	5 3/8	5 1/2	5 5/8	5 3/4	5 7/8	6	6 1/8	6 1/4	6 3/8	6 1/2	6 5/8	6 3/4	6 7/8	7	7 1/8	7 1/4	7 3/8	7 1/2	7 5/8	7 3/4	7 7/8	8	8 1/8	8 1/4	8 3/8	8 1/2	8 5/8	8 3/4	8 7/8	9	9 1/8	9 1/4	9 3/8	9 1/2	9 5/8	9 3/4	9 7/8	10	10 1/8	10 1/4	10 3/8	10 1/2	10 5/8	10 3/4	10 7/8	11	11 1/8	11 1/4	11 3/8	11 1/2	11 5/8	11 3/4	11 7/8	12	12 1/8	12 1/4	12 3/8	12 1/2	12 5/8	12 3/4	12 7/8	13	13 1/8	13 1/4	13 3/8	13 1/2	13 5/8	13 3/4	13 7/8	14	14 1/8	14 1/4	14 3/8	14 1/2	14 5/8	14 3/4	14 7/8	15	15 1/8	15 1/4	15 3/8	15 1/2	15 5/8	15 3/4	15 7/8	16	16 1/8	16 1/4	16 3/8	16 1/2	16 5/8	16 3/4	16 7/8	17	17 1/8	17 1/4	17 3/8	17 1/2	17 5/8	17 3/4	17 7/8	18	18 1/8	18 1/4	18 3/8	18 1/2	18 5/8	18 3/4	18 7/8	19	19 1/8	19 1/4	19 3/8	19 1/2	19 5/8	19 3/4	19 7/8	20	20 1/8	20 1/4	20 3/8	20 1/2	20 5/8	20 3/4	20 7/8	21	21 1/8	21 1/4	21 3/8	21 1/2	21 5/8	21 3/4	21 7/8	22	22 1/8	22 1/4	22 3/8	22 1/2	22 5/8	22 3/4	22 7/8	23	23 1/8	23 1/4	23 3/8	23 1/2	23 5/8	23 3/4	23 7/8	24	24 1/8	24 1/4	24 3/8	24 1/2	24 5/8	24 3/4	24 7/8	25	25 1/8	25 1/4	25 3/8	25 1/2	25 5/8	25 3/4	25 7/8	26	26 1/8	26 1/4	26 3/8	26 1/2	26 5/8	26 3/4	26 7/8	27	27 1/8	27 1/4	27 3/8	27 1/2	27 5/8	27 3/4	27 7/8	28	28 1/8	28 1/4	28 3/8	28 1/2	28 5/8	28 3/4	28 7/8	29	29 1/8	29 1/4	29 3/8	29 1/2	29 5/8	29 3/4	29 7/8	30	30 1/8	30 1/4	30 3/8	30 1/2	30 5/8	30 3/4	30 7/8	31	31 1/8	31 1/4	31 3/8	31 1/2	31 5/8	31 3/4	31 7/8	32	32 1/8	32 1/4	32 3/8	32 1/2	32 5/8	32 3/4	32 7/8	33	33 1/8	33 1/4	33 3/8	33 1/2	33 5/8	33 3/4	33 7/8	34	34 1/8	34 1/4	34 3/8	34 1/2	34 5/8	34 3/4	34 7/8	35	35 1/8	35 1/4	35 3/8	35 1/2	35 5/8	35 3/4	35 7/8	36	36 1/8	36 1/4	36 3/8	36 1/2	36 5/8	36 3/4	36 7/8	37	37 1/8	37 1/4	37 3/8	37 1/2	37 5/8	37 3/4	37 7/8	38	38 1/8	38 1/4	38 3/8	38 1/2	38 5/8	38 3/4	38 7/8	39	39 1/8	39 1/4	39 3/8	39 1/2	39 5/8	39 3/4	39 7/8	40	40 1/8	40 1/4	40 3/8	40 1/2	40 5/8	40 3/4	40 7/8	41	41 1/8	41 1/4	41 3/8	41 1/2	41 5/8	41 3/4	41 7/8	42	42 1/8	42 1/4	42 3/8	42 1/2	42 5/8	42 3/4	42 7/8	43	43 1/8	43 1/4	43 3/8	43 1/2	43 5/8	43 3/4	43 7/8	44	44 1/8	44 1/4	44 3/8	44 1/2	44 5/8	44 3/4	44 7/8	45	45 1/8	45 1/4	45 3/8	45 1/2	45 5/8	45 3/4	45 7/8	46	46 1/8	46 1/4	46 3/8	46 1/2	46 5/8	46 3/4	46 7/8	47	47 1/8	47 1/4	47 3/8	47 1/2	47 5/8	47 3/4	47 7/8	48	48 1/8	48 1/4	48 3/8	48 1/2	48 5/8	48 3/4	48 7/8	49	49 1/8	49 1/4	49 3/8	49 1/2	49 5/8	49 3/4	49 7/8	50	50 1/8	50 1/4	50 3/8	50 1/2	50 5/8	50 3/4	50 7/8	51	51 1/8	51 1/4	51 3/8	51 1/2	51 5/8	51 3/4	51 7/8	52	52 1/8	52 1/4	52 3/8	52 1/2	52 5/8	52 3/4	52 7/8	53	53 1/8	53 1/4	53 3/8	53 1/2	53 5/8	53 3/4	53 7/8	54	54 1/8	54 1/4	54 3/8	54 1/2	54 5/8	54 3/4	54 7/8	55	55 1/8	55 1/4	55 3/8	55 1/2	55 5/8	55 3/4	55 7/8	56	56 1/8	56 1/4	56 3/8	56 1/2	56 5/8	56 3/4	56 7/8	57	57 1/8	57 1/4	57 3/8	57 1/2	57 5/8	57 3/4	57 7/8	58	58 1/8	58 1/4	58 3/8	58 1/2	58 5/8	58 3/4	58 7/8	59	59 1/8	59 1/4	59 3/8	59 1/2	59 5/8	59 3/4	59 7/8	60	60 1/8	60 1/4	60 3/8	60 1/2	60 5/8	60 3/4	60 7/8	61	61 1/8	61 1/4	61 3/8	61 1/2	61 5/8	61 3/4	61 7/8	62	62 1/8	62 1/4	62 3/8	62 1/2	62 5/8	62 3/4	62 7/8	63	63 1/8	63 1/4	63 3/8	63 1/2	63 5/8	63 3/4	63 7/8	64	64 1/8	64 1/4	64 3/8	64 1/2	64 5/8	64 3/4	64 7/8	65	65 1/8	65 1/4	65 3/8	65 1/2	65 5/8	65 3/4	65 7/8	66	66 1/8	66 1/4	66 3/8	66 1/2	66 5/8	66 3/4	66 7/8	67	67 1/8	67 1/4	67 3/8	67 1/2	67 5/8	67 3/4	67 7/8	68	68 1/8	68 1/4	68 3/8	68 1/2	68 5/8	68 3/4	68 7/8	69	69 1/8	69 1/4	69 3/8	69 1/2	69 5/8	69 3/4	69 7/8	70	70 1/8	70 1/4	70 3/8	70 1/2	70 5/8	70 3/4	70 7/8	71	71 1/8	71 1/4	71 3/8	71 1/2	71 5/8	71 3/4	71 7/8	72	72 1/8	72 1/4	72 3/8	72 1/2	72 5/8	72 3/4	72 7/8	73	73 1/8	73 1/4	73 3/8	73 1/2	73 5/8	73 3/4	73 7/8	74	74 1/8	74 1/4	74 3/8	74 1/2	74 5/8	74 3/4	74 7/8	75	75 1/8	75 1/4	75 3/8	75 1/2	75 5/8	75 3/4	75 7/8	76	76 1/8	76 1/4	76 3/8	76 1/2	76 5/8	76 3/4	76 7/8	77	77 1/8	77 1/4	77 3/8	77 1/2	77 5/8	77 3/4	77 7/8	78	78 1/8	78 1/4	78 3/8	78 1/2	78 5/8	78 3/4	78 7/8	79	79 1/8	79 1/4	79 3/8	79 1/2	79 5/8	79 3/4	79 7/8	80	80 1/8	80 1/4	80 3/8	80 1/2	80 5/8	80 3/4	80 7/8	81	81 1/8	81 1/4	81 3/8	81 1/2	81 5/8	81 3/4	81 7/8	82	82 1/8	82 1/4	82 3/8	82 1/2	82 5/8	82 3/4	82 7/8	83	83 1/8	83 1/4	83 3/8	83 1/2	83 5/8	83 3/4	83 7/8	84	84 1/8	84 1/4	84 3/8	84 1/2	84 5/8	84 3/4	84 7/8	85	85 1/8	85 1/4	85 3/8	85 1/2	85 5/8	85 3/4	85 7/8	86	86 1/8	86 1/4	86 3/8	86 1/2	86 5/8	86 3/4	86 7/8	87	87 1/8	87 1/4	87 3/8	87 1/2	87 5/8	87 3/4	87 7/8	88	88 1/8	88 1/4	88 3/8	88 1/2	88 5/8	88 3/4	88 7/8	89	89 1/8	89 1/4	89 3/8	89 1/2	89 5/8	89 3/4	89 7/8	90	90 1/8	90 1/4	90 3/8	90 1/2	90 5/8	90 3/4	90 7/8	91	91 1/8	91 1/4	91 3/8	91 1/2	91 5/8	91 3/4	91 7/8	92	92 1/8	92 1/4	92 3/8	92 1/2	92 5/8	92 3/4	92 7/8	93	93 1/8	93 1/4	93 3/8	93 1/2	93 5/8	93 3/4	93 7/8	94	94 1/8	94 1/4	94 3/8	94 1/2	94 5/8	94 3/4	94 7/8	95	95 1/8	95 1/4	95 3/8	95 1/2	95 5/8	95 3/4	95 7/8	96	96 1/8	96 1/4	96 3/8	96 1/2	96 5/8	96 3/4	96 7/8	97	97 1/8	97 1/4	97 3/8	97 1/2	97 5/8	97 3/4	97 7/8	98	98 1/8	98 1/4	98 3/8	98 1/2	98 5/8	98 3/4	98 7/8	99	99 1/8	99 1/4	99 3/8	99 1/2	99 5/8	99 3/4	99 7/8	100	100 1/8	100 1/4	100 3/8	100 1/2	100 5/8	100 3/4	100 7/8	101	101 1/8	101 1/4	101 3/8	101 1/2	101 5/8	101 3/4	101 7/8	102	102 1/8	102 1/4	102 3/8	102 1/2	102 5/8	102 3/4	102 7/8	103	103 1/8	103 1/4	103 3/8	103 1/2	103 5/8	103 3/4	103 7/8	104	104 1/8	104 1/4	104 3/8	104 1/2	104 5/8	104 3/4	104 7/8	105	105 1/8	105 1/4	105 3/8	105 1/2	105 5/8	105 3/4	105 7/8	106	106 1/8	106 1/4	106 3/8	106 1/2	106 5/8	106 3/4	106 7/8	107	107 1/8	107 1/4	107 3/8	107 1/2	107 5/8	107 3/4	107 7/8	108	108 1/8	108 1/4	108 3/8	108 1/2	108 5/8	108 3/4	108 7/8	109	109 1/8	109 1/4	109 3/8	109 1/2	109 5/8	109 3/4	109 7/8	110	110 1/8	110 1/4	110 3/8	110 1/2	110 5/8	110 3/4	110 7/8	111	111 1/8	111 1/4	111 3/8	111 1/2	111 5/8	111 3/4	111 7/8	112	112 1/8	112 1/4	112 3/8	112 1/2	112 5/8	112 3/4	112 7/8	113	113 1/8	113 1/4	113 3/8	113 1/2	113 5/8	113 3/4	113 7/8	114	114 1/8	114 1/4	114 3/8	114 1/2	114 5/8	114 3/4	114 7/8	115	115 1/8	115 1/4	115 3/8	115 1/2	115 5/8	115 3/4	115 7/8	116	116 1/8	116 1/4	116 3/8	116 1/2	116 5/8	116 3/4	116 7/8	117	117 1/8	117 1/4	117 3/8	117 1/2	117 5/8	117 3/4	117 7/8	118	118 1/8	118 1/4	118 3/8	118 1/2	118 5/8	118 3/4	118 7/8	119	119 1/8	119 1/4	119 3/8	119 1/2	119 5/8	119 3/4	119 7/8	120	120 1/8	120 1/4	120 3/8	120 1/2	120 5/8	120 3/4	120 7/8	121	121 1/8	121 1/4	121 3/8	121 1/2	121 5/8	121 3/4	121 7/8	122	122 1/8	122 1/4	122 3/8	122 1/2	122 5/8	122 3/4	122 7/8	123	123 1/8	123 1/4	123 3/8	123 1/2	123 5/8	123 3/4	123 7/8	124	124 1/8	124 1/4	124 3/8	124 1/2	124 5/8	124 3/4	124 7/8	125	125 1/8	125 1/4	125 3/8	125 1/2	125 5/8	125 3/4	125 7/8	126	126 1/8	126 1/4	126 3/8	126 1/2	126 5/8	126 3/4	126 7/8	127	127 1/8	127 1/4	127 3/8	127 1/2	127 5/8	127 3/4	127 7/8	128	128 1/8	128 1/4	128 3/8	128 1/2	128 5/8	128 3/4	128 7/8	129	129 1/8	129 1/4	129 3/8	129 1/2	129 5/8	129 3/4	129 7/8	130	130 1/8	130 1/4	130 3/8	130 1/2	130 5/8	130 3/4	130 7/8	131	131 1/8	131 1/4	131 3/8	131 1/2	131 5/8	131 3/4	131 7/8	132	132 1/8	132 1/4	132 3/8	132 1/2	132 5/8	132 3/4	132 7/8	133	133 1/8	133 1/4	133 3/8	133 1/2	133 5/8	133 3/4	133 7/8	134	134 1/8	134 1/4	134 3/8	134 1/2	134 5/8	134 3/4	134 7/8	135	135 1/8	135 1/4	135 3/8	135 1/2	135 5/8	135 3/4	135 7/8	136	136 1/8	136 1/4	136 3/8	136 1/2	136 5/8	136 3/4	136 7/8	137	137 1/8	137 1/4	137 3/8	137 1/2	137 5/8	137 3/4	137 7/8	138	138 1/8	138 1/4	138 3/8	138 1/2	138 5/8	138 3/4	138 7/8	139	139 1/8	139 1/4	139 3/8	139 1/2	139 5/8	139 3/4	139 7/8	140	140 1/8	140 1/4	140 3/8	140 1/2	140 5/8	140 3/4	140 7/8	141	141 1/8	141 1/4	141 3/8	141 1/2	141 5/8	141 3/4	141 7/8	142	142 1/8	142 1/4	
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## WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES

WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 7/8	2
162	1095	1460	1825	2190	2555	2920	3285	3650	4015	4380	4744	5109	5474	5839	6204	6569
162 1/2	1102	1469	1836	2203	2571	2938	3305	3672	4039	4407	4774	5141	5508	5875	6242	6609
163	1108	1478	1847	2217	2586	2956	3325	3695	4064	4434	4803	5173	5542	5912	6281	6651
163 1/2	1115	1487	1859	2231	2602	2974	3346	3718	4089	4461	4833	5205	5576	5948	6319	6691
164	1122	1496	1870	2244	2618	2992	3366	3740	4114	4488	4862	5236	5610	5984	6357	6731
164 1/2	1129	1505	1882	2258	2634	3010	3387	3763	4139	4516	4892	5268	5645	6021	6398	6775
165	1136	1514	1893	2272	2650	3029	3407	3786	4165	4543	4922	5300	5679	6058	6437	6816
165 1/2	1143	1524	1905	2285	2666	3047	3428	3809	4195	4571	4952	5333	5714	6094	6475	6855
166	1150	1533	1916	2299	2682	3066	3449	3832	4215	4598	4982	5365	5748	6131	6514	6897
166 1/2	1157	1542	1928	2313	2699	3084	3470	3855	4241	4626	5012	5397	5783	6168	6553	6938
167	1164	1551	1939	2327	2715	3103	3491	3878	4266	4654	5042	5430	5818	6205	6592	6979
167 1/2	1170	1561	1951	2341	2731	3121	3511	3902	4292	4682	5072	5462	5852	6243	6633	7020
168	1177	1570	1962	2355	2747	3140	3532	3925	4317	4710	5102	5495	5887	6280	6671	7060
168 1/2	1185	1579	1974	2369	2764	3159	3554	3948	4343	4738	5133	5528	5923	6317	6711	7100
169	1192	1589	1986	2383	2780	3177	3575	3972	4369	4766	5163	5561	5958	6355	6750	7140
169 1/2	1199	1598	1998	2397	2797	3196	3596	3995	4395	4794	5194	5594	5993	6393	6793	7180
170	1206	1608	2009	2411	2813	3215	3617	4019	4423	4831	5235	5637	6028	6430	6831	7231
170 1/2	1213	1617	2021	2426	2830	3234	3638	4043	4447	4857	5263	5667	6064	6468	6871	7270
171	1220	1627	2033	2440	2846	3253	3660	4066	4473	4880	5288	5693	6100	6506	6911	7310
171 1/2	1227	1636	2045	2454	2863	3272	3681	4090	4499	4908	5317	5726	6131	6534	6940	7350
172	1234	1646	2057	2468	2880	3291	3703	4114	4525	4937	5348	5760	6171	6583	6994	7390
172 1/2	1241	1655	2069	2483	2897	3310	3724	4138	4552	4966	5379	5793	6207	6621	7033	7430
173	1249	1665	2081	2497	2913	3330	3746	4162	4578	4994	5411	5827	6243	6659	7070	7470
173 1/2	1256	1674	2093	2512	2930	3349	3768	4186	4605	5023	5442	5861	6279	6698	7110	7510
174	1263	1684	2105	2526	2947	3368	3789	4210	4631	5052	5473	5894	6315	6737	7150	7550
174 1/2	1270	1694	2117	2541	2964	3388	3811	4235	4658	5081	5502	5928	6352	6775	7190	7590
175	1278	1704	2129	2555	2981	3407	3833	4259	4685	5111	5537	5962	6388	6814	7230	7630
175 1/2	1285	1713	2142	2570	2998	3427	3855	4283	4712	5140	5568	5997	6425	6853	7270	7670
176	1292	1723	2154	2585	3015	3446	3877	4308	4738	5169	5600	6031	6461	6892	7310	7710
176 1/2	1300	1733	2166	2599	3033	3465	3899	4332	4765	5199	5632	6065	6498	6931	7350	7750
177	1307	1743	2178	2614	3050	3485	3921	4357	4792	5228	5664	6099	6535	6971	7390	7790
177 1/2	1314	1753	2191	2629	3067	3505	3943	4381	4820	5258	5696	6134	6572	7010	7430	7830
178	1322	1762	2203	2644	3084	3525	3966	4406	4847	5287	5728	6169	6609	7050	7470	7870
178 1/2	1329	1772	2215	2659	3102	3545	3988	4431	4874	5317	5760	6203	6646	7089	7510	7910
179	1337	1782	2228	2673	3119	3565	4010	4456	4901	5347	5792	6238	6684	7129	7550	7950
179 1/2	1344	1792	2240	2688	3136	3585	4033	4481	4929	5377	5825	6273	6721	7169	7590	7990
180	1352	1802	2253	2703	3154	3605	4055	4506	4956	5407	5857	6308	6759	7209	7630	8030
180 1/2	1359	1812	2265	2718	3172	3625	4078	4531	4984	5437	5890	6343	6796	7249	7670	8070
181	1367	1822	2278	2734	3189	3645	4100	4556	5011	5467	5923	6378	6834	7289	7710	8110
181 1/2	1374	1832	2291	2749	3207	3665	4123	4581	5039	5497	5955	6414	6872	7330	7750	8150
182	1382	1843	2303	2764	3224	3685	4146	4606	5067	5528	5988	6449	6910	7370	7790	8190
182 1/2	1390	1853	2316	2779	3242	3705	4169	4632	5095	5558	6021	6484	6948	7411	7830	8230
183	1397	1863	2329	2794	3260	3726	4191	4657	5123	5589	6054	6520	6988	7451	7870	8270
183 1/2	1405	1873	2341	2810	3278	3746	4214	4683	5151	5619	6087	6556	7024	7492	7910	8310
184	1412	1883	2354	2825	3296	3767	4237	4708	5179	5650	6121	6591	7062	7533	7950	8350
184 1/2	1420	1894	2367	2840	3314	3787	4260	4734	5207	5681	6154	6627	7101	7574	7990	8390
185	1428	1904	2380	2856	3332	3808	4284	4759	5235	5711	6187	6663	7139	7615	8010	8430
185 1/2	1436	1914	2393	2871	3350	3828	4307	4785	5264	5742	6221	6699	7178	7656	8050	8470
186	1443	1924	2406	2887	3368	3849	4330	4811	5292	5773	6254	6736	7217	7698	8090	8510
186 1/2	1451	1935	2418	2902	3386	3870	4353	4837	5321	5804	6288	6772	7255	7739	8130	8550
187	1459	1945	2431	2918	3404	3890	4377	4863	5349	5836	6322	6808	7294	7781	8170	8590
187 1/2	1467	1956	2444	2933	3422	3911	4400	4889	5378	5865	6356	6845	7333	7822	8210	8630
188	1475	1966	2458	2949	3441	3932	4424	4915	5407	5898	6390	6881	7373	7864	8250	8670
188 1/2	1482	1977	2471	2965	3459	3953	4447	4941	5435	5930	6424	6918	7412	7906	8290	8710
189	1490	1987	2484	2981	3477	3974	4471	4968	5464	5961	6458	6955	7451	7948	8330	8750
189 1/2	1498	1998	2497	2996	3496	3995	4494	4994	5493	5993	6492	6991	7491	7990	8370	8790

## WEIGHT OF CIRCULAR PLATES

ALL DIMENSIONS IN INCHES

WEIGHTS IN POUNDS

DIA	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 7/8	2
190	1506	2008	2510	3012	3514	4016	4518	5020	5522	6024	6526	7028	7530	8032	8534	9036
190 1/2	1514	2019	2523	3028	3533	4037	4542	5047	5551	6056	6561	7065	7570	8075	8580	9084
191	1522	2029	2537	3044	3551	4059	4566	5073	5581	6088	6595	7102	7610	8117	8624	9131
191 1/2	1530	2040	2550	3060	3570	4080	4590	5100	5610	6120	6630	7140	7650	8160	8670	9180
192	1538	2051	2563	3076	3589	4101	4614	5126	5639	6152	6664	7177	7690	8202	8714	9226
192 1/2	1546	2061	2577	3092	3607	4123	4638	5153	5669	6184	6699	7214	7730	8245	8760	9275
193	1554	2072	2590	3108	3626	4144	4662	5180	5698	6216	6734	7252	7770	8288	8806	9324
193 1/2	1562	2083	2603	3124	3645	4166	4686	5207	5728	6248	6769	7290	7810	8331	8852	9375
194	1570	2094	2617	3140	3664	4187	4710	5234	5757	6281	6804	7327	7851	8374	8897	9426
194 1/2	1578	2104	2630	3157	3683	4209	4735	5261	5787	6313	6839	7365	7891	8417	8943	9477
195	1586	2115	2644	3173	3702	4230	4759	5288	5817	6346	6874	7403	7932	8461	8988	9528
195 1/2	1595	2126	2658	3189	3721	4252	4784	5315	5847	6378	6910	7441	7973	8504	9039	9579
196	1603	2137	2671	3205	3740	4274	4808	5342	5877	6411	6945	7479	8013	8548	9080	9630
196 1/2	1611	2148	2685	3222	3759	4296	4833	5370	5907	6444	6980	7517	8054	8591	9131	9681
197	1619	2159	2698	3238	3778	4318	4857	5397	5937	6476	7016	7556	8095	8635	9182	9732
197 1/2	1627	2170	2712	3255	3797	4340	4882	5424	5967	6509	7052	7594	8137	8679	9233	9783
198	1636	2181	2726	3271	3816	4362	4907	5452	5997	6542	7087	7633	8178	8723	9284	9834
198 1/2	1644	2192	2740	3288	3836	4384	4932	5479	6027	6575	7123	7671	8219	8767	9326	9875
199	1652	2203	2754	3304	3855	4406	4956	5507	6058	6609	7159	7710	8261	8811	9362	9913
199 1/2	1660	2214	2767	3321	3874	4428	4981	5535	6088	6642	7195	7749	8302	8851	9404	9955
200	1669	2225	2781	3338	3894	4450	5006	5563	6119	6675	7231	7788	8344	8900	9456	10000



## WEIGHT OF BOLTS

With square heads and hexagon nuts in pounds per 100

Length Under Head Inches	Diameter of Bolt in Inches									
	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	
1	2.38	6.11	13.0	24.1	38.9	67.3	95.1	143	206	
1 1/4	2.71	6.71	14.0	25.8	41.5	74.9	104	149	213	
1 1/2	3.05	7.47	15.1	27.6	44.0	77.9	109	155	221	
1 3/4	3.39	8.23	16.5	29.3	46.5	82.0	114	161	229	
2	3.73	8.99	17.8	31.4	49.1	86.1	119	168	237	
2 1/4	4.06	9.75	19.1	33.5	52.1	89.4	124	174	246	
2 1/2	4.40	10.5	20.5	35.6	55.1	92.7	129	181	254	
2 3/4	4.74	11.3	21.8	37.7	58.2	96.0	135	188	262	
3	5.07	12.0	23.2	39.8	61.2	99.2	140	195	271	
3 1/4	5.41	12.8	24.5	41.9	64.2	102.4	145	202	279	
3 1/2	5.75	13.5	25.9	44.0	67.2	105.6	151	208	288	
3 3/4	6.09	14.3	27.2	46.1	70.2	108.8	156	215	296	
4	6.42	15.1	28.6	48.2	73.3	111.9	162	222	304	
4 1/4	6.76	15.8	29.9	50.3	76.3	115.1	167	229	313	
4 1/2	7.10	16.6	31.3	52.3	79.3	118.3	172	236	321	
4 3/4	7.43	17.3	32.6	54.4	82.3	121.5	178	243	329	
5	7.77	18.1	33.9	56.5	85.3	124.7	183	250	337	
5 1/4	8.11	18.9	35.3	58.6	88.4	127.9	188	257	345	
5 1/2	8.44	19.6	36.6	60.7	91.4	131.1	193	264	354	
5 3/4	8.78	20.4	38.0	62.8	94.4	134.3	198	271	362	
6	9.12	21.1	39.3	64.9	97.4	137.5	204	278	370	
6 1/4	9.37	21.7	40.4	66.7	100	140.7	209	285	379	
6 1/2	9.71	22.3	41.8	68.7	103	143.9	214	292	387	
6 3/4	10.1	23.3	43.1	70.8	106	147.1	220	300	396	
7	10.4	24.0	44.4	72.9	109	150.3	225	307	404	
7 1/4	10.7	24.8	45.8	75.0	112	153.5	231	314	413	
7 1/2	11.0	25.5	47.1	77.1	115	156.7	236	321	421	
7 3/4	11.4	26.3	48.5	79.2	118	159.9	242	328	429	
8	11.7	27.0	49.8	81.3	121	163.1	247	335	438	
8 1/4		28.6	52.5	85.5	127	169.5	254	343	446	
8 1/2		30.1	55.2	89.7	133	175.9	261	351	454	
8 3/4		31.6	57.9	93.9	139	182.3	268	359	463	
9										
9 1/4										
9 1/2										
9 3/4										
10										
10 1/4										
10 1/2										
10 3/4										
11										
11 1/4										
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14 1/4										
14 1/2										
14 3/4										
15										
15 1/4										
15 1/2										
15 3/4										
16										
Per Inch Additional	1.3	3.0	5.4	8.4	12.1	16.5	21.4	27.2	33.6	

Notes: Bolt is Regular Square Bolt, ASA B18.2 and nut is finished Hexagon Nut, ASA B18.2. This table conforms to weight standards adopted by the Industrial Fasteners Institute.

## WEIGHTS OF OPENINGS

## NOZZLES

With ANSI Welding Neck Flange and Reinforcing Pad  
(Table for Quick Reference)

SIZE	CLASS				
	150	300	600	900	1500
1 1/4	6	11	13	17	18
2	9	12	15	28	30
3	16	25	40	45	70
4	25	40	60	75	105
6	45	70	120	155	225
8	65	110	175	260	380
10	95	145	285	375	620
12	135	220	365	550	920
14	165	285	515	775	
16	215	370	695	965	
18	331	610	935	1379	
20	428	708	1245	1693	
24	589	1131	1815	3041	

## NOZZLES

With ASA Welding Neck Flange, Reinforcing Pad, Blind Flange  
Studs and Gasket (Table for Quick Reference)

SIZE	CLASS				
	150	300	600	900	1500
3	25	41	60	77	118
4	42	67	101	129	178
6	71	120	206	268	384
8	110	191	314	457	682
10	165	272	516	665	1127
12	245	404	660	963	1695
14	296	521	893	1269	
16	440	800	1300	1600	3510
18	540	1000	1600	2250	4460
20	700	1200	2100	2800	5700
24	1000	1885	2990	5140	9350

## SCREWED COUPLINGS

NOMINAL PIPE SIZE

	NOMINAL PIPE SIZE					
	1/2	3/4	1	1 1/2	2	3
3000 lb.	0.25	0.44	0.63	2.19	3.13	4.00
6000 lb.	0.50	1.00	2.13	4.38	7.75	10.75
						13.50







## VOLUME OF SHELLS AND HEADS

I.D. of Vessel in.	Cylindrical SHELL/LIN. FT.				2:1 ELLIP. HEAD*			
	Cu.Ft.	Gal.	Bbl.	Wt. of Water lb.	Cu.Ft.	Gal.	Bbl.	Wt. of Water lb.
12	0.8	5.9	0.14	49	0.1	0.98	0.02	8.17
14	1.1	8.0	0.19	67	0.2	1.55	0.04	12.98
16	1.4	10.4	0.25	87	0.3	2.32	0.06	19.37
18	1.8	13.2	0.31	110	0.4	3.30	0.08	27.58
20	2.2	16.3	0.39	136	0.6	4.53	0.11	37.83
22	2.6	19.7	0.47	165	0.8	6.03	0.14	50.35
24	3.1	23.5	0.56	196	1.0	7.83	0.19	65.37
26	3.7	27.6	0.66	230	1.3	9.96	0.24	83.11
28	4.3	32.0	0.76	267	1.7	12.44	0.30	103.8
30	4.9	36.7	0.87	306	2.0	15.30	0.36	127.7
32	5.6	41.8	0.99	349	2.5	18.57	0.44	155.0
34	6.3	47.2	1.12	394	3.0	22.27	0.53	185.9
36	7.1	52.9	1.26	441	3.5	26.47	0.63	220.1
38	7.9	58.9	1.40	492	4.2	31.09	0.74	259.5
40	8.7	65.3	1.55	545	4.8	36.27	0.86	302.6
42	9.6	72.0	1.71	601	5.6	41.98	1.00	350.4
48	12.6	94.0	2.24	784	8.4	62.67	1.49	523.0
54	15.9	119.0	2.83	993	11.9	89.23	2.12	744.6
60	19.6	146.9	3.50	1226	16.3	122.4	2.91	1021
66	23.8	177.7	4.23	1483	21.8	162.9	3.88	1360
72	28.3	211.5	5.04	1765	28.3	211.5	5.04	1765
78	33.2	248.2	5.91	2071	35.9	268.9	6.40	2244
84	38.5	287.9	6.85	2402	44.9	335.9	8.00	2802
90	44.2	330.5	7.87	2758	55.2	413.1	9.84	3447
96	50.3	376.0	8.95	3138	67.0	501.3	11.94	4184
102	56.7	424.4	10.11	3542	80.3	601.4	14.32	5018
108	63.6	475.9	11.33	3971	95.4	713.8	17.00	5957
114	70.9	530.2	12.62	4425	112.2	839.5	20.00	7006
120	78.5	587.5	13.99	4903	130.9	979.2	23.31	8171
126	86.6	647.7	15.42	5405	151.5	1134	27.00	9459
132	95.0	710.9	16.93	5932	174.2	1303	31.03	10876
138	103.9	777.0	18.50	6484	190.1	1489	35.46	12428
144	113.1	846.0	20.14	7060	226.2	1692	40.29	14120

\*Volume within the straight flange is not included

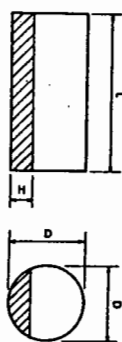
## VOLUME OF SHELLS AND HEADS

I.D. of Vessel in.	ASME F & D. HEAD*				HEMIS. HEAD*			
	Cu.Ft.	Gal.	Bbl.	Wt. of Water lb.	Cu.Ft.	Gal.	Bbl.	Wt. of Water lb.
12	0.08	0.58	0.01	4.83	0.26	1.96	0.05	16.34
14	0.12	0.94	0.02	7.83	0.42	3.11	0.07	25.95
16	0.19	1.45	0.03	12.08	0.62	4.64	0.11	38.74
18	0.27	2.04	0.05	17.00	0.88	6.61	0.16	55.16
20	0.37	2.80	0.07	28.33	1.21	9.07	0.22	75.66
22	0.50	3.78	0.09	31.49	1.61	12.07	0.29	100.7
24	0.65	4.86	0.12	40.49	2.09	15.67	0.37	130.7
26	0.82	6.14	0.15	51.15	2.66	19.92	0.47	166.2
28	1.10	8.21	0.20	68.40	3.33	24.88	0.59	207.6
30	1.30	9.70	0.23	80.81	4.09	30.60	0.73	255.4
32	1.64	12.30	0.29	102.5	4.96	37.14	0.88	309.9
34	1.88	14.10	0.34	117.5	5.95	44.54	1.06	371.7
36	2.15	16.10	0.38	134.1	7.07	52.88	1.26	441.2
38	2.75	20.60	0.49	171.6	8.31	62.19	1.48	519.0
40	3.07	23.00	0.55	191.6	9.70	72.53	1.73	605.3
42	3.68	27.50	0.65	229.1	11.22	83.97	2.00	700.7
48	5.12	38.30	0.91	319.1	16.76	125.3	2.98	1046
54	7.30	54.60	1.30	454.9	23.86	178.5	4.25	1489
60	10.08	75.40	1.80	628.2	32.73	244.8	5.83	2043
66	13.54	101	2.41	843.9	43.56	325.8	7.76	2719
72	17.65	132	3.14	1100	56.55	423.0	10.07	3530
78	22.32	167	3.98	1391	71.90	537.8	12.80	4488
84	28.47	213	5.07	1775	89.80	671.7	16.00	5606
90	35.56	266	6.33	2216	110.4	826.2	19.67	6895
96	42.51	318	7.57	2649	134.0	1003	23.87	8368
102	52.14	390	9.29	3249	160.8	1203	28.63	10037
108	60.96	456	10.86	3799	190.9	1428	34.00	11914
114	73.66	551	13.12	4590	224.5	1679	39.98	14012
120	84.35	631	15.02	5257	261.8	1958	46.63	16343
126	97.32	728	17.33	6065	303.1	2267	53.98	18919
132	108.7	813	19.36	6773	348.5	2607	62.06	21752
138	127.0	950	22.62	7915	398.2	2978	70.91	24856
144	147.9	1106	26.33	9214	452.4	3384	80.57	28241

\*Volume within the straight flange is not included



## PARTIAL VOLUMES IN HORIZONTAL CYLINDERS



EXAMPLE

Partial volumes of horizontal cylinder  
equals total volume x coefficient  
(found from table below)

HORIZONTAL CYLINDER D = 10 ft., 0 in. H = 2.75 ft. L = 60 ft., 0 in.

TOTAL VOLUME:  $0.7854 \times D^2 \times L$  Find the partial volume of the cylindrical shell

Total volume:  $0.7854 \times 10^2 \times 60 = 4712.4$  cu. ft.

Coefficient from table:

H/D = 2.75/10 = .275

Refer to the first two figures (.27) in the column headed (H/D) in the table below. Proceed to the right until the coefficient is found under the column headed (5) which is the third digit. The coefficient of 0.275 is found to be .223507

Total volume x coefficient = partial volume

$4712.4 \times .223507 = 1053.25$  cu. ft.

cu. ft. multiplied by 7.480519 = U. S. Gallon

cu. ft. multiplied by 28.317016 = Liter

## COEFFICIENTS

H/D	0	1	2	3	4	5	6	7	8	9
.00	.000000	.000053	.000151	.000279	.000429	.000600	.000788	.000992	.001212	.001445
.01	.001692	.001952	.002223	.002507	.002800	.003104	.003423	.003757	.004105	.004467
.02	.004733	.005053	.005381	.005719	.006060	.006407	.006761	.007121	.007487	.007859
.03	.008127	.008419	.008723	.009031	.009345	.009660	.009981	.010307	.010638	.010974
.04	.011319	.011647	.011982	.012323	.012670	.013023	.013381	.013744	.014112	.014485
.05	.014862	.015230	.015603	.015982	.016366	.016755	.017149	.017548	.017952	.018361
.06	.018775	.019190	.019610	.020035	.020465	.020899	.021338	.021781	.022228	.022679
.07	.023134	.023583	.024037	.024495	.024957	.025423	.025892	.026364	.026839	.027317
.08	.027798	.028272	.028750	.029231	.029715	.030202	.030691	.031182	.031675	.032170
.09	.032666	.033162	.033660	.034160	.034662	.035166	.035672	.036179	.036687	.037196
.10	.037706	.038217	.038729	.039242	.039756	.040271	.040787	.041304	.041821	.042339
.11	.042857	.043375	.043894	.044413	.044933	.045453	.045973	.046493	.047013	.047533
.12	.048053	.048573	.049093	.049613	.050133	.050653	.051173	.051693	.052213	.052733
.13	.053253	.053773	.054293	.054813	.055333	.055853	.056373	.056893	.057413	.057933
.14	.058453	.058973	.059493	.060013	.060533	.061053	.061573	.062093	.062613	.063133
.15	.063653	.064173	.064693	.065213	.065733	.066253	.066773	.067293	.067813	.068333
.16	.068853	.069373	.069893	.070413	.070933	.071453	.071973	.072493	.073013	.073533
.17	.074053	.074573	.075093	.075613	.076133	.076653	.077173	.077693	.078213	.078733
.18	.079253	.079773	.080293	.080813	.081333	.081853	.082373	.082893	.083413	.083933
.19	.084453	.084973	.085493	.086013	.086533	.087053	.087573	.088093	.088613	.089133
.20	.089653	.090173	.090693	.091213	.091733	.092253	.092773	.093293	.093813	.094333
.21	.094853	.095373	.095893	.096413	.096933	.097453	.097973	.098493	.099013	.099533
.22	.100053	.100573	.101093	.101613	.102133	.102653	.103173	.103693	.104213	.104733
.23	.105253	.105773	.106293	.106813	.107333	.107853	.108373	.108893	.109413	.109933
.24	.110453	.110973	.111493	.112013	.112533	.113053	.113573	.114093	.114613	.115133
.25	.115653	.116173	.116693	.117213	.117733	.118253	.118773	.119293	.119813	.120333
.26	.120853	.121373	.121893	.122413	.122933	.123453	.123973	.124493	.125013	.125533
.27	.126053	.126573	.127093	.127613	.128133	.128653	.129173	.129693	.130213	.130733
.28	.131253	.131773	.132293	.132813	.133333	.133853	.134373	.134893	.135413	.135933
.29	.136453	.136973	.137493	.138013	.138533	.139053	.139573	.140093	.140613	.141133
.30	.141653	.142173	.142693	.143213	.143733	.144253	.144773	.145293	.145813	.146333
.31	.146853	.147373	.147893	.148413	.148933	.149453	.149973	.150493	.151013	.151533

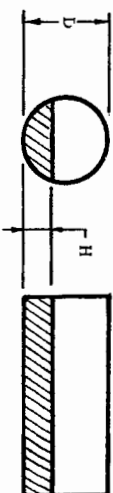
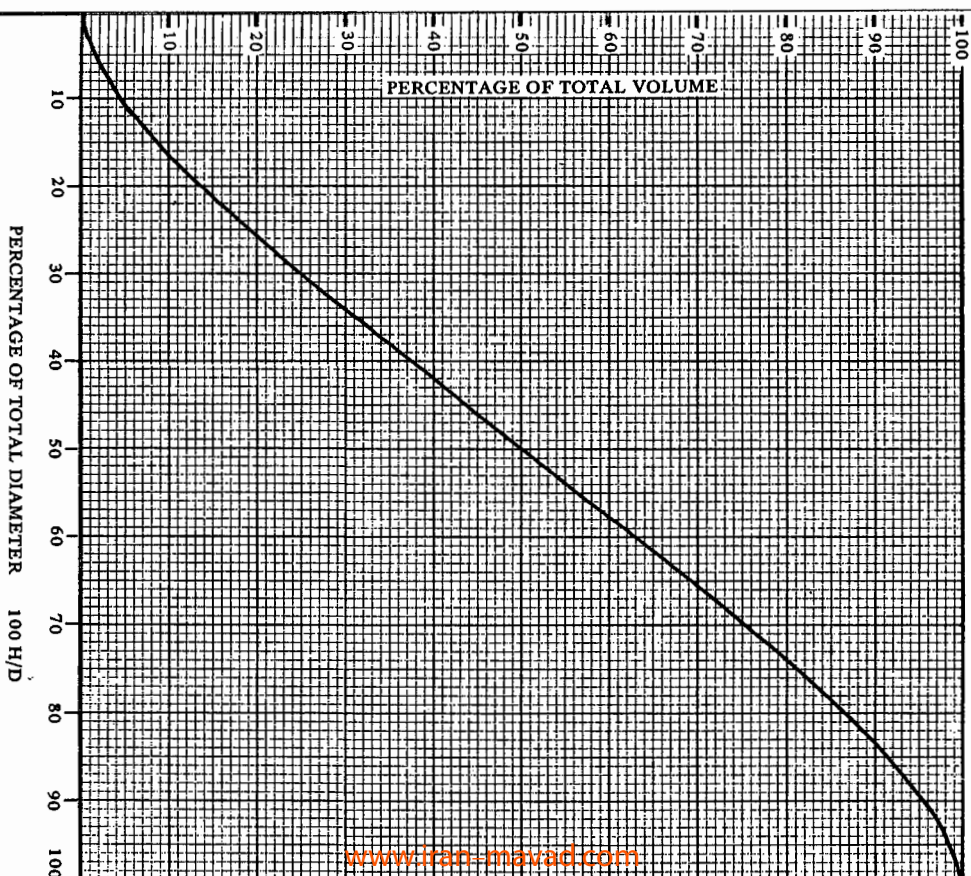
## PARTIAL VOLUMES IN HORIZONTAL CYLINDERS COEFFICIENTS (Cont.)

H/D	0	1	2	3	4	5	6	7	8	9
.32	.275869	.277056	.278247	.279437	.280627	.281820	.283013	.284207	.285401	.286598
.33	.286794	.288992	.290191	.291390	.292591	.293793	.294995	.296198	.297403	.298605
.34	.298614	.301021	.302228	.303388	.304567	.305756	.306948	.308140	.309340	.310545
.35	.311918	.313134	.314350	.315566	.316783	.318001	.319219	.320439	.321660	.322881
.36	.3234104	.3238530	.3242956	.3247382	.3251808	.3256234	.3260660	.3265086	.3269512	.3273938
.37	.3283689	.3287593	.3291497	.3295401	.3299305	.3303209	.3307113	.3311017	.3314921	.3318825
.38	.3348690	.3349926	.3351162	.3352402	.3353642	.3354882	.3356122	.3357362	.3358602	.3359842
.39	.361082	.362325	.363568	.364811	.366054	.367300	.368545	.369790	.371036	.372282
.40	.373530	.374778	.376026	.377275	.378524	.379774	.381024	.382274	.383523	.384778
.41	.386030	.387283	.388535	.389790	.391044	.392298	.393553	.394808	.396063	.397318
.42	.398577	.399834	.401092	.402350	.403608	.404866	.406125	.407384	.408643	.409904
.43	.411165	.412428	.413687	.414949	.416211	.417473	.418736	.419998	.421261	.422525
.44	.423788	.425052	.426316	.427582	.428846	.430112	.431378	.432645	.433911	.435178
.45	.436445	.437712	.438979	.440246	.441514	.442782	.444050	.445318	.446587	.447857
.46	.449125	.450394	.451663	.452938	.454201	.455472	.456744	.458012	.459283	.460554
.47	.461825	.463096	.464367	.465638	.466910	.468182	.469453	.470725	.471998	.473269
.48	.474541	.475814	.477086	.478358	.479631	.480903	.482176	.483449	.484722	.485995
.49	.487269	.488542	.489814	.491087	.492360	.493633	.494906	.496179	.497452	.498726
.50	.500000	.501274	.502548	.503821	.505094	.506367	.507640	.508913	.510186	.511458
.51	.512731	.514005	.515278	.516551	.517824	.519097	.520369	.521642	.522914	.524186
.52	.526450	.528731	.529003	.529275	.530547	.531818	.533090	.534363	.535635	.536906
.53	.538175	.539446	.540717	.541988	.543259	.544528	.545797	.547068	.548337	.549606
.54	.550875	.552143	.553413	.554682	.555950	.557218	.558486	.559754	.561021	.562288
.55	.563525	.564792	.566059	.567325	.568592	.569858	.571124	.572391	.573654	.574918
.56	.576182	.577447	.578713	.580000	.581284	.582568	.583857	.585141	.586431	.587715
.57	.588855	.590066	.591355	.592616	.593875	.595134	.596392	.597650	.598908	.600166
.58	.601429	.602688	.603937	.605197	.606456	.607712	.608968	.610225	.611483	.612741
.59	.613970	.615222	.616474	.617726	.618976	.620226	.621476	.622725	.623974	.625222
.60	.626470	.627718	.628964	.630210	.631455	.632700	.633944	.635189	.636432	.637677
.61	.638910	.640160	.641410	.642641	.643881	.645121	.646360	.647598	.648836	.650077
.62	.651318	.652545	.653780	.655015	.656249	.657481	.658714	.659946	.661177	.662407
.63	.663637	.664866	.666093	.667322	.668549	.669775	.671001	.672226	.673450	.674677
.64	.675896	.677119	.678340	.679561	.680781	.681999	.683217	.684434	.685650	.686866
.65	.688082	.689295	.690508	.691720	.692932	.694143	.695354	.696562	.697772	.698976
.66	.700186	.701392	.702597	.703802	.705005	.706207	.707409	.708610	.709809	.711006
.67	.712205	.713402	.714599	.715795	.716987	.718180	.719373	.720565	.721753	.722945
.68	.723131	.724318	.725505	.726690	.727874	.729058	.730240	.731422	.732603	.733783
.69	.734961	.736137	.737313	.738488	.739662	.740835	.742008	.743178	.744348	.745518
.70	.746685	.747852	.749017	.750181	.751344	.752506	.753667	.754827	.755984	.757141
.71	.758297	.759453	.760605	.761758	.762909	.764059	.765209	.766356	.767502	.768644
.72	.769791	.770935	.772076	.773217	.774357	.775493	.776629	.777765	.778903	.780038
.73	.781171	.782302	.783432	.784561	.785687	.786813	.787938	.789063	.790188	.791313
.74	.792440	.793517	.794592	.795667	.796741	.797815	.798889	.799963	.801037	.802111
.75	.803186	.804260	.805330	.806401	.807470	.808539	.809603	.810673	.811738	.812800
.76	.813850	.814915	.815977	.817038	.818098	.819157	.820214	.821270	.822324	.823378
.77	.824431	.825481	.826528	.827574	.828619	.829663	.830706	.831747	.832788	.833829
.78	.834868	.835914	.836957	.838000	.839041	.840081	.841121	.842160	.843197	.844235
.79	.845271	.846308	.847343	.848378	.849411	.850446	.851478	.852509	.853539	.854567
.80	.855591	.856620	.857647	.858673	.859698	.860722	.861745	.862767	.863789	.864810
.81	.865830	.866849	.867867	.868884	.869899	.870913	.871926	.872938	.873949	.874959
.82	.875968	.876976	.877983	.878989	.879994	.880998	.881999	.882999	.883999	.884999
.83	.885999	.886999	.887999	.888999	.889999	.890999	.891999	.892999	.893999	.894999
.84	.895999	.896999	.897999	.898999	.899999	.900999	.901999	.902999	.903999	.904999
.85	.905999	.906999	.907999	.908999	.909999	.910999	.911999	.912999	.913999	.914999
.86	.915999	.916999	.917999	.918999	.919999	.920999	.921999	.922999	.923999	.924999
.87	.925999	.926999	.927999	.928999	.929999	.930999	.931999	.932999	.933999	.934999
.88	.935999	.936999	.937999	.938999	.939999	.940999	.941999	.942999	.943999	.944999
.89	.945999	.946999	.947999	.948999	.949999	.950999	.951999	.952999	.953999	.954999
.90	.955999	.956999	.957999	.958999	.959999	.960999	.961999	.962999	.963999	.964999
.91	.965999	.966999	.967999	.968999	.969999	.970999	.971999	.972999	.973999	.974999
.92	.975999	.976999	.977999	.978999	.979999	.980999	.981999	.982999	.983999	.984999



## PARTIAL VOLUMES IN HORIZONTAL CYLINDERS COEFFICIENTS (cont.)

H/D	0	1	2	3	4	5	6	7	8	9
.93	.969228	.969876	.970519	.971158	.971792	.972422	.973048	.973669	.974285	.974897
.94	.975504	.976106	.976704	.977297	.977885	.978467	.979045	.979618	.980187	.980750
.95	.981308	.981859	.982407	.982948	.983485	.984015	.984541	.985060	.985573	.986081
.96	.986583	.987080	.987568	.988053	.988530	.989001	.989466	.989924	.990375	.990821
.97	.991258	.991690	.992114	.992530	.992939	.993340	.993733	.994119	.994497	.994866
.98	.995227	.995579	.995923	.996257	.996581	.996896	.997200	.997493	.997777	.998048
.99	.998306	.998555	.998788	.999008	.999212	.999400	.999571	.999721	.999849	.999947
1.00	1.000000									

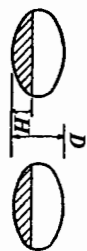
PARTIAL VOLUMES IN HORIZONTAL CYLINDERS  
(Percentage Relation of Diameter to Volume)



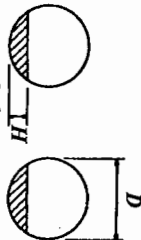
## PARTIAL VOLUMES IN ELLIPSOIDAL HEADS AND SPHERES



Two 2:1 Ellipsoidal Heads on Horizontal Vessel

Total Volume:  $0.2618 D^3$ 

Two 2:1 Ellipsoidal Heads on Vertical Vessel

Total Volume:  $2.0944 D^3$ 

Sphere

Total Volume:  $0.5236 D^3$ 

Partial volumes of ellipsoidal heads and spheres equals total volume  $\times$  coefficient (found from table below)

EXAMPLE:

$$D = 10 \text{ ft., } 0 \text{ in.} \quad H = 2.75 \text{ ft.}$$

Find the partial volume of (2) 2:1 ellipsoidal heads of a horizontal vessel. The total volume of the two heads:

$$0.2618 \times D^3 = 0.2618 \times 10^3 = 261.8 \text{ cu. ft.}$$

Coefficient from table:

$$H/D = 2.75/10 = .275$$

Refer to the first two figures (.27) in the column headed (H/D) in the table below. Proceed to the right until the coefficient is found under the column headed (5) which is the third digit. The coefficient of .275 is found to be .185281.

Total volume  $\times$  coefficient = partial volume

$$261.8 \times .185281 = 48.506 \text{ cu. ft.}$$

cu. ft. multiplied by 7.480519 = U.S. Gallon

c.u. ft. multiplied by 28.317016 = Liter

## COEFFICIENTS

H/D	0	1	2	3	4	5	6	7	8	9
.00	.000000	.000003	.000012	.000027	.000048	.000075	.000108	.000146	.000191	.000242
.01	.000298	.000360	.000429	.000503	.000583	.000668	.000760	.000857	.000960	.001069
.02	.001184	.001304	.001431	.001563	.001700	.001844	.001993	.002148	.002308	.002474
.03	.002646	.002823	.003006	.003195	.003389	.003589	.003795	.004006	.004222	.004444
.04	.004672	.004905	.005144	.005388	.005638	.005893	.006153	.006419	.006691	.006968
.05	.007250	.007538	.007831	.008129	.008433	.008742	.009057	.009377	.009702	.010032
.06	.010368	.010709	.011055	.011407	.011764	.012126	.012493	.012865	.013243	.013626
.07	.014014	.014407	.014806	.015209	.015618	.016031	.016450	.016874	.017303	.017737
.08	.018176	.018620	.019069	.019523	.019983	.020447	.020916	.021390	.021869	.022353
.09	.022842	.023336	.023835	.024338	.024847	.025360	.025879	.026402	.026930	.027462
.10	.028000	.028542	.029090	.029642	.030198	.030760	.031326	.031897	.032473	.033053
.11	.033638	.034228	.034822	.035421	.036025	.036633	.037246	.037864	.038486	.039113
.12	.039744	.040380	.041020	.041665	.042315	.042969	.043627	.044290	.044958	.045630
.13	.046306	.046987	.047672	.048362	.049056	.049754	.050457	.051164	.051876	.052592
.14	.053312	.054037	.054765	.055499	.056236	.056978	.057724	.058474	.059228	.059987
.15	.060750	.061517	.062288	.063064	.063843	.064627	.065415	.066207	.067003	.067804
.16	.068608	.069416	.070229	.071046	.071866	.072691	.073519	.074352	.075189	.076029
.17	.076874	.077723	.078575	.079432	.080292	.081156	.082024	.082897	.083772	.084652

## PARTIAL VOLUMES IN ELLIPSOIDAL HEADS AND SPHERES: COEFFICIENTS (Cont.)

H/D	0	1	2	3	4	5	6	7	8	9
.18	.085336	.086424	.087315	.088210	.089109	.090012	.090918	.091829	.092743	.093660
.19	.094582	.095507	.096436	.097369	.098305	.099245	.100189	.101136	.102087	.103042
.20	.104000	.104962	.105927	.106896	.107869	.108845	.109824	.110808	.111794	.112784
.21	.113778	.114775	.115776	.116780	.117787	.118798	.119813	.120830	.121852	.122876
.22	.123904	.124935	.125970	.127008	.128049	.129094	.130142	.131193	.132247	.133305
.23	.134366	.135430	.136498	.137568	.138642	.139719	.140799	.141883	.142969	.144059
.24	.145152	.146248	.147347	.148449	.149554	.150663	.151774	.152889	.154006	.155127
.25	.156250	.157376	.158506	.159638	.160774	.161912	.163054	.164198	.165345	.166495
.26	.167648	.168804	.169963	.171124	.172289	.173456	.174626	.175799	.176974	.178153
.27	.179334	.180518	.181705	.182894	.184088	.185281	.186479	.187679	.188882	.190088
.28	.191296	.192507	.193720	.194937	.196155	.197377	.198601	.199827	.201056	.202288
.29	.203522	.204759	.205998	.207239	.208484	.209730	.210979	.212231	.213485	.214741
.30	.216000	.217261	.218526	.219792	.221060	.222331	.223604	.224879	.226157	.227437
.31	.228718	.230003	.231289	.232578	.233870	.235163	.236459	.237757	.239057	.240359
.32	.241664	.242971	.244280	.245590	.246904	.248219	.249536	.250855	.252177	.253500
.33	.254826	.256154	.257483	.258815	.260149	.261484	.262822	.264161	.265503	.266847
.34	.268192	.269539	.270889	.272240	.273593	.274948	.276305	.277663	.279024	.280386
.35	.281750	.283116	.284484	.285853	.287224	.288597	.289972	.291348	.292727	.294106
.36	.295488	.296871	.298256	.299643	.301031	.302421	.303812	.305205	.306600	.307996
.37	.309394	.310793	.312194	.313597	.315001	.316406	.317813	.319222	.320632	.322043
.38	.323456	.324870	.326286	.327702	.329122	.330542	.331963	.333386	.334810	.336235
.39	.337662	.339090	.340519	.341950	.343382	.344815	.346250	.347685	.349122	.350559
.40	.352000	.353441	.354882	.356325	.357769	.359215	.360661	.362109	.363557	.365007
.41	.366458	.367910	.369363	.370817	.372272	.373728	.375185	.376644	.378103	.379563
.42	.381024	.382486	.383949	.385413	.386878	.388344	.389810	.391278	.392746	.394215
.43	.395686	.397157	.398629	.400102	.401575	.403049	.404524	.406000	.407477	.408954
.44	.410432	.411911	.413390	.414870	.416351	.417833	.419315	.420798	.422281	.423765
.45	.425250	.426735	.428221	.429708	.431195	.432682	.434170	.435659	.437148	.438638
.46	.440128	.441619	.443110	.444601	.446093	.447586	.449079	.450572	.452066	.453560
.47	.455054	.456549	.458044	.459539	.461035	.462531	.464028	.465524	.467021	.468519
.48	.470016	.471514	.473012	.474510	.476008	.477507	.479005	.480504	.482003	.483503
.49	.485002	.486501	.488001	.489501	.491000	.492500	.494000	.495500	.497000	.498500
.50	.500000	.501500	.503000	.504500	.506000	.507500	.509000	.510499	.511999	.513499
.51	.514998	.516497	.517997	.519496	.520995	.522493	.523992	.525490	.526988	.528486
.52	.529984	.531481	.532979	.534476	.535972	.537469	.538965	.540461	.541956	.543451
.53	.544946	.546440	.547934	.549428	.550921	.552414	.553907	.555399	.556890	.558381
.54	.559872	.561362	.562852	.564341	.565830	.567318	.568805	.570292	.571779	.573265
.55	.574750	.576235	.577719	.579202	.580685	.582167	.583649	.585130	.586610	.588089
.56	.589568	.591046	.592523	.594000	.595476	.596951	.598425	.599898	.601371	.602843
.57	.604314	.605784	.607254	.608722	.610190	.611656	.613122	.614587	.616051	.617514
.58	.618976	.620437	.621897	.623356	.624815	.626272	.627728	.629183	.630637	.632090
.59	.633542	.634993	.636443	.637891	.639339	.640785	.642231	.643675	.645118	.646559



## PARTIAL VOLUMES IN ELLIPSOIDAL HEADS AND SPHERES: COEFFICIENTS (Cont.)

H/D	0	1	2	3	4	5	6	7	8	9
.60	.648000	.649439	.650878	.652315	.653750	.655185	.656618	.658050	.659481	.660910
.61	.662338	.663765	.665190	.666614	.668037	.669458	.670878	.672297	.673714	.675130
.62	.676544	.677957	.679368	.680778	.682187	.683594	.684999	.686403	.687806	.689207
.63	.690606	.692004	.693400	.694795	.696188	.697579	.698969	.700357	.701744	.703129
.64	.704512	.705894	.707273	.708652	.710028	.711403	.712776	.714147	.715516	.716884
.65	.718250	.719614	.720976	.722337	.723695	.725052	.726407	.727760	.729111	.730461
.66	.731808	.733153	.734497	.735839	.737178	.738516	.739851	.741185	.742517	.743846
.67	.745174	.746500	.747823	.749145	.750464	.751781	.753096	.754410	.755720	.757029
.68	.758336	.759641	.760943	.762243	.763541	.764837	.766130	.767422	.768711	.769997
.69	.771282	.772563	.773843	.775121	.776396	.777669	.778940	.780208	.781474	.782739
.70	.784000	.785359	.786715	.788071	.789421	.790770	.792116	.793461	.794802	.796241
.71	.796478	.797712	.798944	.800173	.801399	.802623	.803845	.805063	.806280	.807493
.72	.808704	.809912	.811118	.812321	.813521	.814719	.815914	.817106	.818295	.819482
.73	.820666	.821847	.823026	.824201	.825374	.826544	.827711	.828876	.830037	.831196
.74	.832352	.833505	.834655	.835802	.836946	.838088	.839226	.840362	.841494	.842624
.75	.843750	.844873	.845994	.847111	.848226	.849337	.850446	.851551	.852653	.853752
.76	.854848	.855941	.857031	.858117	.859201	.860281	.861358	.862432	.863502	.864570
.77	.865634	.866695	.867753	.868807	.869858	.870906	.871951	.872992	.874030	.875065
.78	.876096	.877124	.878148	.879170	.880187	.881202	.882213	.883220	.884224	.885225
.79	.886222	.887216	.888206	.889192	.890176	.891155	.892131	.893104	.894073	.895038
.80	.896000	.896958	.897913	.898864	.899811	.900755	.901695	.902631	.903564	.904493
.81	.905418	.906340	.907257	.908171	.909082	.909988	.910891	.911790	.912685	.913576
.82	.914464	.915348	.916228	.917103	.917976	.918844	.919708	.920568	.921425	.922277
.83	.923126	.923971	.924811	.925648	.926481	.927309	.928134	.928954	.929771	.930584
.84	.931392	.932196	.932997	.933793	.934585	.935373	.936157	.936936	.937712	.938483
.85	.939250	.940013	.940772	.941526	.942276	.943022	.943764	.944501	.945235	.945963
.86	.946688	.947408	.948124	.948836	.949543	.950246	.950944	.951638	.952328	.953013
.87	.953694	.954370	.955042	.955710	.956373	.957031	.957685	.958335	.958980	.959620
.88	.960256	.960887	.961514	.962136	.962754	.963367	.963975	.964579	.965178	.965772
.89	.966362	.966947	.967527	.968103	.968674	.969240	.969802	.970358	.970910	.971458
.90	.972000	.972538	.973070	.973598	.974121	.974640	.975153	.975662	.976165	.976664
.91	.977158	.977647	.978131	.978610	.979084	.979553	.980017	.980477	.980931	.981380
.92	.981824	.982263	.982697	.983126	.983550	.983969	.984382	.984791	.985194	.985593
.93	.985986	.986374	.986757	.987135	.987507	.987874	.988236	.988593	.988945	.989291
.94	.989632	.989968	.990298	.990623	.990943	.991258	.991567	.991871	.992169	.992462
.95	.992750	.993032	.993309	.993581	.993847	.994107	.994362	.994612	.994856	.995095
.96	.995328	.995556	.995778	.995994	.996205	.996411	.996611	.996805	.996994	.997177
.97	.997354	.997526	.997692	.997852	.998007	.998156	.998300	.998437	.998569	.998696
.98	.998816	.998931	.999040	.999143	.999240	.999332	.999417	.999497	.999571	.999640
.99	.999702	.999758	.999809	.999854	.999892	.999925	.999952	.999973	.999988	.999997
1.00	1.000000									

## AREA OF SURFACES

(In Square Feet)

\*The area of straight flanges is not included in the figures of the table.

Outside Diameter of Vessel D inches	Cylindrical Shell per Lineal Foot ( $\pi \times D$ )	2:1 Ellipsoidal Head* ( $1.09 \times D^2$ )	ASME* Flanged and Dish Head ( $0.918 \times D^2$ )	Hemispherical Head* ( $1.5708 \times D^2$ )	Flat Head* ( $0.7854 \times D^2$ )
12	3.14	1.09	0.92	1.57	0.79
14	3.66	1.48	1.25	2.14	1.07
16	4.19	1.94	1.64	2.79	1.40
18	4.71	2.45	2.07	3.53	1.77
20	5.23	3.02	2.56	4.36	2.18
22	5.76	3.66	3.10	5.28	2.64
24	6.28	4.36	3.68	6.28	3.14
26	6.81	5.12	4.32	7.08	3.69
28	7.32	5.92	5.00	8.55	4.28
30	7.85	6.81	5.76	9.82	4.91
32	8.37	7.76	6.53	11.17	5.58
34	8.90	8.75	7.39	12.11	6.31
36	9.43	9.82	8.29	14.14	7.07
38	9.94	10.93	9.21	15.75	7.88
40	10.47	12.11	10.20	17.44	8.72
42	11.00	13.35	11.25	19.23	9.62
48	12.57	17.47	14.70	25.13	12.57
54	14.14	22.09	18.60	31.81	15.90
60	15.71	27.30	23.60	39.27	19.64
66	17.28	33.10	27.80	47.52	23.76
72	18.85	39.20	33.00	56.55	28.27
78	20.42	46.00	38.85	66.37	33.18
84	21.99	53.40	45.00	76.97	38.49
90	23.56	61.20	51.60	88.37	44.16
96	25.20	69.80	58.90	100.54	50.27
102	26.70	78.80	66.25	113.43	56.25
108	28.27	88.25	74.35	127.25	63.62
114	29.85	98.25	83.00	141.78	70.88
120	31.50	109.00	92.00	157.08	78.87
126	32.99	120.11	100.85	173.20	86.59
132	34.56	132.00	111.50	190.09	95.03
138	36.20	144.00	121.50	207.76	102.00
144	37.70	157.00	132.20	226.22	113.50



## DECIMALS OF AN INCH WITH MILLIMETER EQUIVALENTS

	Decimal	Milli- meter	Decimal	Milli- meter	Decimal	Milli- meter	Decimal	Milli- meter
$\frac{1}{16}$	.03125	.794	$\frac{3}{16}$	.1875	$\frac{1}{2}$	12.700	$\frac{5}{8}$	15.875
$\frac{1}{8}$	.0625	1.587	$\frac{1}{2}$	12.700	$\frac{3}{4}$	19.050	$\frac{7}{8}$	22.225
$\frac{3}{16}$	.09375	2.381	$\frac{5}{8}$	15.875	$\frac{1}{1}$	25.400		
$\frac{1}{4}$	.125	3.175	$\frac{3}{4}$	19.050				
$\frac{5}{16}$	.15625	3.969	$\frac{1}{1}$	25.400				
$\frac{3}{8}$	.1875	4.762						
$\frac{7}{16}$	.21875	5.556						
$\frac{1}{2}$	.25	6.350						

## DECIMALS OF A FOOT

INCHES										
In.	0	1	2	3	4	5	6	7	8	9
0	.0000	.0833	.1667	.2500	.3333	.4167	.5000	.5833	.6667	.7500
$\frac{1}{16}$	.0052	.0885	.1719	.2552	.3385	.4219	.5052	.5885	.6719	.7552
$\frac{1}{8}$	.0104	.0937	.1771	.2604	.3437	.4271	.5104	.5937	.6771	.7604
$\frac{3}{16}$	.0156	.0989	.1823	.2656	.3489	.4323	.5156	.5989	.6823	.7656
$\frac{1}{4}$	.0208	.1041	.1875	.2708	.3541	.4375	.5208	.6041	.6875	.7708
$\frac{5}{16}$	.0260	.1093	.1927	.2760	.3593	.4427	.5260	.6093	.6927	.7760
$\frac{3}{8}$	.0313	.1146	.1980	.2813	.3646	.4480	.5313	.6146	.6980	.7813
$\frac{7}{16}$	.0365	.1198	.2032	.2865	.3698	.4532	.5365	.6198	.7032	.7865
$\frac{1}{2}$	.0417	.1250	.2084	.2917	.3750	.4584	.5417	.6250	.7084	.7917
$\frac{9}{16}$	.0469	.1302	.2136	.2969	.3802	.4636	.5469	.6302	.7136	.7969
$\frac{5}{8}$	.0521	.1354	.2188	.3021	.3854	.4688	.5521	.6354	.7188	.8021
$\frac{11}{16}$	.0573	.1406	.2240	.3073	.3906	.4740	.5573	.6406	.7240	.8073
$\frac{3}{4}$	.0625	.1458	.2292	.3125	.3958	.4792	.5625	.6458	.7292	.8125
$\frac{13}{16}$	.0677	.1510	.2344	.3177	.4010	.4844	.5677	.6510	.7344	.8177
$\frac{7}{8}$	.0729	.1562	.2396	.3229	.4062	.4896	.5729	.6562	.7396	.8229
$\frac{15}{16}$	.0781	.1614	.2448	.3281	.4114	.4948	.5781	.6614	.7448	.8281
										.9114
										.9948

## METRIC SYSTEM OF MEASUREMENT

This system has the advantage that it is a coherent system. Each quantity has only one unit and all base units are related to each other. The fractions and multiples of the units are made in the decimal system.

### UNITS OF METRIC MEASURES

	unit	symbol	equivalent of
Length	meter	m	39.37 in
Area	meter <sup>2</sup>	m <sup>2</sup>	1.196 sq. yard
Volume	meter <sup>3</sup>	m <sup>3</sup>	1.310 cu. yard
Weight /mass/	gram	g	0.035 oz
Time	second	s	second
Temperature	degree Celsius	°C	0°C = 32°F 100°C = 212°F

### MULTIPLES AND FRACTIONS OF UNITS

Symbol	Prefix	Unit Multiplied by	Name
$\mu$	mikro	10 <sup>-6</sup>	millionth
m	milli	10 <sup>-3</sup>	thousandth
c	centi	10 <sup>-2</sup>	hundredth
d	deci	10 <sup>-1</sup>	tenth
D	deka	10	ten
h	hecto	10 <sup>2</sup>	hundred
k	kilo	10 <sup>3</sup>	thousand
M	mega	10 <sup>6</sup>	million

EXAMPLE: Unit of weight is gram; 1000 gram is one kilogram, 1 kg

1,000m = 1 kilometer, km

MULTIPLES  
OF UNIT

MEASURES OF LENGTH  
UNIT: METER, m

### FRACTIONS OF UNIT

- \*1 decimeter, dm = 0.1m
- 1 centimeter, cm = 0.01 m
- 1 millimeter, mm = 0.001 m

\*not used in practice



## METRIC SYSTEM OF MEASUREMENT

1,000,000 m<sup>2</sup> = 1 sq. kilometer, km<sup>2</sup>  
 10,000 m<sup>2</sup> = 1 sq. hectare, ha  
 100 m<sup>2</sup> = 1 sq. are, a \*

MULTIPLES  
OF UNIT

MEASURES OF AREA  
 UNIT: SQUARE METER, m<sup>2</sup>

\*1 sq. decimeter, dm<sup>2</sup> = 0.01m<sup>2</sup>  
 1 sq. centimeter, cm<sup>2</sup> = 0.0001m<sup>2</sup>  
 1 sq. millimeter, mm<sup>2</sup> = 0.000,001m<sup>2</sup>

\*not used in practice

FRACTIONS  
OF UNIT

not used in practice

MULTIPLES  
OF UNIT

MEASURES OF VOLUME  
 UNIT: CUBIC METER, m<sup>3</sup>

1 hectoliter, hl = 0.1m<sup>3</sup>  
 1 liter, l = 0.001m<sup>3</sup>  
 1 cu. centimeter = 0.000,001m<sup>3</sup>  
 1 cu. millimeter = 0.000,000,001m<sup>3</sup>

FRACTIONS  
OF UNIT

1,000,000 g = 1 ton, t  
 100,000 g = 1 quintal, q  
 1,000 g = 1 kilogram, kg  
 10 g = 1 dekagram, dg

MULTIPLES  
OF UNIT

MEASURES OF WEIGHT

UNIT: GRAM, g

centigram, cg = 0.01 g  
 milligram, mg = 0.001 g

FRACTIONS  
OF UNIT

## METRIC SYSTEM OF MEASUREMENT

## MEASURES OF LENGTH

	km	m	dm	cm	mm	$\mu$	m $\mu$
1 km	1	10 <sup>3</sup>	10 <sup>4</sup>	10 <sup>5</sup>	10 <sup>6</sup>	10 <sup>9</sup>	10 <sup>12</sup>
1 m	10 <sup>-3</sup>	1	10	10 <sup>2</sup>	10 <sup>3</sup>	10 <sup>6</sup>	10 <sup>9</sup>
1 dm*	10 <sup>-4</sup>	10 <sup>-1</sup>	1	10	10 <sup>2</sup>	10 <sup>5</sup>	10 <sup>8</sup>
1 cm	10 <sup>-5</sup>	10 <sup>-2</sup>	10 <sup>-1</sup>	1	10	10 <sup>4</sup>	10 <sup>7</sup>
1 mm	10 <sup>-6</sup>	10 <sup>-3</sup>	10 <sup>-2</sup>	10 <sup>-1</sup>	1	10 <sup>3</sup>	10 <sup>6</sup>
1 $\mu$	10 <sup>-9</sup>	10 <sup>-6</sup>	10 <sup>-5</sup>	10 <sup>-4</sup>	10 <sup>-3</sup>	1	10 <sup>3</sup>
1 m $\mu$	10 <sup>-12</sup>	10 <sup>-9</sup>	10 <sup>-8</sup>	10 <sup>-7</sup>	10 <sup>-6</sup>	10 <sup>-3</sup>	1

## MEASURES OF AREA

	km <sup>2</sup>	ha	a	m <sup>2</sup>	dm <sup>2</sup>	cm <sup>2</sup>	mm <sup>2</sup>
1 km <sup>2</sup>	1	10 <sup>2</sup>	10 <sup>4</sup>	10 <sup>6</sup>	10 <sup>8</sup>	10 <sup>10</sup>	10 <sup>12</sup>
1 ha	10 <sup>-2</sup>	1	10 <sup>2</sup>	10 <sup>4</sup>	10 <sup>6</sup>	10 <sup>8</sup>	10 <sup>10</sup>
1 a	10 <sup>-4</sup>	10 <sup>-2</sup>	1	10 <sup>2</sup>	10 <sup>4</sup>	10 <sup>6</sup>	10 <sup>8</sup>
1 m <sup>2</sup>	10 <sup>-6</sup>	10 <sup>-4</sup>	10 <sup>-2</sup>	1	10 <sup>2</sup>	10 <sup>4</sup>	10 <sup>6</sup>
1 dm <sup>2</sup>	10 <sup>-8</sup>	10 <sup>-6</sup>	10 <sup>-4</sup>	10 <sup>-2</sup>	1	10 <sup>2</sup>	10 <sup>4</sup>
1 cm <sup>2</sup>	10 <sup>-10</sup>	10 <sup>-8</sup>	10 <sup>-6</sup>	10 <sup>-4</sup>	10 <sup>-2</sup>	1	10 <sup>2</sup>
1 mm <sup>2</sup>	10 <sup>-12</sup>	10 <sup>-10</sup>	10 <sup>-8</sup>	10 <sup>-6</sup>	10 <sup>-4</sup>	10 <sup>-2</sup>	1

## MEASURES OF VOLUME

	m <sup>3</sup>	hl	l	dm <sup>3</sup>	cm <sup>3</sup>	mm <sup>3</sup>
1 m <sup>3</sup>	1	10	10 <sup>3</sup>	10 <sup>3</sup>	10 <sup>6</sup>	10 <sup>9</sup>
1 hl	10 <sup>-1</sup>	1	10 <sup>2</sup>	10 <sup>2</sup>	10 <sup>5</sup>	10 <sup>8</sup>
1 l	10 <sup>-3</sup>	10 <sup>-2</sup>	1	1	10 <sup>3</sup>	10 <sup>6</sup>
1 dm <sup>3</sup>	10 <sup>-3</sup>	10 <sup>-2</sup>	1	1	10 <sup>3</sup>	10 <sup>6</sup>
1 cm <sup>3</sup>	10 <sup>-6</sup>	10 <sup>-5</sup>	10 <sup>-3</sup>	10 <sup>-3</sup>	1	10 <sup>3</sup>
1 mm <sup>3</sup>	10 <sup>-9</sup>	10 <sup>-8</sup>	10 <sup>-6</sup>	10 <sup>-6</sup>	10 <sup>-3</sup>	1

## MEASURES OF WEIGHT

	t	q	kg	dg	g	cg	mg
1 t	1	10	10 <sup>3</sup>	10 <sup>5</sup>	10 <sup>6</sup>	10 <sup>8</sup>	10 <sup>9</sup>
1 q	10 <sup>-1</sup>	1	10 <sup>2</sup>	10 <sup>4</sup>	10 <sup>5</sup>	10 <sup>7</sup>	10 <sup>8</sup>
1 kg	10 <sup>-3</sup>	10 <sup>-2</sup>	1	10 <sup>2</sup>	10 <sup>3</sup>	10 <sup>5</sup>	10 <sup>6</sup>
1 dg	10 <sup>-5</sup>	10 <sup>-4</sup>	10 <sup>-2</sup>	1	10	10 <sup>3</sup>	10 <sup>4</sup>
1 g	10 <sup>-6</sup>	10 <sup>-5</sup>	10 <sup>-3</sup>	10 <sup>-1</sup>	1	10 <sup>2</sup>	10 <sup>3</sup>
1 cg	10 <sup>-8</sup>	10 <sup>-7</sup>	10 <sup>-5</sup>	10 <sup>-3</sup>	10 <sup>-2</sup>	1	10
1 mg	10 <sup>-9</sup>	10 <sup>-8</sup>	10 <sup>-6</sup>	10 <sup>-4</sup>	10 <sup>-3</sup>	10 <sup>-1</sup>	1

## EXAMPLE CALCULATION

Weight of the water in a cylindrical vessel of 2,000 mm inside diameter and 10,000 mm length:  $3.1416 \times 1,000^2 \times 10,000 = 31,416,000,000 \text{ mm}^3$

(The weight of one liter of pure water at the maximum density (4°C) equals one kilogram.)

31,416 liter, l  
 31,416 cu. meter, m  
 31416 kilogram, kg



## METRIC SYSTEM OF MEASUREMENT

## RECOMMENDED PRESSURE VESSEL DIAMETERS

Diameter in inches	Diameter in millimeters	Diameter in inches	Diameter in millimeters
24-30	630	66-72	1,600
36	800	78-90	2,000
42-48	1,000	96-120	2,500
54-60	1,250	126-156	3,150

## RECOMMENDED TANK DIAMETERS

Diameters in API feet	Diameters in meters	Diameters in API feet	Diameters in meters
10	3.15	70-80	20.00
15	4.00	90-100	25.00
20	5.00	120	31.50
25	6.30	140-163	40.00
30	8.00	180-200	50.00
35-40	10.00	220-240	63.00
45-50	12.50	260-300	80.00
60	16.00		

The recommended diameters are based on a geometric progression, called Renard Series (R10) of Preferred Numbers. \*

Dimensions on drawings shall be expressed in millimeters. The symbol for millimeters, *mm* (no period) need not be shown on the drawings. However, the following note shall be shown on the drawings: ALL DIMENSIONS ARE IN MILLIMETERS.

Dimensions above 5 digits in millimeters may be expressed in meters (e.g. 110.75 m)

*Scales of Metric Drawings:* enlarging the object, 2, 5, 10, 20 times reducing the object in proportion of 1:2.5, 1:5, 1:10, 1:20, 1:50, 1:100, 1:200, 1:500, 1:1000

\* Reference: *Making it with Metric*, The National Board of Boiler and Pressure Vessel Inspectors.

CONVERSION TABLE – LENGTH  
INCHES TO MILLIMETERS  
(1 Inch = 25.4 Millimeters)

IN.	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
0	0.0	1.6	3.2	4.8	6.4	7.9	9.5	11.1	12.7	14.3	15.9	17.5	19.1	20.6	22.2	23.8
1	25.4	27.0	28.6	30.2	31.8	33.3	34.9	36.5	38.1	39.7	41.3	42.9	44.5	46.0	47.6	49.2
2	50.8	52.4	54.0	55.6	57.2	58.7	60.3	61.9	63.5	65.1	66.7	68.3	69.9	71.4	73.0	74.6
3	76.2	77.8	79.4	81.0	82.6	84.1	85.7	87.3	88.9	90.5	92.1	93.7	95.3	96.8	98.4	100.0
4	101.6	103.2	104.8	106.4	108.0	109.5	111.1	112.7	114.3	115.9	117.5	119.1	120.7	122.2	123.8	125.4
5	127.0	128.6	130.2	131.8	133.4	134.9	136.5	138.1	139.7	141.3	142.9	144.5	146.1	147.6	149.2	150.8
6	152.4	154.0	155.6	157.2	158.8	160.3	161.9	163.5	165.1	166.7	168.3	169.9	171.5	173.0	174.6	176.2
7	177.8	179.4	181.0	182.6	184.2	185.7	187.3	188.9	190.5	192.1	193.7	195.3	196.9	198.4	200.0	201.6
8	203.2	204.8	206.4	208.0	209.6	211.1	212.7	214.3	215.9	217.5	219.1	220.7	222.3	223.8	225.4	227.0
9	228.6	230.2	231.8	233.4	235.0	236.5	238.1	239.7	241.3	242.9	244.5	246.1	247.7	249.2	250.8	252.4
10	254.0	255.6	257.2	258.8	260.4	261.9	263.5	265.1	266.7	268.3	269.9	271.5	273.1	274.6	276.2	277.8
11	279.4	281.0	282.6	284.2	285.8	287.3	288.9	290.5	292.1	293.7	295.3	296.9	298.5	300.0	301.6	303.2
12	304.8	306.4	308.0	309.6	311.2	312.7	314.3	315.9	317.5	319.1	320.7	322.3	323.9	325.4	327.0	328.6
13	330.2	331.8	333.4	335.0	336.6	338.1	339.7	341.3	342.9	344.5	346.1	347.7	349.3	350.8	352.4	354.0
14	355.6	357.2	358.8	360.4	362.0	363.5	365.1	366.7	368.3	369.9	371.5	373.1	374.7	376.2	377.8	379.4
15	381.0	382.6	384.2	385.8	387.4	388.9	390.5	392.1	393.7	395.3	396.9	398.5	400.1	401.6	403.2	404.8
16	406.4	408.0	409.6	411.2	412.8	414.3	415.9	417.5	419.1	420.7	422.3	423.9	425.5	427.0	428.6	430.2
17	431.8	433.4	435.0	436.6	438.2	439.7	441.3	442.9	444.5	446.1	447.7	449.3	450.9	452.4	454.0	455.6
18	457.2	458.8	460.4	462.0	463.6	465.1	466.7	468.3	469.9	471.5	473.1	474.7	476.3	477.8	479.4	481.0
19	482.6	484.2	485.8	487.4	489.0	490.5	492.1	493.7	495.3	496.9	498.5	500.1	501.7	503.2	504.8	506.4
20	508.0	509.6	511.2	512.8	514.4	515.9	517.5	519.1	520.7	522.3	523.9	525.5	527.1	528.6	530.2	531.8
21	533.4	535.0	536.6	538.2	539.8	541.3	542.9	544.5	546.1	547.7	549.3	550.9	552.5	554.0	555.6	557.2
22	558.8	560.4	562.0	563.6	565.2	566.7	568.3	569.9	571.5	573.1	574.7	576.3	577.9	579.4	581.0	582.6
23	584.2	585.8	587.4	589.0	590.6	592.1	593.7	595.3	596.9	598.5	600.1	601.7	603.3	604.8	606.4	608.0
24	609.6	611.2	612.8	614.4	616.0	617.5	619.1	620.7	622.3	623.9	625.5	627.1	628.7	630.2	631.8	633.4



## INCHES TO MILLIMETERS (con't.)

IN.	0	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16
25	635.0	636.6	638.2	639.8	641.4	642.9	644.5	646.1	647.7	649.3	650.9	652.5	654.1	655.6	657.2	658.8
26	660.4	662.0	663.6	665.2	666.8	668.3	669.9	671.5	673.1	674.7	676.3	677.9	679.5	681.0	682.6	684.2
27	685.8	687.4	689.0	690.6	692.2	693.7	695.3	696.9	698.5	700.1	701.7	703.3	704.9	706.4	708.0	709.6
28	711.2	712.8	714.4	716.0	717.6	719.1	720.7	722.3	723.9	725.5	727.1	728.7	730.3	731.8	733.4	735.0
29	736.6	738.2	739.8	741.4	743.0	744.5	746.1	747.7	749.3	750.9	752.5	754.1	755.7	757.2	758.8	760.4
30	762.0	763.6	765.2	766.8	768.4	769.9	771.5	773.1	774.7	776.3	777.9	779.5	781.1	782.6	784.2	785.8
31	787.4	789.0	790.6	792.2	793.8	795.3	796.9	798.5	800.1	801.7	803.3	804.9	806.5	808.0	809.6	811.2
32	812.8	814.4	816.0	817.6	819.2	820.7	822.3	823.9	825.5	827.1	828.7	830.3	831.9	833.4	835.0	836.6
33	838.2	839.8	841.4	843.0	844.6	846.1	847.7	849.3	850.9	852.5	854.1	855.7	857.3	858.8	860.4	862.0
34	863.6	865.2	866.8	868.4	870.0	871.5	873.1	874.7	876.3	877.9	879.5	881.1	882.7	884.2	885.8	887.4
35	889.0	890.6	892.2	893.8	895.4	896.9	898.5	900.1	901.7	903.3	904.9	906.5	908.1	909.6	911.2	912.8
36	914.4	916.0	917.6	919.2	920.8	922.3	923.9	925.5	927.1	928.7	930.3	931.9	933.5	935.0	936.6	938.2
37	939.8	941.4	943.0	944.6	946.2	947.7	949.3	950.9	952.5	954.1	955.7	957.3	958.9	960.4	962.0	963.6
38	965.2	966.8	968.4	970.0	971.6	973.1	974.7	976.3	977.9	979.5	981.1	982.7	984.3	985.8	987.4	989.0
39	990.6	992.2	993.8	995.4	997.0	998.5	1000.1	1001.7	1003.3	1004.9	1006.5	1008.1	1009.7	1011.2	1012.8	1014.4
40	1016.0	1017.6	1019.2	1020.8	1022.4	1023.9	1025.5	1027.1	1028.7	1030.3	1031.9	1033.5	1035.1	1036.6	1038.2	1039.8
41	1041.4	1043.0	1044.6	1046.2	1047.8	1049.3	1050.9	1052.5	1054.1	1055.7	1057.3	1058.9	1060.5	1062.0	1063.6	1065.2
42	1066.8	1068.4	1070.0	1071.6	1073.2	1074.7	1076.3	1077.9	1079.5	1081.1	1082.7	1084.3	1085.9	1087.4	1089.0	1090.6
43	1092.2	1093.8	1095.4	1097.0	1098.6	1100.1	1101.7	1103.3	1104.9	1106.5	1108.1	1109.7	1111.3	1112.8	1114.4	1116.0
44	1117.6	1119.2	1120.8	1122.4	1124.0	1125.5	1127.1	1128.7	1130.3	1131.9	1133.5	1135.1	1136.7	1138.2	1139.8	1141.4
45	1143.0	1144.6	1146.2	1147.8	1149.4	1150.9	1152.5	1154.1	1155.7	1157.3	1158.9	1160.5	1162.1	1163.6	1165.2	1166.8
46	1166.4	1168.0	1169.6	1171.2	1172.8	1174.3	1175.9	1177.5	1179.1	1180.7	1182.3	1183.9	1185.5	1187.1	1188.7	1190.3
47	1193.8	1195.4	1197.0	1198.6	1200.2	1201.7	1203.3	1204.9	1206.5	1208.1	1209.7	1211.3	1212.9	1214.4	1216.0	1217.6
48	1219.2	1220.8	1222.4	1224.0	1225.6	1227.1	1228.7	1230.3	1231.9	1233.5	1235.1	1236.7	1238.3	1239.8	1241.4	1243.0
49	1244.6	1246.2	1247.8	1249.4	1251.0	1252.5	1254.1	1255.7	1257.3	1258.9	1260.5	1262.1	1263.7	1265.2	1266.8	1268.4
50	1270.0	1271.6	1273.2	1274.8	1276.4	1277.9	1279.5	1281.1	1282.7	1284.3	1285.9	1287.5	1289.1	1290.6	1292.2	1293.8

CONVERSION TABLE -- LENGTH  
MILLIMETERS TO INCHES  
(1 Millimeter = 0.0394 Inch)

Millimeters	0	1	2	3	4	5	6	7	8	9	Millimeters
0	0.00	0.039	0.079	0.118	0.157	0.197	0.236	0.276	0.315	0.354	0
10	0.39	0.43	0.47	0.51	0.55	0.59	0.63	0.67	0.71	0.75	10
20	0.79	0.83	0.87	0.91	0.94	0.98	1.02	1.06	1.10	1.14	20
30	1.18	1.22	1.26	1.30	1.34	1.38	1.42	1.46	1.50	1.54	30
40	1.57	1.61	1.65	1.69	1.73	1.77	1.81	1.85	1.89	1.93	40
50	1.97	2.01	2.05	2.09	2.13	2.17	2.20	2.24	2.28	2.32	50
60	2.36	2.40	2.44	2.48	2.52	2.56	2.60	2.64	2.68	2.72	60
70	2.76	2.80	2.83	2.87	2.91	2.95	2.99	3.03	3.07	3.11	70
80	3.15	3.19	3.23	3.27	3.31	3.35	3.39	3.43	3.46	3.50	80
90	3.54	3.58	3.62	3.66	3.70	3.74	3.78	3.82	3.86	3.90	90
100	3.94	3.98	4.02	4.06	4.09	4.13	4.17	4.21	4.25	4.29	100
110	4.33	4.37	4.41	4.45	4.49	4.53	4.57	4.61	4.65	4.69	110
120	4.72	4.76	4.80	4.84	4.88	4.92	4.96	5.00	5.04	5.08	120
130	5.12	5.16	5.20	5.24	5.28	5.31	5.35	5.39	5.43	5.47	130
140	5.51	5.55	5.59	5.63	5.67	5.71	5.75	5.79	5.83	5.87	140
150	5.91	5.94	5.98	6.02	6.06	6.10	6.14	6.18	6.22	6.26	150
160	6.30	6.34	6.38	6.42	6.46	6.50	6.54	6.57	6.61	6.65	160
170	6.69	6.73	6.77	6.81	6.85	6.89	6.93	6.97	7.01	7.05	170
180	7.09	7.13	7.17	7.20	7.24	7.28	7.32	7.36	7.40	7.44	180
190	7.48	7.52	7.56	7.60	7.64	7.68	7.72	7.76	7.80	7.83	190
200	7.87	7.91	7.95	7.99	8.03	8.07	8.11	8.15	8.19	8.23	200
210	8.27	8.31	8.35	8.39	8.43	8.46	8.50	8.54	8.58	8.62	210
220	8.66	8.70	8.74	8.78	8.82	8.86	8.90	8.94	8.98	9.02	220
230	9.06	9.09	9.13	9.17	9.21	9.25	9.29	9.33	9.37	9.41	230
240	9.45	9.49	9.53	9.57	9.61	9.65	9.69	9.72	9.76	9.80	240
250	9.84	9.88	9.92	9.96	10.00	10.04	10.08	10.12	10.16	10.20	250
260	10.24	10.28	10.31	10.35	10.39	10.43	10.47	10.51	10.55	10.59	260
270	10.63	10.67	10.71	10.75	10.79	10.83	10.87	10.91	10.94	10.98	270
280	11.02	11.06	11.10	11.14	11.18	11.22	11.26	11.30	11.34	11.38	280
290	11.42	11.46	11.50	11.54	11.57	11.61	11.65	11.69	11.73	11.77	290

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MEASURES



## MILLIMETERS TO INCHES (con't.)

Millimeters	0	1	2	3	4	5	6	7	8	9	Millimeters
300	11.81	11.85	11.89	11.93	11.97	12.01	12.05	12.09	12.13	12.17	300
310	12.20	12.24	12.28	12.32	12.36	12.40	12.44	12.48	12.52	12.56	310
320	12.60	12.64	12.68	12.72	12.76	12.80	12.83	12.87	12.91	12.95	320
330	12.99	13.03	13.07	13.11	13.15	13.19	13.23	13.27	13.31	13.35	330
340	13.39	13.43	13.46	13.50	13.54	13.58	13.62	13.66	13.70	13.74	340
350	13.78	13.82	13.86	13.90	13.94	13.98	14.02	14.06	14.09	14.13	350
360	14.17	14.21	14.25	14.29	14.33	14.37	14.41	14.45	14.49	14.53	360
370	14.57	14.61	14.65	14.69	14.72	14.76	14.80	14.84	14.88	14.92	370
380	14.96	15.00	15.04	15.08	15.12	15.16	15.20	15.24	15.28	15.31	380
390	15.35	15.39	15.43	15.47	15.51	15.55	15.59	15.63	15.67	15.71	390
400	15.75	15.79	15.83	15.87	15.91	15.94	15.98	16.02	16.06	16.10	400
410	16.14	16.18	16.22	16.26	16.30	16.34	16.38	16.42	16.46	16.50	410
420	16.54	16.57	16.61	16.65	16.69	16.73	16.77	16.81	16.85	16.89	420
430	16.93	16.97	17.01	17.05	17.09	17.13	17.17	17.20	17.24	17.28	430
440	17.32	17.36	17.40	17.44	17.48	17.52	17.56	17.60	17.64	17.68	440
450	17.72	17.76	17.80	17.83	17.87	17.91	17.95	17.99	18.03	18.07	450
460	18.11	18.15	18.19	18.23	18.27	18.31	18.35	18.39	18.43	18.46	460
470	18.50	18.54	18.58	18.62	18.66	18.70	18.74	18.78	18.82	18.86	470
480	18.90	18.94	18.98	19.02	19.06	19.09	19.13	19.17	19.21	19.25	480
490	19.29	19.33	19.37	19.41	19.45	19.49	19.53	19.57	19.61	19.65	490
500	19.69	19.72	19.76	19.80	19.84	19.88	19.92	19.96	20.00	20.04	500
510	20.08	20.12	20.16	20.20	20.24	20.28	20.31	20.35	20.39	20.43	510
520	20.47	20.51	20.55	20.59	20.63	20.67	20.71	20.75	20.79	20.83	520
530	20.87	20.91	20.94	20.98	21.02	21.06	21.10	21.14	21.18	21.22	530
540	21.26	21.30	21.34	21.38	21.42	21.46	21.50	21.54	21.58	21.61	540
550	21.65	21.69	21.73	21.77	21.81	21.85	21.89	21.93	21.97	22.01	550
560	22.05	22.09	22.13	22.17	22.20	22.24	22.28	22.32	22.36	22.40	560
570	22.44	22.48	22.52	22.56	22.60	22.64	22.68	22.72	22.76	22.80	570
580	22.83	22.87	22.91	22.95	22.99	23.03	23.07	23.11	23.15	23.19	580
590	23.23	23.27	23.31	23.35	23.39	23.43	23.46	23.50	23.54	23.58	590

## MILLIMETERS TO INCHES (con't.)

Millimeters	0	1	2	3	4	5	6	7	8	9	Millimeters
600	23.62	23.66	23.70	23.74	23.78	23.82	23.86	23.90	23.94	23.98	600
610	24.02	24.06	24.09	24.13	24.17	24.21	24.25	24.29	24.33	24.37	610
620	24.41	24.45	24.49	24.53	24.57	24.61	24.65	24.68	24.72	24.76	620
630	24.80	24.84	24.88	24.92	24.96	25.00	25.04	25.08	25.12	25.16	630
640	25.20	25.24	25.28	25.31	25.35	25.39	25.43	25.47	25.51	25.55	640
650	25.59	25.63	25.67	25.71	25.75	25.79	25.83	25.87	25.91	25.94	650
660	25.98	26.02	26.06	26.10	26.14	26.18	26.22	26.26	26.30	26.34	660
670	26.38	26.42	26.46	26.50	26.54	26.57	26.61	26.65	26.69	26.73	670
680	26.77	26.81	26.85	26.89	26.93	26.97	27.01	27.05	27.09	27.13	680
690	27.17	27.20	27.24	27.28	27.32	27.36	27.40	27.44	27.48	27.52	690
700	27.56	27.60	27.64	27.68	27.72	27.76	27.80	27.83	27.87	27.91	700
710	27.95	27.99	28.03	28.07	28.11	28.15	28.19	28.23	28.27	28.31	710
720	28.35	28.39	28.43	28.46	28.50	28.54	28.58	28.62	28.66	28.70	720
730	28.74	28.78	28.82	28.86	28.90	28.94	28.98	29.02	29.06	29.09	730
740	29.13	29.17	29.21	29.25	29.29	29.33	29.37	29.41	29.45	29.49	740
750	29.53	29.57	29.61	29.65	29.68	29.72	29.76	29.80	29.84	29.88	750
760	29.92	29.96	30.00	30.04	30.08	30.12	30.16	30.20	30.24	30.28	760
770	30.31	30.35	30.39	30.43	30.47	30.51	30.55	30.59	30.63	30.67	770
780	30.71	30.75	30.79	30.83	30.87	30.91	30.94	30.98	31.02	31.06	780
790	31.10	31.14	31.18	31.22	31.26	31.30	31.34	31.38	31.42	31.46	790
800	31.50	31.54	31.57	31.61	31.65	31.69	31.73	31.77	31.81	31.85	800
810	31.89	31.93	31.97	32.01	32.05	32.09	32.13	32.17	32.20	32.24	810
820	32.28	32.32	32.36	32.40	32.44	32.48	32.52	32.56	32.60	32.64	820
830	32.68	32.72	32.76	32.80	32.83	32.87	32.91	32.95	32.99	33.03	830
840	33.07	33.11	33.15	33.19	33.23	33.27	33.31	33.35	33.39	33.43	840
850	33.46	33.50	33.54	33.58	33.62	33.66	33.70	33.74	33.78	33.82	850
860	33.86	33.90	33.94	33.98	34.02	34.06	34.09	34.13	34.17	34.21	860
870	34.25	34.29	34.33	34.37	34.41	34.45	34.49	34.53	34.57	34.61	870
880	34.65	34.68	34.72	34.76	34.80	34.84	34.88	34.92	34.96	35.00	880
890	35.04	35.08	35.12	35.16	35.20	35.24	35.28	35.31	35.35	35.39	890



## MILLIMETERS TO INCHES (con't.)

Millimeters	0	1	2	3	4	5	6	7	8	9	Millimeters
900	35.43	35.47	35.51	35.55	35.59	35.63	35.67	35.71	35.75	35.79	900
910	35.83	35.87	35.91	35.94	35.98	36.02	36.06	36.10	36.14	36.18	910
920	36.22	36.26	36.30	36.34	36.38	36.42	36.46	36.50	36.54	36.57	920
930	36.61	36.65	36.69	36.73	36.77	36.81	36.85	36.89	36.93	36.97	930
940	37.01	37.05	37.09	37.13	37.17	37.20	37.24	37.28	37.32	37.36	940
950	37.40	37.44	37.48	37.52	37.56	37.60	37.64	37.68	37.72	37.76	950
960	37.80	37.83	37.87	37.91	37.95	37.99	38.03	38.07	38.11	38.15	960
970	38.19	38.23	38.27	38.31	38.35	38.39	38.43	38.46	38.50	38.54	970
980	38.58	38.62	38.66	38.70	38.74	38.78	38.82	38.86	38.90	38.94	980
990	38.98	39.02	39.06	39.09	39.13	39.17	39.21	39.25	39.29	39.33	990
1000	39.37	39.41	39.45	39.49	39.53	39.57	39.61	39.65	39.68	39.72	1000

## SQUARE FEET TO SQUARE METERS

1 Sq. Ft. = 0.0929034

Square Meters

Square Feet	0	1	2	3	4	5	6	7	8	9
0	0.000	0.093	0.186	0.279	0.372	0.465	0.557	0.650	0.743	0.836
10	0.929	1.022	1.115	1.208	1.301	1.394	1.486	1.579	1.672	1.765
20	1.858	1.951	2.044	2.137	2.230	2.323	2.415	2.508	2.601	2.694
30	2.787	2.880	2.973	3.066	3.159	3.252	3.345	3.437	3.530	3.623
40	3.716	3.809	3.902	3.995	4.088	4.181	4.274	4.366	4.459	4.552
50	4.645	4.738	4.831	4.924	5.017	5.110	5.203	5.295	5.388	5.481
60	5.574	5.667	5.760	5.853	5.946	6.039	6.132	6.225	6.317	6.410
70	6.503	6.596	6.689	6.782	6.875	6.968	7.061	7.154	7.246	7.339
80	7.432	7.525	7.618	7.711	7.804	7.897	7.990	8.083	8.175	8.268
90	8.361	8.454	8.547	8.640	8.733	8.826	8.919	9.012	9.105	9.197

## SQUARE METERS TO SQUARE FEET

1 Sq. M = 10.76387

Square Feet

Square Meters	0	1	2	3	4	5	6	7	8	9
0	0.00	10.76	21.53	32.29	43.06	53.82	64.58	75.35	86.11	96.87
10	107.64	118.40	129.17	139.93	150.69	161.46	172.22	182.99	193.75	204.51
20	215.28	226.04	236.81	247.57	258.33	269.10	279.86	290.62	301.39	312.15
30	322.92	333.68	344.44	355.21	365.97	376.74	387.50	398.26	409.03	419.79
40	430.56	441.32	452.08	462.85	473.61	484.37	495.14	505.90	516.67	527.43
50	538.19	548.96	559.72	570.49	581.25	592.01	602.78	613.54	624.30	635.07
60	645.83	656.60	667.36	678.12	688.89	699.65	710.42	721.18	731.94	742.71
70	753.47	764.23	775.00	785.76	796.53	807.29	818.05	828.82	839.58	850.35
80	861.11	871.87	882.64	893.40	904.17	914.93	925.69	936.46	947.22	957.98
90	968.75	979.51	990.28	1001.04	1011.80	1022.57	1033.33	1044.10	1054.86	1065.62



## CONVERSION TABLE – WEIGHTS

## POUNDS TO KILOGRAMS

(1 pound = 0.4536 kilogram)

Pounds	0	1	2	3	4	5	6	7	8	9
0	0.00	0.45	0.91	1.36	1.81	2.27	2.72	3.18	3.63	4.08
10	4.54	4.99	5.44	5.90	6.35	6.80	7.26	7.71	8.16	8.62
20	9.07	9.53	9.98	10.43	10.89	11.34	11.79	12.25	12.70	13.15
30	13.61	14.06	14.52	14.97	15.42	15.88	16.33	16.78	17.24	17.69
40	18.14	18.60	19.05	19.50	19.96	20.41	20.87	21.32	21.77	22.23
50	22.68	23.13	23.59	24.04	24.49	24.95	25.40	25.86	26.31	26.76
60	27.22	27.67	28.12	28.58	29.03	29.48	29.94	30.39	30.84	31.30
70	31.75	32.21	32.66	33.11	33.57	34.02	34.47	34.93	35.38	35.83
80	36.29	36.74	37.20	37.65	38.10	38.56	39.01	39.46	39.92	40.37
90	40.82	41.28	41.73	42.18	42.64	43.09	43.55	44.00	44.45	44.91

## KILOGRAMS TO POUNDS

(1 kilogram = 2.2046 pounds)

Kilograms	0	1	2	3	4	5	6	7	8	9
0	0.00	2.20	4.41	6.61	8.82	11.02	13.23	15.43	17.64	19.84
10	22.05	24.25	26.46	28.66	30.86	33.07	35.27	37.48	39.68	41.89
20	44.09	46.30	48.50	50.71	52.91	55.12	57.32	59.52	61.73	63.93
30	66.14	68.34	70.55	72.75	74.96	77.16	79.37	81.57	83.77	85.98
40	88.18	90.39	92.59	94.80	97.00	99.21	101.41	103.62	105.82	108.03
50	110.23	112.43	114.64	116.84	119.05	121.25	123.46	125.66	127.87	130.07
60	132.28	134.48	136.69	138.89	141.09	143.30	145.50	147.71	149.91	152.12
70	154.32	156.53	158.73	160.94	163.14	165.35	167.55	169.75	171.96	174.16
80	176.37	178.57	180.78	182.98	185.19	187.39	189.60	191.80	194.00	196.21
90	198.41	200.62	202.82	205.03	207.23	209.44	211.64	213.85	216.05	218.26

## U. S. GALLONS TO LITERS

1 U. S. Gallon = 3.785329 Liter

Gallon	0	1	2	3	4	5	6	7	8	9
0	0	3.79	7.57	11.36	15.14	18.93	22.71	26.50	30.28	34.07
10	37.85	41.64	45.42	49.21	52.99	56.78	60.57	64.35	68.14	71.92
20	75.71	79.49	83.28	87.01	90.85	94.63	98.42	102.20	105.99	109.77
30	113.56	117.35	121.13	124.92	128.70	132.49	136.27	140.06	143.84	147.63
40	151.41	155.20	158.98	162.77	166.55	170.34	174.13	177.91	181.70	185.48
50	189.27	193.05	196.84	200.62	204.41	208.19	211.98	215.76	219.55	223.33
60	227.12	230.91	234.69	238.48	242.26	246.05	249.83	253.62	257.40	261.19
70	264.97	268.76	272.54	276.33	280.11	283.90	287.69	291.47	295.26	299.04
80	302.83	306.61	310.40	314.18	317.97	321.75	325.54	329.32	333.11	336.89
90	340.68	344.46	348.25	352.04	355.82	359.60	363.39	367.18	370.96	374.75

## LITER TO U. S. GALLON

1 Liter = 0.264168 U. S. Gallon

Liter	0	1	2	3	4	5	6	7	8	9
0	0	0.26	0.53	0.79	1.06	1.32	1.59	1.85	2.11	2.38
10	2.64	2.91	3.17	3.43	3.70	3.96	4.23	4.49	4.76	5.02
20	5.28	5.55	5.81	6.08	6.34	6.60	6.87	7.13	7.40	7.66
30	7.93	8.19	8.45	8.72	8.98	9.25	9.51	9.77	10.04	10.30
40	10.57	10.83	11.10	11.36	11.62	11.89	12.15	12.42	12.68	12.94
50	13.21	13.47	13.74	14.00	14.27	14.53	14.79	15.06	15.32	15.59
60	15.85	16.11	16.38	16.64	16.91	17.17	17.44	17.70	17.96	18.23
70	18.49	18.76	19.02	19.28	19.55	19.81	20.08	20.34	20.61	20.87
80	21.13	21.40	21.66	21.93	22.19	22.45	22.72	22.98	23.25	23.51
90	23.78	24.04	24.30	24.57	24.83	25.10	25.36	25.62	25.89	26.15



## CONVERSION TABLE – PRESSURE

## POUNDS PER SQUARE INCH TO KILOGRAMS PER SQUARE CENTIMETER

(1 pound per square inch = .0703066 kilogram per square centimeter)

1 to 30		31 to 60		61 to 90		91 to 200		205 to 400		410 to 700		710 to 1000		1010 to 1500	
Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.	Lbs. Per Sq. In.	Kg. Per Sq. Cm.
1	.07	31	2.18	61	4.29	91	6.40	205	14.41	410	28.83	710	49.92	1010	71.01
2	.14	32	2.25	62	4.36	92	6.47	210	14.76	420	29.53	720	50.62	1020	71.71
3	.21	33	2.32	63	4.43	93	6.54	215	15.12	430	30.23	730	51.32	1030	72.42
4	.28	34	2.39	64	4.50	94	6.61	220	15.47	440	30.93	740	52.03	1040	73.12
5	.35	35	2.46	65	4.57	95	6.68	225	15.82	450	31.64	750	52.73	1050	73.82
6	.42	36	2.53	66	4.64	96	6.75	230	16.17	460	32.34	760	53.43	1060	74.52
7	.49	37	2.60	67	4.71	97	6.82	235	16.52	470	33.04	770	54.14	1070	75.23
8	.56	38	2.67	68	4.78	98	6.89	240	16.87	480	33.75	780	54.84	1080	75.93
9	.63	39	2.74	69	4.85	99	6.96	245	17.23	490	34.45	790	55.54	1090	76.63
10	.70	40	2.81	70	4.92	100	7.03	250	17.58	500	35.15	800	56.25	1100	77.34
11	.77	41	2.88	71	4.99	105	7.38	255	17.93	510	35.86	810	56.95	1120	78.74
12	.84	42	2.95	72	5.06	110	7.73	260	18.28	520	36.56	820	57.65	1140	80.15
13	.91	43	3.02	73	5.13	115	8.09	265	18.63	530	37.26	830	58.35	1160	81.56
14	.98	44	3.09	74	5.20	120	8.44	270	18.98	540	37.97	840	59.06	1180	82.96
15	1.05	45	3.16	75	5.27	125	8.79	275	19.33	550	38.67	850	59.76	1200	84.37
16	1.12	46	3.23	76	5.34	130	9.14	280	19.69	560	39.37	860	60.46	1220	85.77
17	1.20	47	3.30	77	5.41	135	9.49	285	20.04	570	40.07	870	61.17	1240	87.18
18	1.27	48	3.37	78	5.48	140	9.84	290	20.39	580	40.78	880	61.87	1260	88.59
19	1.34	49	3.45	79	5.55	145	10.19	295	20.74	590	41.48	890	62.57	1280	89.99
20	1.41	50	3.52	80	5.62	150	10.55	300	21.09	600	42.18	900	63.28	1300	91.40
21	1.48	51	3.59	81	5.69	155	10.90	310	21.80	610	42.89	910	63.98	1320	92.80
22	1.55	52	3.66	82	5.77	160	11.25	320	22.50	620	43.59	920	64.68	1340	94.21
23	1.62	53	3.73	83	5.84	165	11.60	330	23.20	630	44.29	930	65.39	1360	95.62
24	1.69	54	3.80	84	5.91	170	11.95	340	23.90	640	45.00	940	66.09	1380	97.02
25	1.76	55	3.87	85	5.98	175	12.30	350	24.61	650	45.70	950	66.79	1400	98.43
26	1.83	56	3.94	86	6.05	180	12.66	360	25.31	660	46.40	960	67.49	1420	99.84
27	1.90	57	4.01	87	6.12	185	13.01	370	26.01	670	47.11	970	68.20	1440	101.24
28	1.97	58	4.08	88	6.19	190	13.36	380	26.72	680	47.81	980	68.90	1460	102.65
29	2.04	59	4.15	89	6.26	195	13.71	390	27.42	690	48.51	990	69.60	1480	104.05
30	2.11	60	4.22	90	6.33	200	14.06	400	28.12	700	49.21	1000	70.31	1500	105.46

## CONVERSION TABLE – DEGREE

## DEGREES TO RADIANS

$$1 \text{ DEGREE} = \frac{\pi}{180} = 0.01745 \text{ RADIANS}$$

## Degrees

## Minutes

## Seconds

0°	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
0.00000	0.01745	0.03491	0.05236	0.06981	0.08727	0.10472	0.12217	0.13962	0.15707	0.17453	0.19198	0.20943	0.22689	0.24434	0.26179	0.27924	0.29670	0.31415	0.33160	0.34906	0.36651	0.38397	0.40142	0.41887	0.43633	0.45378	0.47123	0.48868	0.50614	0.52359	0.54105	0.55850	0.57595	0.59341	0.61086	0.62831	0.64577	0.66322	0.68068	0.69813	0.71558	0.73303	0.75049	0.76794	0.78539	0.80284	0.82029	0.83774	0.85519	0.87264	0.89010	0.90755	0.92500	0.94245	0.95990	0.97735	0.99480	1.01225	1.02970	1.04716																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
1.04719	1.06465	1.08210	1.09955	1.11701	1.13446	1.15191	1.16937	1.18682	1.20427	1.22173	1.23918	1.25663	1.27409	1.29154	1.30899	1.32645	1.34390	1.36135	1.37881	1.39626	1.41371	1.43117	1.44862	1.46607	1.48352	1.50098	1.51843	1.53588	1.55334	1.57079	1.58824	1.60570	1.62315	1.64060	1.65806	1.67551	1.69296	1.71042	1.72787	1.74533	1.76278	1.78023	1.79768	1.81514	1.83259	1.85004	1.86750	1.88495	1.90240	1.91986	1.93731	1.95476	1.97222	1.98967	2.00712	2.02458	2.04203	2.05948	2.07694	2.09439																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
120°	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
2.09439	2.11184	2.12930	2.14675	2.16420	2.18166	2.19911	2.21656	2.23402	2.25147	2.26892	2.28638	2.30383	2.32128	2.33874	2.35619	2.37364	2.39110	2.40855	2.42600	2.44346	2.46091	2.47836	2.49582	2.51327	2.53072	2.54818	2.56563	2.58308	2.60054	2.61799	2.63544	2.65290	2.67035	2.68780	2.70526	2.72271	2.74016	2.75762	2.77507	2.79252	2.80998	2.82743	2.84488	2.86234	2.87979	2.89724	2.91469	2.93215	2.94960	2.96705	2.98450	2.99695	3.01390	3.03085	3.04780	3.06475	3.08170	3.09865	3.11560	3.13255	3.14950	3.16645	3.18340	3.20035	3.21730	3.23425	3.25120	3.26815	3.28510	3.30205	3.31900	3.33595	3.35290	3.36985	3.38680	3.40375	3.42070	3.43765	3.45460	3.47155	3.48850	3.50545	3.52240	3.53935	3.55630	3.57325	3.59020	3.60715	3.62410	3.64105	3.65800	3.67495	3.69190	3.70885	3.72580	3.74275	3.75970	3.77665	3.79360	3.81055	3.82750	3.84445	3.86140	3.87835	3.89530	3.91225	3.92920	3.94615	3.96310	3.98005	3.99700	4.01395	4.03090	4.04785	4.06480	4.08175	4.09870	4.11565	4.13260	4.14955	4.16650	4.18345	4.20040	4.21735	4.23430	4.25125	4.26820	4.28515	4.30210	4.31905	4.33600	4.35295	4.36990	4.38685	4.40380	4.42075	4.43770	4.45465	4.47160	4.48855	4.50550	4.52245	4.53940	4.55635	4.57330	4.59025	4.60720	4.62415	4.64110	4.65805	4.67500	4.69195	4.70890	4.72585	4.74280	4.75975	4.77670	4.79365	4.81060	4.82755	4.84450	4.86145	4.87840	4.89535	4.91230	4.92925	4.94620	4.96315	4.98010	4.99705	5.01400	5.03095	5.04790	5.06485	5.08180	5.09875	5.11570	5.13265	5.14960	5.16655	5.18350	5.20045	5.21740	5.23435	5.25130	5.26825	5.28520	5.30215	5.31910	5.33605	5.35300	5.36995	5.38690	5.40385	5.42080	5.43775	5.45470	5.47165	5.48860	5.50555	5.52250	5.53945	5.55640	5.57335	5.59030	5.60725	5.62420	5.64115	5.65810	5.67505	5.69200	5.70895	5.72590	5.74285	5.75980	5.77675	5.79370	5.81065	5.82760	5.84455	5.86150	5.87845	5.89540	5.91235	5.92930	5.94625	5.96320	5.98015	5.99710	6.01405	6.03100	6.04795	6.06490	6.08185	6.09880	6.11575	6.13270	6.14965	6.16660	6.18355	6.20050	6.21745	6.23440	6.25135	6.26830	6.28525	6.30220	6.31915	6.33610	6.35305	6.37000	6.38695	6.40390	6.42085	6.43780	6.45475	6.47170	6.48865	6.50560	6.52255	6.53950	6.55645	6.57340	6.59035	6.60730	6.62425	6.64120	6.65815	6.67510	6.69205	6.70900	6.72595	6.74290	6.75985	6.77680	6.79375	6.81070	6.82765	6.84460	6.86155	6.87850	6.89545	6.91240	6.92935	6.94630	6.96325	6.98020	6.99715	7.01410	7.03105	7.04800	7.06495	7.08190	7.09885	7.11580	7.13275	7.14970	7.16665	7.18360	7.20055	7.21750	7.23445	7.25140	7.26835	7.28530	7.30225	7.31920	7.33615	7.35310	7.37005	7.38700	7.40395	7.42090	7.43785	7.45480	7.47175	7.48870	7.50565	7.52260	7.53955	7.55650	7.57345	7.59040	7.60735	7.62430	7.64125	7.65820	7.67515	7.69210	7.70905	7.72600	7.74295	7.75990	7.77685	7.79380	7.81075	7.82770	7.84465	7.86160	7.87855	7.89550	7.91245	7.92940	7.94635	7.96330	7.98025	7.99720	8.01415	8.03110	8.04805	8.06500	8.08195	8.09890	8.11585	8.13280	8.14975	8.16670	8.18365	8.20060	8.21755	8.23450	8.25145	8.26840	8.28535	8.30230	8.31925	8.33620	8.35315	8.37010	8.38705	8.40400	8.42095	8.43790	8.45485	8.47180	8.48875	8.50570	8.52265	8.53960	8.55655	8.57350	8.59045	8.60740	8.62435	8.64130	8.65825	8.67520	8.69215	8.70910	8.72605	8.74300	8.75995	8.77690	8.79385	8.81080	8.82775	8.84470	8.86165	8.87860	8.89555	8.91250	8.92945	8.94640	8.96335	8.98030	8.99725	9.01420	9.03115	9.04810	9.06505	9.08200	9.09895	9.11590	9.13285	9.14980	9.16675	9.18370	9.20065	9.21760	9.23455	9.25150	9.26845	9.28540	9.30235	9.31930	9.33625	9.35320	9.37015	9.38710	9.40405	9.42100	9.43795	9.45490	9.47185	9.48880	9.50575	9.52270	9.53965	9.55660	9.57355	9.59050	9.60745	9.62440	9.64135	9.65830	9.67525	9.69220	9.70915	9.72610	9.74305	9.76000	9.77695	9.79390	9.81085	9.82780	9.84475	9.86170	9.87865	9.89560	9.91255	9.92950	9.94645	9.96340	9.98035	9.99730	10.01425	10.03120	10.04815	10.06510	10.08205	10.09900	10.11595	10.13290	10.14985	10.16680	10.18375	10.20070	10.21765	10.23460	10.25155	10.26850	10.28545	10.30240	10.31935	10.33630	10.35325	10.37020	10.38715	10.40410	10.42105	10.43800	10.45495	10.47190	10.48885	10.50580	10.52275	10.53970	10.55665	10.57360	10.59055	10.60750	10.62445	10.64140	10.65835	10.67530	10.69225	10.70920	10.72615	10.74310	10.76005	10.77700	10.79395	10.81090	10.82785	10.84480	10.86175	10.87870	10.89565	10.91260	10.92955	10.94650	10.96345	10.98040	10.99735	11.01430	11.03125	11.04820	11.06515	11.08210	11.09905	11.11600	11.13295	11.14990	11.16685	11.18380	11.20075	11.21770	11.23465	11.25160	11.26855	11.28550	11.30245	11.31940	11.33635	11.35330	11.37025	11.38720	11.40415	11.42110	11.43805	11.45500	11.47195	11.48890	11.50585	11.52280	11.53975	11.55670	11.57365	11.59060	11.60755	11.62450	11.64145	11.65840	11.67535	11.69230	11.70925	11.72620	11.74315	11.76010	11.77705	11.79400	11.81095	11.82790	11.84485	11.86180	11.87875	11.89570	11.91265	11.92960	11.94655	11.96350	11.98045	11.99740	12.01435	12.03130	12.04825	12.06520	12.08215	12.09910	12.11605	12.13300	12.14995	12.16690	12.18385	12.20080	12.21775	12.23470	12.25165	12.26860	12.28555	12.30250	12.31945	12.33640	12.35335	12.37030	12.38725	12.40420	12.42115	12.43810	12.45505	12.47200	12.48895	12.50590	12.52285	12.53980	12.55675	12.57370	12.59065	12.60760	12.62455	12.64150	12.65845	12.67540	12.69235	12.70930	12.72625	12.74320	12.76015	12.77710	12.79405	12.81100	12.82795	12.84490	12.86185	12.87880	12.89575	12.91270	12.92965	12.94660	12.96355	12.98050	12.99745	13.01440	13.03135	13.04830	13.06525	13.08220	13.09915	13.11610	13.13305	13.15000	13.16695	13.18390	13.20085	13.21780	13.23475	13.25170	13.26865	13.28560	13.30255	13.31950	13.33645	13.35340	13.37035	13.38730	13.40425	13.42120	13.43815	13.45510	13.47205	13.48900	13.50595	13.52290	13.53985	13.55680	13.57375	13.59070	13.60765	13.62460	13.64155	13.65850	13.67545	13.69240	13.70935	13.72630	13.74325	13.76020	13.77715	13.79410	13.81105	13.82800	13.84495	13.86190	13.87885	13.89580	13.91275	13.92970	13.94665	13.96360	13.98055	13.99750	14.01445	14.03140	14.04835	14.06530	14.08225	14.09920	14.11615	14.13310	14.15005	14.16700	14.18395	14.20090	14.21785	14.23480	14.25175	14.26870	14.28565	14.30260	14.31955	14.33650	14.35345	14.37040	14.38735	14.40430	14.42125	14.43820	14.45515	14.47210	14.48905	14.50600	14.52295	14.53990	14.55685	14.57380	14.59075	14.60770	14.62465	14.64160	14.65855	14.67550	14.69245	14.70940	14.72635	14.74330	14.76025	14.77720	14.79415	14.81110	14.82805	14.84500	14.86195	14.87890	14.89585	14.91280	14.92975	14.94670	14.96365	14.98060	14.99755	15.01450	15.03145	15.04840	15.06535	15.08230	15.09925	15.11620	15.13315	15.15010	15.16705	15.18400	15.20095	15.21790	15.23485	15.25180	15.26875	15.28570	15.30265	15.31960	15.33655	15.35350	15.37045	15.38740	15.40435	15.42130	15.43825	15.45520	15.47215	15.48910	15.50605	15.52300	15.53995	15.55690	15.57385	15.59080	15.60775	15.62470	15.64165	15.65860	15.67555	15.69250	15.70945	15.72640	15.74



## CONVERSION TABLE – DEGREE

RADIANS TO DEGREES  
1 RADIAN =  $\frac{180}{\pi}$  = 57.29578 DEGREES

	Radians	Tenths	Hundredths	Thousandths	Ten-thousandths
1	57° 17' 44".8	5° 43' 46".5	0° 34' 22".6	0° 3' 26".3	0° 0' 20".6
2	114° 35' 29".6	11° 27' 33".0	1° 8' 45".3	0° 6' 52".5	0° 0' 41".3
3	171° 53' 14".4	17° 11' 19".4	1° 43' 07".9	0° 10' 18".8	0° 1' 01".9
4	229° 10' 59".2	22° 55' 05".9	2° 17' 30".6	0° 13' 45".1	0° 1' 22".5
5	286° 28' 44".0	28° 38' 52".4	2° 51' 53".2	0° 17' 11".3	0° 1' 43".1
6	343° 46' 28".8	34° 22' 38".9	3° 26' 15".9	0° 20' 37".6	0° 2' 03".8
7	401° 4' 13".6	40° 6' 35".4	4° 0' 38".5	0° 24' 03".9	0° 2' 24".4
8	458° 21' 58".4	45° 50' 11".8	4° 35' 01".2	0° 27' 30".1	0° 2' 45".0
9	515° 39' 43".3	51° 33' 58".3	5° 9' 23".8	0° 30' 56".4	0° 3' 05".6

## EXAMPLES

1. Change 87° 26' 34" to radian

Solution: From table on opposite page

87° = 1.5184364 radians  
 26' = 0.0075631 radians  
 34" = 0.0001648 radians  
 87° 26' 34" = 1.5261643 radians

2. Change 1.5262 radians to degrees

Solution: From table above

1 radian = 57° 17' 44.8"  
 0.5 = 28° 38' 52.4"  
 0.02 = 1° 8' 45.3"  
 0.006 = 0° 20' 37.6"  
 0.0002 = 0° 0' 41.3"  
 1.5262 = 86° 83' 221.4"  
 = 87° 26' 41.4"

## CONVERSION TABLE – DEGREE

MINUTES AND SECONDS TO  
DECIMALS OF A DEGREEDECIMALS OF A DEGREE TO  
MINUTES AND SECONDS

	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
0	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
1	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
2	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
3	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
4	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
5	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
6	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
7	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
8	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
9	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
10	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
11	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
12	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
13	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
14	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
15	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
16	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
17	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
18	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
19	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
20	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
21	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
22	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
23	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
24	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
25	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
26	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
27	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
28	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
29	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833
30	0.0000	0.0167	0.0333	0.0500	0.0667	0.0833	0.1000	0.1167	0.1333	0.1500	0.1667	0.1833	0.2000	0.2167	0.2333	0.2500	0.2667	0.2833	0.3000	0.3167	0.3333	0.3500	0.3667	0.3833	0.4000	0.4167	0.4333	0.4500	0.4667	0.4833



## CONVERSION TABLE – TEMPERATURE

## CENTIGRADE – FAHRENHEIT

$$\text{Degrees Cent., } C^{\circ} = \frac{5}{9} (F^{\circ} + 40) - 40 \quad \text{Degrees Fahr., } F^{\circ} = \frac{9}{5} (C^{\circ} + 40) - 40$$

NOTE: The numbers in boldface refer to the temperature either in degrees, Centigrade or Fahrenheit which it is desired to convert into the other scale. If converting from Fahrenheit to Centigrade degrees, the equivalent temperature will be found in the left column; while if converting from degrees Centigrade to degrees Fahrenheit, the answer will be found in the column on the right.

Centigrade		Fahrenheit	Centigrade	Fahrenheit	Centigrade	Fahrenheit	Centigrade	Fahrenheit			
-73.3	-100	-148.0	-15.6	4	39.2	-3.3	26	78.8	9.4	49	120.2
-67.8	-90	-130.0	-15.0	5	41.0	-2.8	27	80.6	10.0	50	122.0
-62.2	-80	-112.0				-2.2	28	82.4	10.6	51	123.8
-59.5	-75	-103.0	-14.4	6	42.8	-1.7	29	84.2	11.1	52	125.6
-56.7	-70	-94.0	-13.9	7	44.6						
-53.9	-65	-85.0	-13.3	8	46.4	-1.1	30	86.0	11.7	53	127.4
-51.1	-60	-76.0	-12.8	9	48.2	-0.6	31	87.8	12.2	54	129.2
-48.4	-55	-67.0	-12.2	10	50.0	0.0	32	89.6	12.8	55	131.0
			-11.7	11	51.8	0.6	33	91.4	13.3	56	132.8
-45.6	-50	-58.0	-11.1	12	53.6	1.1	34	93.2	13.9	57	134.6
-42.8	-45	-49.0	-10.6	13	55.4	1.7	35	95.0	14.4	58	136.4
-40.0	-40	-40.0				2.2	36	96.8	15.0	59	138.2
-37.2	-35	-31.0	-10.0	14	57.2	2.8	37	98.6	15.6	60	140.0
-34.4	-30	-22.0	-9.4	15	59.0	3.3	38	100.4			
-31.6	-25	-13.0	-8.9	16	60.8	3.9	39	102.2	16.1	61	141.8
-28.8	-20	-4.0	-8.3	17	62.6	4.4	40	104.0	16.7	62	143.6
-26.1	-15	5.0	-7.8	18	64.4	5.0	41	105.8	17.2	63	145.4
			-7.2	19	66.2	5.6	42	107.6	17.8	64	147.2
-23.3	-10	14.0	-6.7	20	68.0	6.1	43	109.4	18.3	65	149.0
-20.6	-5	23.0	-6.1	21	69.8	6.7	44	111.2	18.9	66	150.8
-17.8	0	32.0							19.4	67	152.6
-17.2	1	33.8	-5.6	22	71.6	7.2	45	113.0	20.0	68	154.4
-16.7	2	35.6	-5.0	23	73.4	7.8	46	114.8			
-16.1	3	37.4	-4.4	24	75.2	8.3	47	116.6	20.6	69	156.2
			-3.9	25	77.0	8.9	48	118.4	21.1	70	158.0

## CENTIGRADE – FAHRENHEIT (con't.)

Centigrade			Fahrenheit			Centigrade			Fahrenheit			Centigrade			Fahrenheit		
21.7	71	159.8	54	130	266	226	440	824	410	770	1418						
22.2	72	161.6	60	140	284	232	450	842	415	780	1436						
22.8	73	163.4	65	150	302	238	460	860	421	790	1454						
23.3	74	165.2	71	160	320	243	470	878									
23.9	75	167.0	76	170	338	249	480	896	426	800	1472						
24.4	76	168.8							432	810	1490						
			83	180	356	254	490	914	438	820	1508						
25.0	77	170.6	88	190	374	260	500	932	443	830	1526						
25.6	78	172.4	93	200	392	265	510	950	449	840	1544						
26.1	79	174.2	99	210	410	271	520	968	454	850	1562						
26.7	80	176.0	100	212	413	276	530	986	460	860	1580						
27.2	81	177.8	104	220	428	282	540	1004	465	870	1598						
27.8	82	179.6	110	230	446	288	550	1022									
28.3	83	181.4	115	240	464	293	560	1040	471	880	1616						
28.9	84	183.2				299	570	1058	476	890	1634						
			121	250	482	304	580	1076	482	900	1652						
29.4	85	185.0	127	260	500	310	590	1094	487	910	1670						
30.0	86	186.8	132	270	518	315	600	1112	493	920	1688						
30.6	87	188.6	138	280	536	321	610	1130	498	930	1706						
31.1	88	190.4	143	290	554	326	620	1148	504	940	1724						
31.7	89	192.2	149	300	572	332	630	1166	510	950	1742						
32.2	90	194.0	154	310	590												
32.8	91	195.8	160	320	608	338	640	1184	515	960	1760						
						343	650	1202	520	970	1778						
33.3	92	197.6	165	330	626	349	660	1220	526	980	1796						
33.9	93	199.4	171	340	644	354	670	1238	532	990	1814						
34.4	94	201.2	177	350	662	360	680	1256	538	1000	1832						
35.0	95	203.0	182	360	680	365	690	1274	565	1050	1922						
35.6	96	204.8	188	370	698	371	700	1292	593	1100	2012						
36.1	97	206.6	193	380	716	376	710	1310	620	1150	2102						
36.7	98	208.4	199	390	734												
37.2	99	210.2	204	400	752	382	720	1328	648	1200	2192						
						387	730	1346	675	1250	2282						
37.8	100	212.0	210	410	770	393	740	1364	704	1300	2372						
43	110	230	215	420	806	404	750	1382	734	1350	2462						
49	120	248	221	430	866				760	1400	2552						
									787	1450	2642						
									815	1500	2732						



## CONVERSION FACTORS

(For conversion factors meeting the standards of the SI metric system, refer to ASTM E380-72)

MULTIPLY	BY	TO OBTAIN
centimeters .....	$3.28083 \times 10^{-2}$	feet
centimeters .....	.3937	inches
cubic centimeters .....	$6.102 \times 10^{-2}$	cubic inches
cubic feet .....	$2.8317 \times 10^{-2}$	cubic meters
cubic feet .....	6.22905	gallons, British Imperial
cubic feet .....	28.3170	liters
cubic inches .....	16.38716	cubic centimeters
cubic meters .....	35.3145	cubic feet
cubic meters .....	1.30794	cubic yards
cubic meters .....	.764559	cubic meters
cubic yards .....	.0174533	radians
degrees angular .....	.13826	kilogram meters
foot pounds .....	30.4801	centimeters
feet .....	.160538	cubic feet
gallons, British Imperial .....	1.20091	gallons, U.S.
gallons, British Imperial .....	4.54596	liters
gallons, British Imperial .....	.832702	gallons, British Imperial
gallons, U.S. ....	.13368	cubic feet
gallons, U.S. ....	3.78543	liters
grams, metric .....	$2.20462 \times 10^{-3}$	pounds, avoirdupois
horse-power, metric .....	.98632	horse-power, U.S.
horse-power, U.S. ....	1.01387	horse-power, metric
inches .....	2.54001	centimeters
kilograms .....	2.20462	pounds
kilograms per sq. centimeter .....	14.2234	pounds per sq. inch
kilometers .....	.62137	miles, statute
liters .....	.26417	gallons, U.S.
meters .....	3.28083	feet
meters .....	39.37	inches
meters .....	1.09361	yards
miles, statute .....	1.60935	kilometer
millimeters .....	$3.28083 \times 10^{-3}$	feet
millimeters .....	$3.937 \times 10^{-2}$	inches
pounds avoirdupois .....	.453592	kilograms
pounds per square foot .....	4.88241	kilograms per sq. meter
pounds per square inch .....	$7.031 \times 10^{-2}$	kilograms per sq. centimeter
radians .....	57.29578	degrees angular
square centimeters .....	.1550	square inches
square inches .....	6.45163	square centimeters
square meters .....	1.19599	square yards
square miles .....	2.590	square kilometers
square yards .....	.83613	square meters
tons, long .....	1016.05	kilograms
tons, long .....	2240.	pounds
tons, metric .....	2204.62	pounds
tons, metric .....	.98421	tons, long
tons, metric .....	1.10231	tons, short
tons, short .....	.892857	tons, long
tons, short .....	.907185	tons, metric
yards .....	.914402	meters




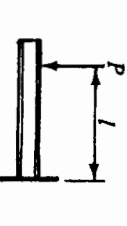
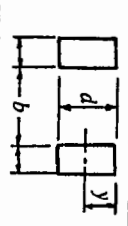
## PART IV.

### DESIGN OF STEEL STRUCTURES

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## STRESS AND STRAIN FORMULAS

DEFINITION OF SYMBOLS		
$A$	= Cross sectional area, in <sup>2</sup>	$S_s$ = Bending stress, psi
$A_R$	= Required cross sectional Area, in <sup>2</sup>	$S_s'$ = Shear stress, psi
$I$	= Moment of inertia, in <sup>4</sup>	$S_A$ = Allowable tensile or compressive stress, psi
$M$	= Moment, in-lb	$S_{BA}$ = Allowable bending stress, psi
$M_A$	= Allowable moment, in-lb	$S_{SA}$ = Allowable shear stress, psi
$P$	= Force, lb	$\gamma$ = Distance from neutral axis to extreme fiber, in
$P_A$	= Allowable force, lb	$Z$ = Section modulus, in <sup>3</sup>
$S$	= Tensile or compressive stress, psi	
TYPE OF LOADING		EXAMPLES
 TENSION	$S = \frac{P}{A}$ (psi) $P_A = AS_A$ (lb) $A_R = \frac{P}{S_A}$ (in <sup>2</sup> )	The stress in a 2 x 1/4 in. bar made from SA 285-C steel due to 5,000 lb. tensional load is: Area, $A = 2 \times 1/4 = 0.5$ in <sup>2</sup> ; $S = \frac{P}{A} = \frac{5,000}{0.5} = 10,000$ psi
 COMPRESSION	$S = \frac{P}{A}$ (psi) $P_A = AS_A$ (lb) $A_R = \frac{P}{S_A}$ (in <sup>2</sup> )	To support a load of 11,000 lbs. in compression, the required area of steel bar made from SA 285C steel is: $A_R = \frac{P}{S_A} = \frac{11,000}{22,000} = 0.5$ in <sup>2</sup>
 SHEAR	$S_s = \frac{P}{A}$ (psi) $P_A = AS_{SA}$ (lb) $A_R = \frac{P}{S_{SA}}$ (in <sup>2</sup> )	The required area of bolt made from SA-307 B steel to support a load of 15,000 lbs. in double shear: $A_R = \frac{P}{2S_A} = \frac{15,000}{2 \times 10,000} = 0.75$ in <sup>2</sup>
 BENDING	$M = Pl$ (in-lb) $M_A = ZS_A$ (in-lb) $Z_R = \frac{M}{S_{BA}}$ (in <sup>3</sup> ) $S = \frac{M}{Z}$ (psi)	The maximum bending moment at the support of a cantilever beam due to a load of 1,000 lbs. acting at a distance of 60 inches from the support: $M = Pl = 1,000 \times 60 = 60,000$ in-lb.
 SECTION MODULUS		Section modulus If dimension $b = 2$ in. and $d = 4$ in., axis of moment on the base, $I = 42.67$ . $Z = I/y = 42.67/4 = 10.67$ in <sup>3</sup> axis of moment through center, $I = 10.67$ , $Z = I/y = 10.67/2 = 5.335$ in <sup>3</sup>

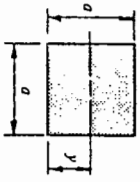
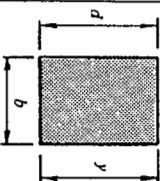
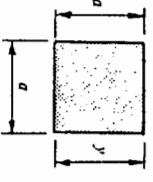
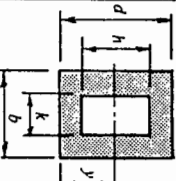
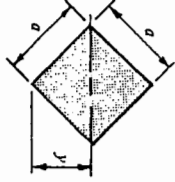
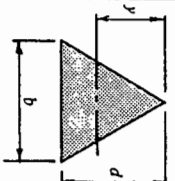
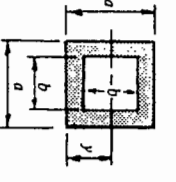
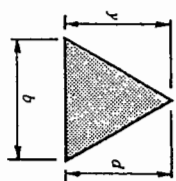
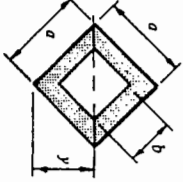
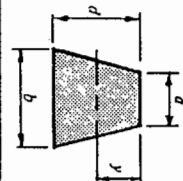
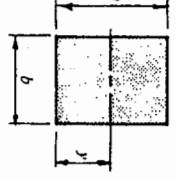
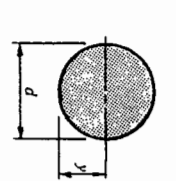
## ALLOWABLE STRESSES

### FOR NON PRESSURE PARTS OF VESSELS AND OTHER STRUCTURES

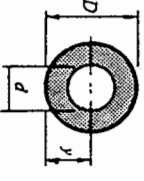

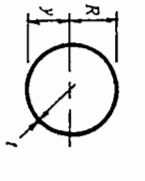
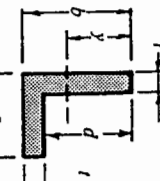
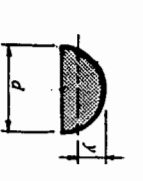
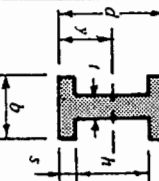
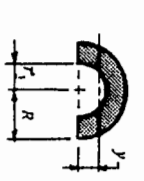
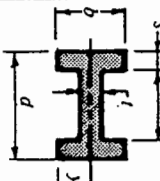
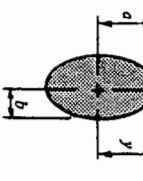
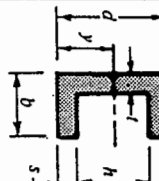
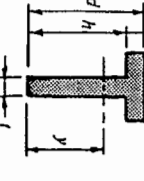
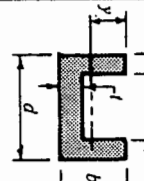
TYPE OF STRESS & JOINT	ALLOWABLE STRESS	SOURCE
<b>STEEL</b>		
Bearing Shear	$1.60 \times \left\{ \begin{array}{l} \text{The values of} \\ 0.80 \times \end{array} \right\}$ tables UCS-23	CODE UCS-23 Notes
Compression Tension (except pin connection) Bending Shear Bearing (on projected area of bolts in shear on connection)	$0.60 \times \left\{ \begin{array}{l} \text{Specified} \\ 0.60 \times \text{minimum} \\ 0.66 \times \text{yield stress} \\ 0.40 \times \text{Min. tensile strength} \end{array} \right\}$	American Institute of Steel Construction
<b>WELDED JOINT OF STEEL</b>		
Full penetration groove weld tension, compression, shear	same as for the steel welded	American Welding Society
Partial penetration groove weld 1. tension transverse to axis of weld, shear on throat 2. tension parallel to axis of weld or compression on throat	13,600 psi same as for the steel welded	
Fillet weld, shear on throat	13,600 psi (using throat dimension) 9,600 psi (using leg dimension)	
Plug or slot weld	same as fillet weld	



## PROPERTIES OF SECTIONS

DEFINITION OF SYMBOLS			
$A$ = Area, in. <sup>2</sup>	$r$ = Radius of gyration, $\sqrt{I/A}$		
$I$ = Moment of inertia, in. <sup>4</sup>	$y$ = Distance from neutral axis to extreme fiber, in.		
	$Z$ = Section modulus, $I/y$ , in. <sup>3</sup>		
	$A = a^2$ $y = \frac{1}{2}a$ $I = \frac{a^4}{12}$ $Z = \frac{a^3}{6}$ $r = 0.289a$		$A = bd$ $y = d$ $I = \frac{bd^3}{3}$ $Z = \frac{bd^2}{3}$ $r = 0.577d$
	$A = a^2$ $y = a$ $I = \frac{a^4}{3}$ $Z = \frac{a^3}{3}$ $r = 0.577a$		$A = bd - hk$ $y = \frac{1}{2}d$ $I = \frac{(bd^3 - hk^3)}{12}$ $Z = \frac{(bd^2 - hk^2)}{6d}$ $r = 0.289 \sqrt{\frac{bd^3 - hk^3}{bd - hk}}$
	$A = a^2$ $y = 0.707a$ $I = \frac{a^4}{12}$ $Z = 0.118a^3$ $r = 0.289a$		$A = \frac{1}{2}bd$ $y = \frac{3}{4}d$ $I = \frac{bd^3}{36}$ $Z = \frac{bd^2}{24}$ $r = 0.236d$
	$A = a^2 - b^2$ $y = \frac{1}{2}a$ $I = \frac{(a^4 - b^4)}{12}$ $Z = \frac{(a^4 - b^4)}{6a}$ $r = 0.289 \sqrt{a^2 + b^2}$		$A = \frac{1}{2}bd$ $y = d$ $I = \frac{bd^3}{12}$ $Z = \frac{bd^2}{12}$ $r = 0.408d$
	$A = a^2 - b^2$ $y = 0.707a$ $I = \frac{(a^4 - b^4)}{12}$ $Z = \frac{(0.118a^4 - b^4)}{a}$ $r = 0.289 \sqrt{a^2 + b^2}$		$A = \frac{d(a+b)}{2}$ $y = \frac{d(a+2b)}{3(a+b)}$ $I = \frac{d^3(a^2 + 4ab + b^2)}{36(a+b)}$ $Z = \frac{d^2(a^2 + 4ab + b^2)}{12(a+2b)}$ $r = \sqrt{I/A}$
	$A = bd$ $y = \frac{1}{2}d$ $I = \frac{bd^3}{12}$ $Z = \frac{bd^2}{6}$ $r = 0.289d$		$A = 0.7854d^2$ $y = d/2$ $I = 0.049d^4$ $Z = 0.098d^3$ $r = d/4$

## PROPERTIES OF SECTIONS

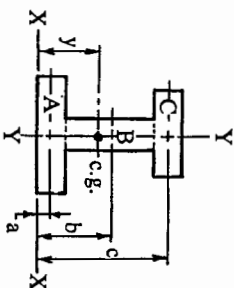
DEFINITION OF SYMBOLS			
$A$ = Area, in. <sup>2</sup>	$r$ = Radius of gyration, $\sqrt{I/A}$		
$I$ = Moment of inertia, in. <sup>4</sup>	$y$ = Distance from neutral axis to extreme fiber, in.		
	$Z$ = Section modulus, $I/y$ , in. <sup>3</sup>		
	$A = 0.7854(D^2 - d^2)$ $y = D/2$ $I = 0.049(D^4 - d^4)$ $Z = 0.098(D^3 - d^3)/D$ $r = \sqrt{D^2 + d^2}/4$		$A = (2a - t)$ $y = a - \frac{d^2 + at - t^2}{2(2a - t)}$ $I = \frac{1}{12}(y^3 + at^3 - y^3) - (a - t)(a - y - y)^3$ $Z = I/y$ $r = \sqrt{I/A}$
	Section of thin walled cylinder when $R > 10t$ $A = 2R\pi t$ $y = R$ $I = R^3\pi$ $Z = R^2\pi$ $r = 0.707R$		$A = (a + b - t)$ $y = b - \frac{(2d + a) + d^2}{2(d + a)}$ $I = \frac{1}{12}(y^3 + at^3 - y^3) - (a - t)(b - y - t)^3$ $Z = I/y$ $r = \sqrt{I/A}$
	$A = 0.393d^2$ $y = 0.288d$ $I = 0.007d^4$ $Z = 0.024d^3$ $r = 0.132d$		$A = bd - h(b - t)$ $y = d/2$ $I = [bd^3 - h^3(b - t)]/12$ $Z = \frac{bd^2 - h^2(b - t)}{6d}$ $r = \sqrt{I/A}$
	$A = 1.5708(R^2 - r_1^2)$ $y = 0.424(R^2 - r_1^2)/\sqrt{R^2 - r_1^2}$ $I = 0.1098(R^4 - r_1^4) - \frac{0.283}{R + r_1}R^2r_1^2(R - r_1)$ $Z = I/y$ $r = \sqrt{I/A}$		$A = bd - h(b - t)$ $y = b/2$ $I = (2sb^2 + ht^3)/12$ $Z = (2sb^2 + ht^3)/6b$ $r = \sqrt{I/A}$
	$A = 3.1416ab$ $y = a$ $I = 0.7854ab^3$ $Z = 0.7854ab^2$ $r = a/2$		$A = bd - h(b - t)$ $y = d/2$ $I = [bd^3 - h^3(b - t)]/12$ $Z = [bd^2 - h^2(b - t)]/6d$ $r = \sqrt{I/A}$
	$A = bs + ht$ $y = d - \frac{d^2 + st^2 - t^2}{2(bs + ht)}$ $I = \frac{1}{12}(y^3 + bt^3 - y^3) - (b - t)(d - y - y)^3$ $Z = I/y$ $r = \sqrt{I/A}$		$A = bd - h(b - t)$ $y = b - \frac{2bd^2 + ht^2}{2bd - 2h(b - t)}$ $I = (2bd^3 + ht^3)/3 - (b - t)y^3$ $Z = I/y$ $r = \sqrt{I/A}$



## CENTER OF GRAVITY

The center of gravity of an area or body is the point through which about any axis the moment of the area or body is zero. If a body of homogeneous material at the center of gravity were suspended it would be balanced in all directions.

The center of gravity of symmetrical areas as square, rectangle, circle, etc. coincides with the geometrical center of the area. For areas which are not symmetrical or which are symmetrical about one axis only, the center of gravity may be determined by calculation.



EXAMPLE #1

- The center of gravity is located on the centerline of symmetry. (Axis  $y-y$ )  
To determine the exact location of it:
1. Divide the area into 3 rectangles and calculate the area of each. ( $A, B, C$ )
  2. Determine the center of gravity of the rectangles and determine the distances  $a, b$  and  $c$  to a selected axis ( $x-x$ ) perpendicular to axis  $y-y$ .
  3. Calculate distance  $y$  to locate the center of gravity by the formula:

$$y = \frac{Aa + Bb + Cc}{A + B + C}$$

Assuming for areas of rectangles:  $A = 16$ ,  $B = 14$  and  $C = 12$  square inches and for the distances of center of gravities:  $a = 1$ ,  $b = 5$  and  $c = 9$  inches.

$$y = \frac{16 \times 1 + 14 \times 5 + 12 \times 9}{16 + 14 + 12} = 4.62 \text{ in.}$$

The area is not symmetrical about any axis. The center of gravity may be determined by calculating the moments with reference to two selected axes. To determine the distances of center of gravity to these axes:

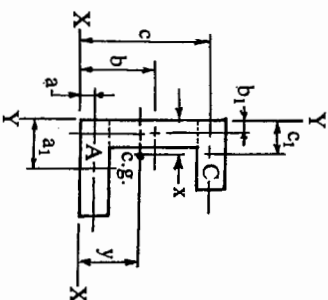
1. Divide the area into 3 rectangles and calculate the areas of each. ( $A, B, C$ )
2. Determine the center of gravity of the rectangles and the distances,  $a, b$  and  $c$  to axis  $x-x$  and the distances  $a_1, b_1, c_1$  to axis  $y-y$ .
3. Calculate distances  $x$  and  $y$  by the formulas:

$$x = \frac{Aa_1 + Bb_1 + Cc_1}{A + B + C}$$

$$y = \frac{Aa + Bb + Cc}{A + B + C}$$

Assuming for areas of rectangles:  $A = 16$ ,  $B = 14$  and  $C = 12$  square inches and for distances of center of gravities:  $a = 1$ ,  $b = 5$ ,  $c = 9$ ,  $a_1 = 4$ ,  $b_1 = 1$  and  $c_1 = 3$

$$x = \frac{16 \times 4 + 14 \times 1 + 12 \times 3}{16 + 14 + 12} = 2.71 \text{ in.} \quad y = \frac{16 \times 1 + 14 \times 5 + 12 \times 9}{16 + 14 + 12} = 4.62 \text{ in.}$$



EXAMPLE #2

## CENTER OF GRAVITY

### TRIANGLE

The center of gravity is at the intersection of lines  $AD$  and  $BE$ , which bisect the sides  $BC$  and  $AC$ . The perpendicular distance from the center of gravity to any one of the sides is equal to one-third the height perpendicular to that side. Hence,  $a = h \div 3$ .

### TRAPEZOID

The center of gravity is on the line joining the middle points of parallel lines  $AB$  and  $DE$ .

$$c = \frac{h(a+2b)}{3(a+b)} \quad d = \frac{h(2a+b)}{3(a+b)} \quad e = \frac{a^2 + ab + b^2}{3(a+b)}$$

### SECTOR OF CIRCLE

Distance  $b$  from center of gravity to center of circle is:

$$b = \frac{2rc}{3l} = \frac{r^2c}{3A} = 38.197 \frac{r \sin \alpha}{\alpha}$$

in which  $A$  = area of sector, and  $\alpha$  is expressed in degrees.

For the area of a half-circle:

$$b = 4r \div 3 \pi = 0.4244 r$$

For the area of a quarter circle:

$$b = 4\sqrt{2} \times r \div 3 \pi = 0.6002 r$$

For the area of a sixth of a circle:

$$b = 2r \div \pi = 0.6366 r$$

### SEGMENT OF CIRCLE

The distance of the center of gravity from the center of the circle is:

$$b = \frac{c^3}{12A} = \frac{2}{3} \times \frac{r^3 \sin^3 \alpha}{A}$$

in which  $A$  = area of segment.

### PART OF CIRCULAR RING

Distance  $b$  from center of gravity to center of circle is:

$$b = 38.197 \frac{(R^3 - r^3) \sin \alpha}{(R^2 - r^2) \alpha}$$

Angle  $\alpha$  is expressed in degrees.

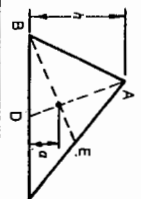
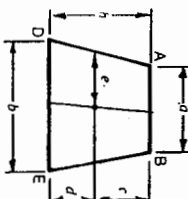
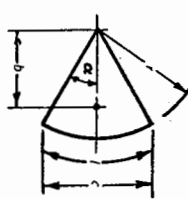
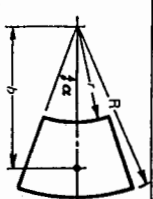
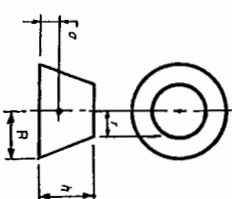
### FRUSTUM OF CONE

For a solid frustum of a circular cone the formula:

$$a = \frac{h(R^2 + 2Rr + 3r^2)}{4(R^2 + Rr + r^2)}$$

The location of the center of gravity of the conical surface of a frustum of a cone is determined by:

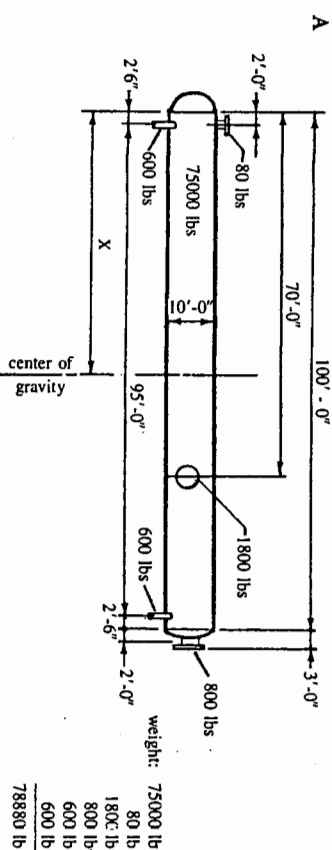
$$a = \frac{h(R + 2r)}{3(R + r)}$$





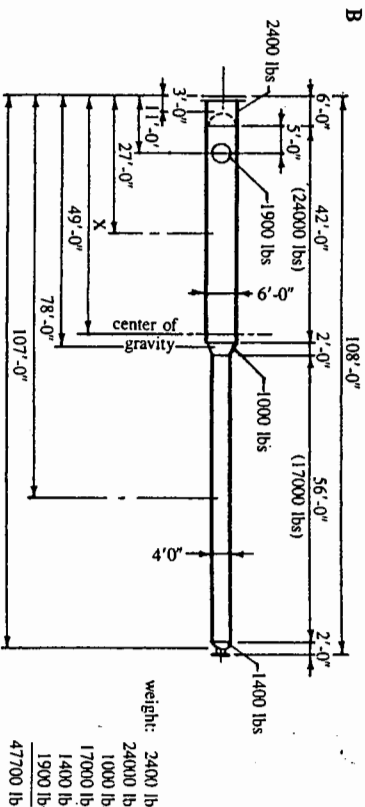
# CENTER OF GRAVITY

## EXAMPLES



$$X = \frac{75,000 \times 50' + 80 \times 2' + 1,800 \times 70' + 800 \times 102' + 600 \times 2'-6" + 600 \times 97'-6"}{78,880}$$

$$= \frac{4,017,760}{78,880} = 50.935' = 50' - 11\frac{1}{4}"$$



$$X = \frac{2,400 \times 3' + 24,000 \times 27' + 1,000 \times 49' + 17,000 \times 78' + 1,400 \times 107' + 1,900 \times 11'}{47,700}$$

$$= \frac{2,200,900}{47,700} = 46.14' = 46' - 1\frac{1}{6}"$$

# BEAM FORMULAS

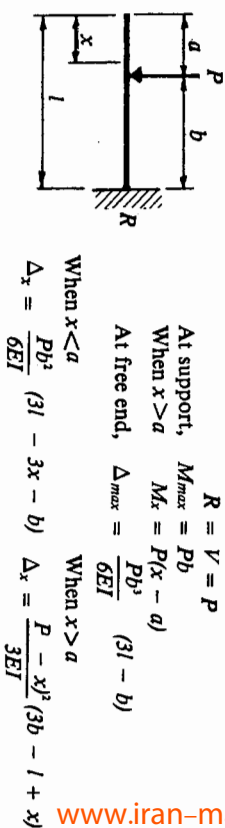
## DEFINITION OF SYMBOLS

$E$ = Modulus of elasticity, psi.	$W$ = load, lb.
$I$ = Moment of inertia, in. <sup>4</sup>	$V$ = Total shear, lb.
$l$ = Length, in.	$v$ = Unit shear, lb./in.
$M$ = Moment of force, in. lb.	$w$ = uniformly distributed load, lb./in.
$P$ = Force of concentrated load, lb.	$x$ = Distance parallel to axis $X$ , in.
$R$ = Reaction, lb.	$\Delta$ = Deflection, in.
	$\theta$ = Angle of deflection, radians

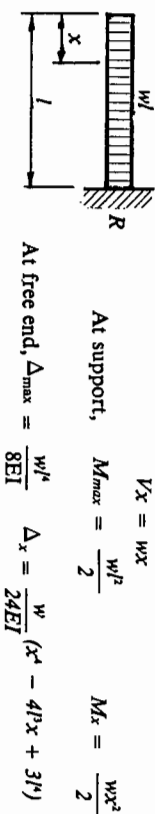
### 1 Cantilever fixed at one end — Concentrated load at free end



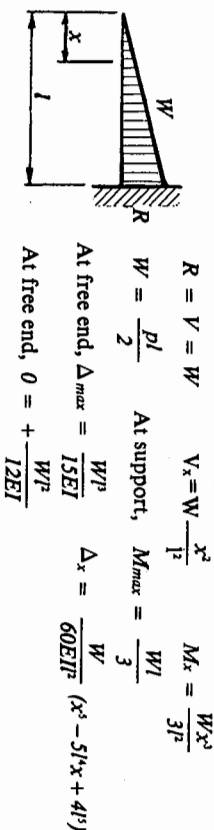
### 2 Cantilever fixed at one end — Concentrated load at any point



### 3 Cantilever fixed at one end — Uniform load over entire span

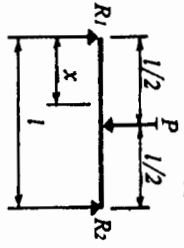
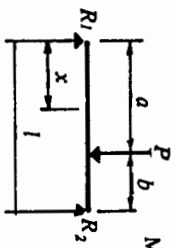


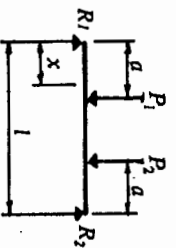
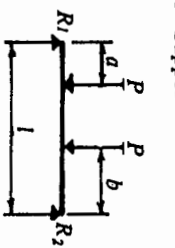
### 4 Cantilever fixed at one end — Load increasing uniformly from free end to support

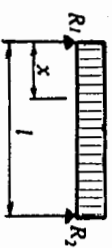




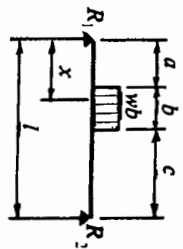
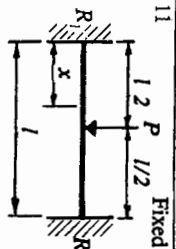
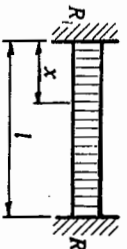
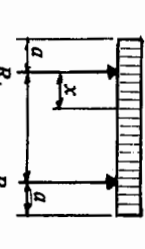
## BEAM FORMULAS

5		Supported at both ends Concentrated load at mid-span
		$R_1 = R_2 = V = P/2$ At load, $M_{max} = \frac{Pl}{4}$ When $x < l/2$ $M_x = \frac{Px}{2}$ At load, $\Delta_{max} = \frac{Pl^3}{48EI}$ At end, $\theta_1 = -\frac{Pl^2}{16EI} = -\theta_2$ When $x < l/2$ $\Delta_x = \frac{Px}{48EI} (3l^2 - 4x^2)$
6		Supported at both ends Concentrated load at any point
		Max when $a < b$ $R_1 = V_1 = \frac{Pb}{l}$ At load, $M_{max} = \frac{Pab}{l}$ Max when $a > b$ $R_2 = V_2 = \frac{Pa}{l}$ When $x < a$ $M_x = \frac{Pbx}{l}$ When $a > b$ $\Delta_{max} = \frac{Pb}{3EI} \sqrt{\frac{l^2 - b^2}{3}}$ At load, $\Delta = \frac{Pa^2b^2}{3EI}$ When $x < a$ $\Delta_x = \frac{Pbx}{6EI} (l^2 - b^2 - x^2)$ $\theta_1 = -\frac{P}{6EI} \left( 2al + \frac{a^3}{1} - 3a^2 \right)$ At ends, $\theta_2 = +\frac{P}{6EI} \left( al - \frac{a^3}{1} \right)$

7		Supported at both ends Two unequal concentrated loads, equally spaced from ends
		$R = V = P$ $M_{max} = Pa$ When $x < a$ $M_x = Px$ At center, $\Delta_{max} = \frac{Pa}{24EI} (3l^2 - 4a^2)$ When $x < a$ $\Delta_x = \frac{Px}{6EI} (3la - 3a^2 - x^2)$ When $x > a$ $\Delta_x = \frac{Pa}{6EI} (3lx - 3x^2 - a^2)$ but $x < (l-a)$ At ends, $\theta = Pa 2EI(l-a)$
8		Supported at both ends Two equal concentrated loads, unequally spaced from ends
		$R_1 = V_1 = \frac{P(l-a+b)}{2}$ $R_2 = V_2 = \frac{P(l-a+b)}{2}$ When $x > a$ but $x < (l-b)$ $V = R_1 - P_1$ Max when $R_1 < P_1$ $M_1 = R_1 a$ When $x < a$ $M_x = R_1 x$ Max when $R_2 < P_2$ $M_2 = R_2 b$ When $x > a$ but $x < (l-b)$ $M_x = R_1 x - (x-a)$

9		Supported at both ends Uniform load over entire span
		$R = V = \frac{wl}{2}$ $V = w \left( \frac{l}{2} - x \right)$ At center, $M_{max} = \frac{wl^2}{8}$ $M_x = \frac{wx}{2} (l-x)$ At center, $\Delta_{max} = \frac{5wl^4}{384EI}$ $\Delta_x = \frac{wx}{24EI} (l^3 - 2lx^2 + x^3)$ At ends, $\theta = \frac{wl^3}{24EI}$

## BEAM FORMULAS

10		Supported at both ends Uniform load partially distributed over span
		Max when $a < c$ $R_1 = V_1 = \frac{wb}{2l} (2c+b)$ Max when $a > c$ $R_2 = V_2 = \frac{wb}{2l} (2a+b)$ When $x > a$ but $x < (a+b)$ $V_x = R_1 - w(x-a)$ $M_{max} = R_1 \left( a + \frac{R_1}{2w} \right)$ At $x = a + \frac{R_1}{w}$ When $x < a$ $M_x = R_1 x$ When $x > a$ but $x < (a+b)$ $M_x = R_1 x - \frac{w}{2} (x-a)^2$ When $x > (a+b)$ $M_x = R_2 (l-x)$
11		Fixed at both ends Concentrated load at mid-span
		$R = V = \frac{P}{2}$ At center and $M_{max} = \frac{Pl}{8}$ When $x < l/2$ $M_x = \frac{P}{8} (4x-l)$ At center, $\Delta_{max} = \frac{Pl^3}{192EI}$ $\Delta_x = \frac{Px^2}{48EI} (3l-4x)$
12		Fixed at both ends Uniform load over entire span
		$R = V = \frac{wl}{2}$ $V_x = w \left( \frac{l}{2} - x \right)$ At ends, $M_{max} = \frac{wl^2}{12}$ At center, $M = \frac{wl^2}{24}$ $M_x = w/l^2 (6lx - l^2 - 6x^2)$ At center, $\Delta_{max} = \frac{wl^4}{384EI}$ $\Delta_x = \frac{wx^2}{24EI} (l-x)^2$
13		Both ends are overhanging Uniform load over entire beam
		$R = V_1 + V_2 = w(a+l/2)$ $V_{x1} = wx$ $V_{x2} = w(l-x-l/2)$ For overhang, $M_{x1} = \frac{wx^2}{2}$ At support, $M = \frac{w}{2}$ Between supports, $M_x = \frac{w}{2} (lx - x^2 - a^2)$ At center, $M_c = \frac{w}{8} (l^2 - 4a^2)$ When $a = .207 \times \text{total length or } l = .354l$ $M = M_c = \frac{wl^2}{16}$



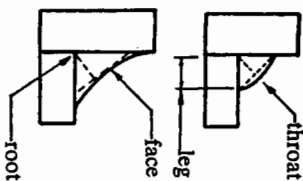
## DESIGN OF WELDED JOINTS FOR STRUCTURAL MEMBERS

### GROOVE WELD

Groove welds are usually a continuation of the base metal. For groove welds the same strength is ascribed as for the members that they join.

### FILLET WELD

#### Size of weld



The size of an equal-leg fillet weld is the leg dimension of the largest 45° right triangle inscribed in the cross section of the weld.

The size of an unequal-leg fillet weld is the shortest distance from the root to the face of the fillet weld.

$$\text{Throat dimension} = 0.707 \times \text{leg dimension}$$

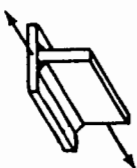
#### Minimum Weld size\*

Thickness of the thicker plate, in.	1/2	3/4	1/2	2 1/4	6	6	over
Minimum fillet weld size, in.	3/16	1/4	3/16	3/8	1/2	3/4	

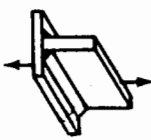
\* Weld size need not to exceed the thickness of the thinner part joined

#### Economy of fillet welding

1. Use the minimum size of fillet weld required for the desired strength. Increasing the size of a fillet weld in direct proportion, the volume (and costs) of it will increase with the square of its size.
2. Locate weld to avoid eccentricity, to be readily accessible, and in down-welding position.
3. Apply fillet weld transversely to the force to achieve greater strength.



PARALLEL  
WELD



TRANSVERSE  
WELD

#### Allowable Load

The strength of the welds is a function of the welding procedure and the electrode used. For carbon steel joints commonly used maximum allowable static load 9,600 (9.6 kips) lbs per 1 square inch of the fillet weld leg-area, or 600 lbs on a 1/8" leg x 1" long fillet weld. For example: the allowable load on a 1/4" x 1" long fillet weld 4 x 600 = 2,400 lbs.

#### Combined Loads

Shear stress and bending or torsional stresses due to eccentric loadings may be combined vectorially. It is based on the elastic theory and provides a simplified and conservative method.

## DESIGN OF WELDED JOINTS FOR STRUCTURAL MEMBERS

### DEFINITION OF SYMBOLS

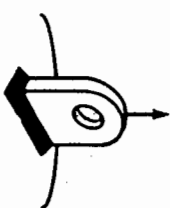
	subjected to bending moment, in <sup>2</sup>
$A_w$ = Length of weld, in.	$V$ = Vertical shear, kips
$f$ = Allowable load on weld, 9.6 kips per in <sup>2</sup> leg-area	$w$ = Fillet weld leg dimension, in
$M$ = Bending moment, kips	$W$ = Load on fillet weld, kips per lineal inch of weld
$P$ = Allowable concentrated axial load, kips	$W_s$ = Average vertical shear on fillet weld, kips per lin. inch of weld
$S_w$ = Section Modulus of weld lines	$W_b$ = Bending force on weld, kips per lin. inch of weld

### FORMULAS FOR FORCES ON WELD

TENSION OR COMPRESSION	VERTICAL SHEAR	BENDING
 $W = \frac{P}{A_w}$	 $W_s = \frac{V}{A_w}$	 $W_b = \frac{M}{S_w}$
RESULTANT FORCE: $W = \sqrt{W_s^2 + W_b^2 + W^2}$		

#### EXAMPLE #1

Determine the required size of fillet weld. The length of the weld is all around 8.5 inches and the tensional load 20 kips.



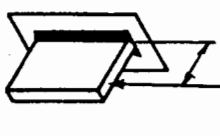
20,000 lbs.

$$W = \frac{P}{A_w} = \frac{20}{8.5} = 2.35 \text{ kips per lin. in.}$$

$$w = \frac{W}{f} = \frac{2.35}{9.6} = 0.24; \text{ use } 1/4" \text{ fillet weld}$$

#### EXAMPLE #2

Determine the required size of fillet weld. The length of the weld 12 inches (6" each side) and the load 9 kips.



9,000 lbs

$$\text{Section modulus, (from table)} \quad S_w = \frac{d^2}{3} = \frac{6^2}{3} = 12 \text{ in}^3$$

$$\text{Bending Force, } \frac{M}{S_w} = \frac{3 \times 9}{12} = 2.25 \text{ kips per lin. inch}$$

$$\text{Shear Force } W_s = \frac{V}{A_w} = \frac{9}{12} = 0.75 \text{ kips per lin. inch}$$

$$\text{Resultant force, } W = \sqrt{W_b^2 + W_s^2} = \sqrt{2.25^2 + 0.75^2} = 2.37 \text{ kips per lin. inch.}$$

$$\text{Fillet weld size, } w = \frac{W}{f} = \frac{2.37}{9.6} = .247", \text{ use } 1/4" \text{ fillet weld}$$



## DESIGN OF WELDED JOINTS

### PROPERTIES OF WELD OUTLINES

	$S_w = \frac{d^2}{6}$
	$S_w = \frac{d^2}{3}$
	$S_w = bd$
	$S_w (\text{top}) = \frac{d(4b+d)}{6}$ $S_w (\text{bottom}) = \frac{d^3(4b+d)}{6(2b+d)}$ (max. stress at bottom)
	$S_w = bd + \frac{d^2}{6}$
	$S_w (\text{top}) = \frac{d(2b+d)}{3}$ $S_w (\text{bottom}) = \frac{d^2(2b+d)}{3(b+d)}$ (max. force at bottom)
	$S_w = bd + \frac{d^2}{3}$
	$S_w = \frac{\pi d^2}{4}$

## EXAMPLE CALCULATIONS

### EXAMPLE #1

A platform is supported by 3 equally spaced channels bolted to lugs. The floor load is 125 lbs per square feet. The other design data are shown in the figures.

Determine the stresses in the channels and bolts.

One half of the total load is supported by the middle channel, thus the stress conditions only of this channel shall be investigated.

Area supported by the middle channel:

$$\frac{60}{360} \cdot 7854 (12^2 - 5^2) = 15,577 \text{ sq. ft.}$$

$$\text{Load: } 15,577 \times 125 = 1947 \text{ lbs}$$

Center of gravity (see page 434):

$$b = 38.197 \frac{(R^3 - r^3) \sin \alpha}{(R^2 - r^2) \propto}$$

$$38.197 \frac{(6^3 - 2.5^3) 0.500}{(6^2 - 2.5^2) 30} = 4.28$$

Moment:

$$1947 \times 2.28 \times 12 = 53,270 \text{ in-lb}$$

Moment of inertia:

$$I_{xx} = \frac{bd^3}{12} - \frac{b_i d_i^3}{12} =$$

$$I_{xx} = \frac{2 \times 12^3}{12} - \frac{1.75 \times 11.5^3}{12} = 66,206$$

Section modulus:

$$Z = \frac{I}{y} = \frac{66,206}{6} = 11,034$$

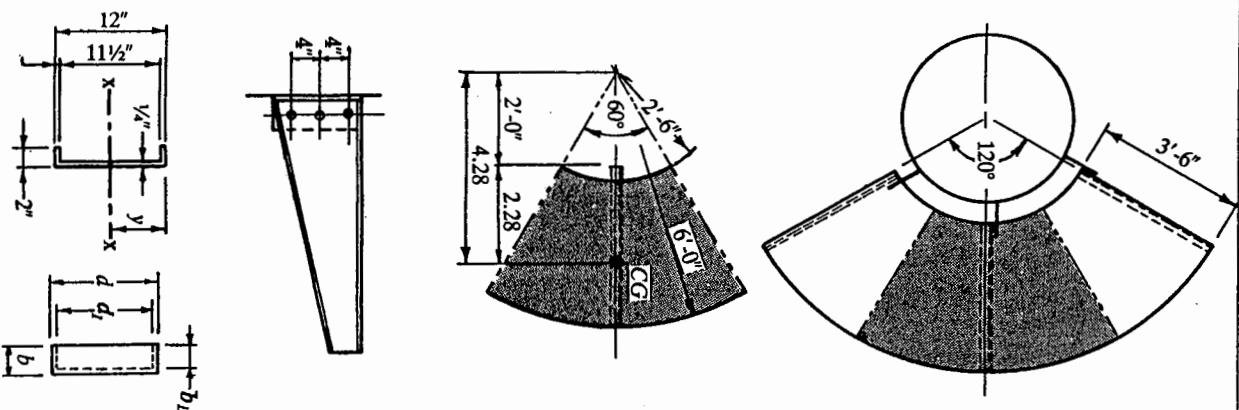
Stress in channel at the support:

$$S = \frac{53,270}{11,034} = 4828 \text{ psi}$$

Stress in bolts: (center on bolts pattern) load on one bolt:  $\frac{53,270}{8} = 6659 \text{ lb.}$

$$\text{try } \frac{7}{8} \text{ bolt; } A = 0.6013 \text{ in}^2$$

$$S = \frac{6659}{0.6013} = 11074 \text{ psi.}$$





## EXAMPLE CALCULATIONS

### EXAMPLE #2

A vertical vessel is supported by two beams.

The weight of the vessel is 20,000 lbs  
 $l = 120$  in Assume pin joint

The load on one beam:

Moment:

$$M = \frac{Pl}{4} = \frac{10,000 \times 120}{4} = 300,000 \text{ in-lb}$$

Required section modulus:

$$Z = \frac{M}{S_A}$$

Assuming for allowable stress,  $S_A$ : 20,000 psi,

Section modulus:

$$Z = \frac{300,000}{20,000} = 15 \text{ in}^3$$

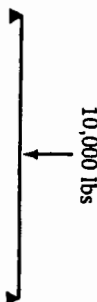
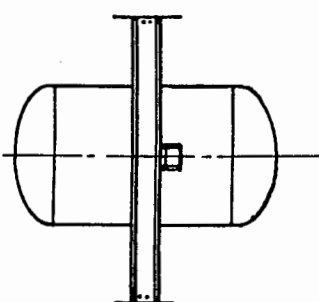
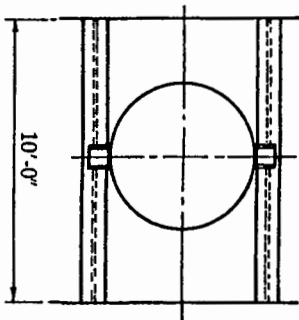
The section modulus of a wide flange W/F 8 × 20 is 17 in<sup>3</sup>  
 Moment of inertia: 69.2

Stress at the center of wide flange:

$$S = \frac{M}{Z} = \frac{300,000}{17} = 17,647 \text{ psi}$$

Deflection:

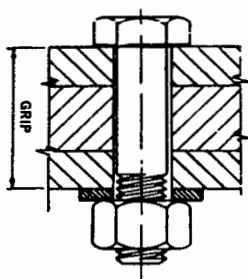
$$\Delta = \frac{Pl^3}{48EI} = \frac{10,000 \times 120^3}{48 \times 29,000,000 \times 69.2} = 1.794 \text{ in} \sim \frac{3}{16} \text{ in.}$$



## BOLTED CONNECTIONS FOR STRUCTURAL MEMBERS

### REQUIRED LENGTH OF BOLTS

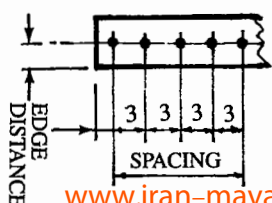
NOMINAL BOLT DIAMETER in.	REQUIRED BOLT LENGTH = GRIP + DIMENSIONS BELOW, inches		
	NO WASHERS	1 WASHER	2 WASHERS
1/2	1 1/16	3/4	1
3/8	7/8	1 1/16	1 3/16
3/4	1	1 3/16	1 3/16
7/8	1 1/8	1 3/16	1 3/16
1	1 1/4	1 3/16	1 3/16
1 1/8	1 1/2	1 11/16	1 3/16
1 1/4	1 5/8	1 13/16	1 13/16
1 3/4	1 3/4	1 15/16	2 1/16
1 1/2	1 1/4	2 1/16	2 3/16



### MINIMUM EDGE DISTANCE AND SPACE

The minimum distance from the center of bolt hole to any edge

BOLT DIAMETER in	MINIMUM EDGE DISTANCE	
	AT SHEARED EDGES	AT ROLLED OR GAS CUT EDGES
1/2	3/4	3/4
3/8	1 1/8	7/8
3/4	1 1/4	1
7/8	1 1/2	1 1/8
1	1 3/4	1 1/4
1 1/8	2	1 1/2
1 1/4	2 1/4	1 3/4
1 1/2	2 3/4	1 7/8



BOLT HOLES shall be 1/16" larger than bolt diameter.

### ALLOWABLE LOADS in kips

SA 307 unfinished bolts and connected material: SA 283C, SA 285C, SA 36

Nominal Diameter of Bolt	3/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2
Tensile Stress Area, in	0.2260	0.3345	0.4617	0.6057	0.7633	0.9691	1.1549	1.4053
Allowable Loads in Tension	4.52	6.69	9.23	12.11	15.27	19.38	23.10	28.11
Allowable Loads in Shear	3.07	4.42	6.01	7.85	9.94	12.27	14.85	17.67
	Double	6.14	8.84	12.03	15.71	19.88	24.54	29.70
								35.34



## PART V. MISCELLANEOUS

1. Abbreviations .....	466
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## ABBREVIATIONS

COMPILED: From 1. ASA Z32.13-1950 ABBREVIATIONS FOR USE ON DRAWINGS  
2. ASA Z10.1-1941 ABBREVIATIONS FOR SCIENTIFIC & ENGINEERING TERMS

ADDED:  
ABBREVIATIONS GENERALLY USED ON VESSEL & PIPING DRAWINGS

AB	Anchor Bolt	CCW	Counter Clockwise
AISC	American Institute of Steel Construction	cfm	Cubic Foot per Minute
ALLOW	Allowance	CFW	Continuous Fillet Weld
ANSI	Allowable	CG	Commercial Grade
ASA	American National Standards Institute	CG	Center of Gravity
API	American Standard Association	cm	Centimeter
APPROX	American Petroleum Institute	ℓ to ℓ	Centerline to Centerline
ASB	Approximately	CO	Company
ASME	Asbestos	CONC	Concentric
ASTM	American Society of Mechanical Engineers	CPLG	Coupling
AVG	American Society for Testing Mat'ls. Average	CORR	Corrosion Allowance
bbl	Barrel	COUP	Coupling
BC	Bolt Circle	CRS	Cold Rolled Steel
BEV	Bevel	CS	Carbon Steel
BLD	Blind	C to C	Center to Center
BOP	Bottom of Pipe	CTR	Center
BOT	Bottom	cu	Cubic
BRKT	Bracket	cu. ft.	Cubic Foot
btu	British Thermal Unit	CW	Clockwise
BW	Bevel Weld	CWT	Hundred Weight
BWG	Birmingham Wire Gauge	DC	Downcorner
C	Degree Centigrade	DEH	Double Extra Heavy
CA	Corrosion Allowance	DET	Detail
		DIA	Diameter
		DIAM	Diameter
		DIM	Dimension
		DP	Design Pressure

## ABBREVIATIONS (cont.)

DT'L	Detail	H/A	High Level Alarm
DWG	Drawing	HLL	High Liquid Level
EA	Each	HLSD	High Level Shut
EH	Extra Heavy	HR	Hot Rolled
EL	Elevation	HT	Heat Treatment
ELEV	Elevation	ID	Inside Diameter
ELL	Elbow	in	inches
ELLIP	Ellipse, Elliptical, Ellipsoid	INCL	Including, Included
EQ	Equal, Equally	INS	Inspection
ETC	Et Cetera	INT	Internal
EXT	External	JE	Joint Efficiency
F	Fahrenheit	kg	Kilogram
F-F	Face to Face	l	Liter
F&D	Flanged & Dist'd	lb	Pound
FF	Flat Face	lbf	Pound Force
FIG	Figure	lbs	Pounds
FIN	Finish	LC	Level Control
FLG	Flange	LCV	Liquid Control Valve
FS	Far Side, Forged Steel	LG	Long
ft	Foot, Feet	LG	Level Gage
FT3	Cubic Foot	Lin. ft.	Lineal Foot (Feet)
FW	Fillet Weld	LLA	Low Level Alarm
g	Gram	LLC	Liquid Level Control
GA	Gage	LLSD	Low Level Shut
GALV	Galvanized	LR	Down
gal	Gallon	LS	Long Radius
GG	Gage Glass	LWN	Low Stage
GOL	Gage of Outstanding Leg	m	Meter
gpd	Gallon per Day	MB	Machine Bolt
gpm	Gallon per Minute	MK	Mark
GR	Grade	MAT'L	Material
HVY	Heavy	MAWP	Maximum Allowable Working Pressure
HD	Head	MAX	Maximum
HEMIS	Hemispherical	MH	Manhole
HEX	Hexagonal	MIN	Minimum
HH	Handhole	MKD	Marked
HL	Hole		



## ABBREVIATIONS (cont.)

mm	Millimeter	RAD	Radial
MMSCF	Million Standard Cubic Feet	REF	Reference
MSCF	Thousand Standard Cubic Feet	REINF	Reinforcing
		REPAD	Reinforcing Pad
		REQ'D	Required
MW	Manway	RF	Raised Face
N	North	RJ	Ring Joint
N & C	New & Cold	RTJ	Ring Type Joint
NLL	Normal Liquid Level	RV	Relief Valve
NO	Number	S	Schedule
NOM	Nominal	S/C	Shop Coat
NPS	National Pipe Size	SCF	Standard Cubic Foot
NPT	American National Taper Pipe Thread	SCH	Schedule
		SCR	Screw
NS	Near Side	SCR'D	Screw
NTS	Not to Scale	SDV	Screw
OA	Overall	SERV	Shutdown Valve
OD	Outside Diameter	Sht.	Service Sheet
OR	Outside Radius	SF	Straight Flange
OSHA	Occupational Safety and Health Administration	SHT	Sheet
		SM	Seam
oz	Ounce	SMLS	Seamless
ozs	Ounces	SO	Slip On
P	Pressure	SPA	Spacing
PBE	Plain Both Ends	SPEC	Specification
PC	Pressure Control	SP GR	Specific Gravity
PCS	Pieces	SQ	Square
PCV	Pressure Control Valve	SR	Short Radius
PI	Pressure Indicator	SS	Stainless Steel
PL	Plate	S-S	Seam to Seam
PROJ	Projection	S/S	Standard
PSE	Plain Small End	STD	Steel
psi	Pound per Square Inch	STR	Straddle
psia	Pound per Square Inch Absolute	SUPT	Support
psig	Pound per Square Inch Gage	SYM	Symmetrical
		T&B	Top & Bottom
		TC	Temperature Control
		TBE	Threaded Both Ends

## ABBREVIATIONS (cont.)

PSV	Pressure Safety Valve	TYP	Typical
R	Radius	USAS	United States of America Standards Institute
TEMA	Tubular Exchanger Manufacturers Association	VA	Valve
		VOL	Volume
THD	Threaded, Thread	WJ	With
THK	Thick	WG	Water Gallon
TI	Temperature Indicator	WN	Welding Neck
		WJ OUT	Without
TLE	Threaded Large End	WP	Working Pressure
TOC	Top of Concrete	WT	Weight
TOS	Top of Steel	XH	Extra Heavy
TS	Tube Sheet	XXH	Double Extra Heavy
TSE	Threaded Small End		Heavy
T-T	Tangent to Tangent	XX STG	Double Extra Strong
TW	Tack Weld		
TW	Thermowell		



## CODES, STANDARDS, SPECIFICATIONS

### PRESSURE VESSELS, BOILERS

#### ASME Boiler and Pressure Vessel Code, 2001

- I Power Boilers
- II Materials
- III Nuclear Power Plant Components
- IV Heating Boilers
- V Nondestructive Examination
- VI Recommended Rules for Care and Operation of Heating Boilers
- VII Recommended Rules for Care of Power Boilers
- VIII Pressure Vessels — Division 1, Division 2 and 3 Alternate Rules
- IX Welding and Brazing Qualifications
- X Fiberglass-Reinforced Plastic Pressure Vessels
- XI Rules for Inservice Inspection of Nuclear Power Plant Components

#### British Standards Institution (BSI)

- 1500 — Fusion Welded Pressure Vessels for Use in the Chemical, Petroleum and Allied Industries
- 1515 — Fusion Welded Pressure Vessels for Use in the Chemical, Petroleum and Allied Industries (advanced design and construction)

#### Canadian Standards Association (CSA)

- B-51-M1991 — Code for the Construction and Inspection of Boilers and Pressure Vessels

### TANKS

#### American Petroleum Institute (API)

- Spec 12B Specification for Bolted Tanks for Storage of Production Liquids, 1990
- Spec 12D Specification for Field Welded Tanks for Storage of Production Liquids, 1982

## CODES, STANDARDS, SPECIFICATIONS

(Continued)

- Spec 12F Specification for Shop Welded Tanks for Storage of Production Liquids, 1988
- Std. 620 Recommended Rules for Design and Construction of Large Welded, Low-Pressure Storage Tanks, 1990
- Std. 650 Welded Steel Tanks for Oil Storage, 1988

#### Underwriters Laboratories, Inc. (UL)

- No. 142 Steel Aboveground Tanks for Flammable and Combustible Liquids
- No. 58 Steel Underground Tanks for Flammable and Combustible Liquids

#### American Water Works Association (AWWA)

- No. 30 Flammable & Combustible Liquids Code
- No. 58 Liquefied Petroleum Gases, Storage and Handling
- No. 59 Liquefied Petroleum Gases at Utility Gas Plants

### PIPING

#### American National Standards Institute (ANSI)

- B31.1—1998 Power Piping
- B31.2—1968 Fuel Gas Piping
- B31.3—1999 Chemical Plant and Petroleum Refinery Piping
- B31.4—1998 Liquid Petroleum Transportation Piping Systems
- B31.5—2000 Refrigeration Piping with 1978 Addenda
- B31.8—1999 Gas Transmission and Distribution Piping Systems

### HEATEXCHANGERS

#### Expansion Joint Manufacturers Association, Inc.

- Standards, 5th Edition with 1985 Addenda and Practical Guide to Expansion Joints

### PIPES

#### American National Standards Institute (ANSI)

- ANSI B36.19—1976 Stainless Steel Pipe
- ANSI/ASME B36.10M—1985 Welded and Seamless Wrought Steel Pipe



## CODES, STANDARDS, SPECIFICATIONS

### FITTINGS, FLANGES, AND VALVES

#### American National Standards Institute (ANSI)

- ANSI B16.25-1992 Buttwelding Ends
- ANSI B16.10-1992 Face-to-Face and End-to-End Dimensions of Ferrous Valves
- ANSI B16.9-1993 Factory-Made Wrought Steel Buttwelding Fittings
- ANSI B16.14-1991 Ferrous Pipe Plugs, Bushings, and Locknuts with Pipe Threads
- ANSI B16.11-1991 Forged Steel Fittings, Socket-Welding and Threaded
- ANSI B16.5 1988 Pipe Flanges and Flanged Fittings, Steel, Nickel Alloy and Other Special Alloys
- ANSI B16.20-1993 Ring-Joint Gaskets and Grooves for Steel Pipe Flanges

### MATERIALS

#### The American Society for Testing and Materials (ASTM)

- 1989 Annual Book of ASTM Standards, Section 1 Iron and Steel Products
- Volume 01.01/Steel Piping, Tubing and Fittings, 131 Standards
- Volume 01.03/Steel Plate, Sheet, Strip, and Wire, 95 Standards
- Volume 01.04/Structural Steel, Concrete Reinforcing Steel, Pressure Vessel Plate and Forgings, Steel Rails, Wheels, and Tires — 135 Standards

### MISCELLANEOUS

#### International Conference of Building Officials (ICBO)

- Uniform Building Code — 1991

#### Steel Structures Painting Council (SSPC)

- Steel Structures Painting Manual
- Volume 1, Good Painting Practice
- Volume 2, Systems and Specifications

#### Uniform Boiler and Pressure Vessel Laws Society

- Synopsis of Boiler and Pressure Vessel Laws, Rules and Regulations by States, Cities, Counties and Provinces (United States and Canada) —1990

## CODES, STANDARDS, SPECIFICATIONS

### Environment Protection

Code of Federal Regulations, Protection of Environment, 1988 40-Parts 53 to 60 (Obtainable from any Government Printing Office).

### American Society of Civil Engineers (ASCE)

- Minimum Design Loads for Buildings and Other Structures
- ANSI/ASCE 7-95 (Formerly ANSI/ASCE 7-93)



# TABULATION OF THE BOILER AND PRESSURE VESSEL LAWS OF THE UNITED STATES AND CANADA

JURISDICTION	I	III	IV	VIII(1)	VIII(2)	XI	EXPLANATION
Alabama	Y	Y	Y	Y	Y	Y	The column headings indicate the Sections and Divisions of ASME Boiler and Pressure Vessel Code.  I - Power Boilers II - Nuclear Components IV - Heating Boilers VIII(1) - Pressure Vessels VIII(2) - Pressure Vessels IX - Inservice Inspection Nuclear Y - Design and construction shall conform to the appropriate code section. Y <sub>3</sub> - Denotes Section VIII, Division 2 and 3. N - Design and construction is not covered by law. * - Only portions of code.
Alaska	Y	Y	Y	Y	Y	Y	
Arizona	Y	N	Y	N	N	N	
Arkansas	Y	Y	Y	Y	Y	Y	
California	Y	Y	Y	Y	Y	Y	
Colorado	Y	Y	Y	Y	Y <sub>3</sub>	Y	
Connecticut	Y	Y	Y	N	N	N	
Delaware	Y	Y	Y	Y	Y <sub>3</sub>	Y	
Florida Y	Y	N	Y	N	N	N	
Georgia	Y	Y	Y	Y	Y	Y	
Hawaii	Y	N	Y	Y	Y	N	
Idaho	Y	Y	Y	Y	Y <sub>3</sub>	Y	The column headings indicate the Sections and Divisions of ASME Boiler and Pressure Vessel Code.  I - Power Boilers II - Nuclear Components IV - Heating Boilers VIII(1) - Pressure Vessels VIII(2) - Pressure Vessels IX - Inservice Inspection Nuclear Y - Design and construction shall conform to the appropriate code section. Y <sub>3</sub> - Denotes Section VIII, Division 2 and 3. N - Design and construction is not covered by law. * - Only portions of code.
Illinois	Y	Y	Y	Y	Y	Y	
Indiana	Y	Y	Y	Y	Y	Y	
Iowa	Y	Y	Y	Y	Y <sub>3</sub>	N	
Kansas	Y	Y	Y	Y	Y <sub>3</sub>	Y	
Kentucky	Y	Y	Y	Y	Y	N	
Louisiana	Y	N	Y	N	N	N	
Maine	Y	Y	Y	Y	Y <sub>3</sub>	Y	
Maryland	Y	Y	Y	Y	Y <sub>3</sub>	Y	
Massachusetts	Y	Y	Y	Y	N	Y	
Michigan	Y	Y	Y	Y	N	Y	The column headings indicate the Sections and Divisions of ASME Boiler and Pressure Vessel Code.  I - Power Boilers II - Nuclear Components IV - Heating Boilers VIII(1) - Pressure Vessels VIII(2) - Pressure Vessels IX - Inservice Inspection Nuclear Y - Design and construction shall conform to the appropriate code section. Y <sub>3</sub> - Denotes Section VIII, Division 2 and 3. N - Design and construction is not covered by law. * - Only portions of code.
Minnesota	Y	Y	Y	Y	N	Y	
Mississippi	Y	N	Y	Y	N	N	
Missouri	Y	Y	Y	Y	Y <sub>3</sub>	N	
Montana	Y	N	Y	N	N	N	
Nebraska	Y	N	Y	Y	Y <sub>3</sub>	N	
Nevada	Y	N	Y	Y	Y	N	
New Hampshire	Y	N	Y	Y	Y	Y	
New Jersey	Y	Y	Y	Y	Y	Y	
New Mexico	Y	N	Y	N	N	N	
New York	Y	N	Y	Y	N	N	The column headings indicate the Sections and Divisions of ASME Boiler and Pressure Vessel Code.  I - Power Boilers II - Nuclear Components IV - Heating Boilers VIII(1) - Pressure Vessels VIII(2) - Pressure Vessels IX - Inservice Inspection Nuclear Y - Design and construction shall conform to the appropriate code section. Y <sub>3</sub> - Denotes Section VIII, Division 2 and 3. N - Design and construction is not covered by law. * - Only portions of code.
North Carolina	Y	Y	Y	Y	Y	Y	
North Dakota	Y	N	Y	Y	Y <sub>3</sub>	N	
Ohio	Y	Y	Y	Y	Y	Y	
Oklahoma	Y	N	Y	Y	Y	N	
Oregon	Y	Y	Y	Y	Y	Y	
Pennsylvania	Y	Y	Y	Y	Y	Y	
Puerto Rico	Y	Y	Y	Y	Y	Y	
Rhode Island	Y	Y	Y	Y	Y	Y	
South Carolina	N	N	N	N	N	N	
South Dakota	Y	Y	Y	Y	N	N	The column headings indicate the Sections and Divisions of ASME Boiler and Pressure Vessel Code.  I - Power Boilers II - Nuclear Components IV - Heating Boilers VIII(1) - Pressure Vessels VIII(2) - Pressure Vessels IX - Inservice Inspection Nuclear Y - Design and construction shall conform to the appropriate code section. Y <sub>3</sub> - Denotes Section VIII, Division 2 and 3. N - Design and construction is not covered by law. * - Only portions of code.
Tennessee	Y	Y	Y	Y	Y <sub>3</sub>	Y	
Texas	Y	Y	Y	N	N	Y	
Utah	Y	Y	Y	Y	Y <sub>3</sub>	Y	
Vermont	Y	N	Y	Y	Y	N	
Virginia	Y	Y	Y	Y	Y	Y	

# TABULATION OF THE BOILER AND PRESSURE VESSEL LAWS OF THE UNITED STATES AND CANADA (Continued)

JURISDICTION	I	III	IV	VIII(1)	VIII(2)	XI	EXPLANATION
Washington	Y	Y	Y	Y	Y <sub>3</sub>	Y	The column headings indicate the Sections and Divisions of ASME Boiler and Pressure Vessel Code.  I - Power Boilers II - Nuclear Components IV - Heating Boilers VIII(1) - Pressure Vessels VIII(2) - Pressure Vessels IX - Inservice Inspection Nuclear Y - Design and construction shall conform to the appropriate code section. Y <sub>3</sub> - Denotes Section VIII, Division 2 and 3. N - Design and construction is not covered by law. * - Only portions of code.
West Virginia	Y	Y	Y	N	N	N	
Wisconsin	Y	Y	Y	Y	Y <sub>3</sub>	Y	
Wyoming	N	N	N	Y	N	N	
Alberta	Y	Y	Y	Y	Y	Y	
British Columbia	Y	Y	Y	Y	Y	Y <sub>3</sub>	
Manitoba	Y	Y	Y	Y	Y	Y	
New Brunswick	Y	Y	Y	Y	Y	Y	
Newfoundland & Labrador	Y	N	Y	Y	Y	N	
Northwest Territories	Y	N	Y	Y	Y	N	
Nova Scotia	Y	N	Y	Y	Y	N	The column headings indicate the Sections and Divisions of ASME Boiler and Pressure Vessel Code.  I - Power Boilers II - Nuclear Components IV - Heating Boilers VIII(1) - Pressure Vessels VIII(2) - Pressure Vessels IX - Inservice Inspection Nuclear Y - Design and construction shall conform to the appropriate code section. Y <sub>3</sub> - Denotes Section VIII, Division 2 and 3. N - Design and construction is not covered by law. * - Only portions of code.
Ontario	Y	Y	Y	Y	Y <sub>3</sub>	Y	
Prince Edward Island	Y	Y	Y	Y	Y	N	
Quebec	Y	Y	Y	Y	Y	N	
Saskatchewan	Y	Y	Y	Y	Y	Y	
Yukon Territory	Y	N	Y	Y	Y	N	
Albuquerque	Y	N	Y	N	N	N	
Buffalo	Y	Y	Y	Y	N	N	
Chicago	Y	Y	Y	Y	Y	Y	
Denver	Y	Y	Y	Y	Y	Y	
Des Moines	Y	N	Y	N	N	N	The column headings indicate the Sections and Divisions of ASME Boiler and Pressure Vessel Code.  I - Power Boilers II - Nuclear Components IV - Heating Boilers VIII(1) - Pressure Vessels VIII(2) - Pressure Vessels IX - Inservice Inspection Nuclear Y - Design and construction shall conform to the appropriate code section. Y <sub>3</sub> - Denotes Section VIII, Division 2 and 3. N - Design and construction is not covered by law. * - Only portions of code.
Detroit	Y	Y	Y	Y	Y	Y	
Los Angeles	Y	Y	Y	Y	Y	N	
Miami	Y	Y	Y	Y	Y	N	
Milwaukee	Y	Y	Y	Y	Y	N	
New Orleans	Y	Y	Y	Y	Y	Y	
New York	Y	N	N	Y	N	N	
Omaha	Y	Y	Y	Y	Y	N	
St. Joseph	Y	Y	Y	Y	Y	N	
Seattle	Y	Y	Y	Y	Y	Y	
Spokane	Y	N	Y	Y	Y	N	The column headings indicate the Sections and Divisions of ASME Boiler and Pressure Vessel Code.  I - Power Boilers II - Nuclear Components IV - Heating Boilers VIII(1) - Pressure Vessels VIII(2) - Pressure Vessels IX - Inservice Inspection Nuclear Y - Design and construction shall conform to the appropriate code section. Y <sub>3</sub> - Denotes Section VIII, Division 2 and 3. N - Design and construction is not covered by law. * - Only portions of code.
Tacoma	Y	Y	Y	Y	Y	N	
Tucson	Y	N	Y	Y	Y	N	
Tulsa	Y	N	Y	Y	Y	N	
University City	Y	N	Y	Y	Y	N	
Dade County	Y	N	Y	Y	Y	N	
Jefferson Parish	Y	Y	Y	Y	Y	N	
St. Louis County	Y	Y	Y	Y	Y	N	
District of Columbia	Y	Y	Y	Y	Y	Y	



# LIST OF ORGANIZATIONS SPONSORING OR PUBLISHING CODES AND STANDARDS OR SPECIFICATIONS DEALING WITH PIPING AND PRESSURE VESSELS

T = Telephone • F = Fax • E = e-mail • W = Website

<b>ABS</b> American Bureau of Shipping Two World Trade Center, 106th Floor New York, NY 10048 USA	T F E W	212-839-5016 212-839-5208 devans@eagle.org www.eagle.org
<b>AISG</b> American Insurance Services Group, Inc. 85 John Street New York, NY 10038	T F E W	212-669-0427 212-669-0550 rthomings@aisg.org www.aisg.org
<b>ANSI</b> American National Standards Institute 11 West 42nd Street New York, NY 10026	T F E W	212-642-4900 212-302-1286 quote@ansi.org www.ansi.org
<b>API</b> American Petroleum Institute 1220 L Street Northwest Washington, D.C. 20005	T F E W	202-682-8375 202-962-4776 publications@api.org www.api.org
<b>ASCE</b> The American Society of Civil Engineers 1801 Alexander Bell Drive Reston, VA 20191-4400	T F E W	800-548-2723 703-295-6333 marketing@asce.org www.pubs.asce.org
<b>ASME</b> The American Society of Mechanical Engineers 3 Park Avenue New York, NY 10016-5980	T F E W	800-843-2763 973-882-1717 infocentral@asme.org www.asme.org
<b>ASTM</b> American Society for Testing and Material 100 Barr Harbor Drive West Conshohocken, PA 19428	T F E W	610-832-9500 610-832-9555 service@astm.org www.astm.org
<b>AWWA</b> American Water Works Association 6666 West Quincy Avenue Denver, CO 80235	T F E W	303-794-7711 303-347-0804 www.awwa.org
<b>AWS</b> American Welding Society P.O. Box 351040 Miami, FL 33135	T F E W	800-334-9353 305-443-7559 www.aws.org
<b>BSI</b> British Standards Institution 389 Chiswick High Road London W4 4AL *British Standard Publications are available from The American National Standards Institute	T F E W	181-996-7474 181-996-7048 www.bsi.org.uk/bsi

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(Continued)

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<b>Commercial Union Insurance Company of America</b> 1 Beacon Street Boston, MA 02108	T F E W	617-725-7309 617-725-6094 www.cuusa.com
<b>CGA</b> Compressed Gas Association, Inc. 1725 Jefferson Davis Highway, Ste. 1004 Arlington, VA 22202	T F E W	703-412-0900 703-412-0128 customerservice@cganet.com www.cganet.com
<b>EFMA</b> Expansion Joint Manufacturers Assoc. 25 North Broadway Terrytown, NY 10591	T F E W	914-332-0040 914-332-1541 ejma@ejma.org www.ejma.org
<b>HEI</b> Heat Exchange Institute, Inc. 1300 Summer Avenue Cleveland, OH 44115	T F E W	216-241-7333 216-241-0105 hei@taol.com www.taol.com/hei
<b>ICBO</b> International Conference of Building Officials 5360 Workman Mill Road Whittier, CA 90601	T F E W	800-284-4406 888-329-4226 www.icbo.org
<b>National Board of Boiler and Pressure Vessel Inspectors</b> 1055 Crupper Avenue Columbus, OH 43229	T F E W	614-888-2463 614-847-1147 orders@nationalboard.org www.nationalboard.org
<b>NFPA</b> National Fire Protection Association P.O. Box 9101, Batterymarch Park Quincy, MA 02269	T F E W	800-344-3555 800-593-6372
<b>Occupational Safety &amp; Health Administration</b> 200 Constitution Avenue, N.W. Washington, D.C.	T F E W	202-219-4667 202-219-9266
<b>PVRC</b> Pressure Vessel Research Council (formerly: Welding Research Council) 3 Park Avenue, 27th Floor New York, NY 10016	T F E W	212-705-7956 212-371-9622 wrc@forengineers.org www.forengineers.org/wrc

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Steel Tank Institute 570 Oakwood Road Lake Zurich, IL 60047	T F E W	847-438-8265 847-438-8766 ankiefer@interaccess.com www.steel-tank.com
TEMA Tubular Exchanger Manufacturers 25 North Broadway Terrytown, NY 10591	T F E W	914-332-0040 914-332-1541 tema@tema.org www.tema.org
SSPC The Society for Protective Coatings (formerly: Steel Structure Painting Council) 40 24th Street, 6th Floor Pittsburgh, PA 15222	T F E W	412-281-2331 412-281-9992 books@sspc.org www.sspc.org
UL Underwriters Laboratories, Inc. 333 Pflingsten Road Northbrook, IL 60062	T F E W	847-272-8800 847-509-6235 walker@ul.com www.ul.com
UBPVL Uniform Boiler and Pressure Vessel Laws Society 308 Evergreen Road, Ste. 240 Louisville, KY 40243	T F E W	502-244-6029 502-244-6030 ray@ubolier.com www.ubolier.com
United States Coast Guard 2100 Second Street S.W. Washington, D.C. 20593	T F E W	202-267-2967 202-267-4816 comd.uscg.mil
US EPA Headquarters Information Resources Center Public Access Ariel Rios Building 1200 Pennsylvania Ave., N.W. (3404) Washington, D.C. 20460	T F E W	202-260-5922 202-260-6257 E-public-access@epa.gov www.epa.gov

## LITERATURE

1. S. Timoshenko, *Strength of Materials*, 1955, D. Van Nostrand Co., New York.
2. S. P. Timoshenko, *Theory of Plates and Shells*, 1959, McGraw-Hill Book Co., New York.
3. R. J. Roark and W. C. Young, *Formulas for Stress and Strain, 5th Edition*, 1975, McGraw-Hill Book Co., New York.
4. K. K. Mahajan, *Design of Process Equipment, 2nd Edition*, 1985, Pressure Vessel Handbook Publishing, Inc., Tulsa, OK.
5. L. E. Brownell and R. H. Young, *Process Equipment Design: Vessel Design*, 1956, John Wiley and Sons, New York. (Out of print.)
6. M. B. Bickel and C. Ruiz, *Pressure Vessel Design and Analysis*, 1967, Mcmillan Publishing Co., Inc., New York.
7. H. H. Bednar, *Pressure Vessel Design Handbook*, 2nd Edition, 1986, Van Nostrand Reinhold Co., New York.
8. S. S. Gill, *The Stress Analysis of Pressure Vessels and Pressure Vessel Components*, 1970, Pergamon Press, New York.
9. J. F. Harvey, *Theory and Design of Modern Pressure Vessels, 2nd Edition*, 1974, Van Nostrand Reinhold Co., New York.
10. *Pressure Vessels and Piping: Design and Analysis*, (Collected Papers), Volume I, Analysis, 1972, ASME.
11. *Pressure Vessels and Piping: Design and Analysis*, (Collected Papers), Volume II, Components and Structural Dynamics, 1972, ASME.
12. *Pressure Vessels and Piping: Design and Analysis*, (Collected Papers), Volume III, Materials and Fabrication, 1976, ASME.
13. W. Soedel, *Vibrations of Shells and Plates*, 1981, Marcel Dekker, Inc., New York.
14. W. Flügge, *Stresses in Shells, 2nd Edition*, 1973, Springer - Verlag, New York.
15. R. Szilád, *Theory and Analysis of Plates*, 1974, Prentice-Hall, Inc., Englewood Cliffs, NJ.



16. M. Hetényi, *Beams on Elastic Foundation*, 1974, The University of Michigan Press, Ann Arbor.
17. *Foundation Design Handbook* (Collected Papers), 1968, Hydrocarbon Processing, Houston, TX.
18. *Design of Flanges for Full Face Gaskets*, Bulletin No. 45, Taylor Forge & Pipe Works, Chicago, IL.
19. M. L. Betterley, *Sheet Metal Drafting*, 1961, McGraw-Hill Book Co., Inc., New York.
20. M. H. Jawad & J. R. Farr, *Structural Analysis and Design of Process Equipment*, 1984, John Wiley & Sons, New York.
21. Kohan, Anthony Lawrence, *Pressure Vessel Systems*, 1987, McGraw-Hill Book Company, New York, NY.
22. Moss, Dennis R., *Pressure Vessel Design Manual*, 1987, Gulf Publishing Co., Houston, TX.

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## DEFINITIONS

**Abrasion** — The removal of surface material from any solid through the frictional action of another solid, a liquid, or a gas or combination thereof.

**Absolute Pressure** — The pressure above the absolute zero value of pressure that theoretically obtains in empty space or at the absolute zero of temperature, as distinguished from gage pressure.

**Alloy** — Any of a large number of substances having metallic properties and consisting of two or more elements; with few exceptions, the components are usually metallic elements.

**Angle Joint** — A joint between two members located in intersecting planes between zero (a butt joint) and 90 deg. (a corner joint). (Code U-A-60)

**Angle Valve** — A valve, usually of the globe type, in which the inlet and outlet are at right angles.

**Annealing** — Annealing generally refers to the heating and controlled cooling of solid material for the purpose of removing stresses, making it softer, refining its structure or changing its ductility, toughness or other properties. Specific heat treatments covered by the term annealing include black annealing, blue annealing, box annealing, bright annealing, full annealing, graphitizing, malleabilizing and process annealing.

**Arc Welding** — A group of welding processes wherein coalescence is produced by heating with an electric arc, with or without the application of pressure and with or without the use of filler metal.

**Automatic Welding** — Welding with equipment which performs the entire welding operation without constant observation and adjustment of the controls by an operator. The equipment may or may not perform the loading and unloading of the work.



**Backing** — Material backing up the joint during welding to facilitate obtaining a sound weld at the root.  
**Backing Strip** is a backing in a form of a strip.

**Brittle Fracture** — The tensile failure with negligible plastic deformation of an ordinary ductile metal.

**Brittleness** — Materials are said to be brittle when they show practically no permanent distortion before failure.

**Bushing** — A pipe fitting for connecting a pipe with a female fitting of larger size. It is a hollow plug with internal and external threads.



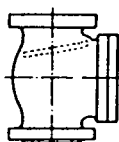
**Butt Weld** — A weld joining two members lying approximately in the same plane. Butt welded joints in pressure vessel construction shall have complete penetration and fusion.  
 Types of butt welded joints:  
 Single or Double Bevel Joint, Square Butt Joint, Full Penetration, Penetration Butt Joint, Butt Joints with or without backing strips.



**Centroid of an Area (Center of Gravity of an Area)** — That point in the plane of the area about any axis through which the moment of the area is zero; it coincides with the center of gravity of the area materialized as an infinitely thin homogeneous and uniform plate.



**Chain Intermittent Fillet Welds** — Two lines of intermittent fillet welding in a tee or lap joint, in which the increments of welding in one line are approximately opposite to those in the other line.



**Check Valve** — A valve designed to allow a fluid to pass through in one direction only. A common type has a plate so suspended that the reverse flow aids gravity in forcing the plate against a seat, shutting off reverse flow.

**Chipping** — One method of removing surface defects such as small fissures or seams from partially worked metal. If not eliminated, the defects might carry through to the finished material. If the defects are removed by means of a gas torch the term "desanding" or "scarfing" is used.

**Clad Vessel** — A vessel made from plate having a corrosion resistant material integrally bonded to a base of less resistant material. (Code UA-60)

**Complete Fusion** — Fusion which has occurred over the entire base-metal surfaces exposed for welding.

**Complete Penetration** — Penetration which extended completely through the joint.

**Corner Joint** — A welded joint at the junction of two parts located approximately at right angles to each other.

**Corrosion** — Chemical erosion by motionless or moving agents. Gradual destruction of a metal or alloy due to chemical processes such as oxidation or the action of a chemical agent.

**Corrosion Fatigue** — Damage to or failure of a

metal due to corrosion combined with fluctuating fatigue stresses.

**Coupling** — A threaded sleeve used to connect two pipes. They have internal threads at both ends to fit external threads on pipe.

**Creep** — Continuous increase in deformation under constant or decreasing stress. The term is usually used with reference to the behavior of metals under tension at elevated temperatures. The similar yielding of a material under compressive stress is usually called *plastic flow* or *flow*.

**Damaging Stress** — The least unit stress, of a given kind and for a given material and condition of service, that will render a member unfit for service before the end of its normal life. It may do this by producing excessive set, or by causing creep to occur at an excessive rate, or by causing fatigue cracking, excessive strain hardening, or rupture.

**Deformation (Strain)** — Change in the form or in the dimension of a body produced by stress. *Elongation* is often used for tensile strain, *compression* or *shortening* for compressive strain, and *derrision* for shear strain. *Elastic deformation* is such deformation as disappears on removal of stress; *permanent deformation* is such deformation as remains on removal of stress.

**Design Pressure** — The pressure used in determining the minimum permissible thickness or physical characteristics of the different parts of the vessel. (Code UA-60)

**Design Temperature** — The mean metal temperature (through the thickness) expected under operating conditions for the part considered. (Code UG-20)

**Discontinuity, Gross Structural** — A source of stress or strain intensification which affects a relatively large portion of a structure and has a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles, and junctions between shells of different diameters or thicknesses.

**Discontinuity, Local Structural** — A source of stress or strain intensification which affects a relatively small volume of material and does not have a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples are small fillet radii, small attachments, and partial penetration welds.

**Double-Welded Butt Joint** — A butt joint welded from both side.



**Double-Welded Lap Joint** — A lap joint in which the overlapped edges of the members to be joined are welded along the edges of both members.

**Ductility** — The ability of a metal to stretch and become permanently deformed without breaking or cracking. Ductility is measured by the percentage reduction in area and percentage elongation of test bar.

**Eccentricity** — A load or component of a load normal to a given cross section of a member is eccentric with respect to that section if it does not act through the centroid. The perpendicular distance from the line of action of the load to either principal central axis is the *eccentricity* with respect to that axis.

**Efficiency of a Welded Joint** — The efficiency of a welded joint is expressed as a numerical quantity and is used in the design of a joint as a multiplier of the appropriate allowable stress value. (Code UA-60)

**Elastic** — Capable of sustaining stress without permanent deformation; the term is also used to denote conformity to the law of stress-strain proportionality. An elastic stress or elastic strain is a stress or strain within the elastic limit.

**Elastic Limit** The least stress that will cause permanent set.

**Electroslag Welding** — A welding process in which consumable electrodes are fed into a joint containing flux; the current melts the flux, and the flux in turn melts the faces of the joint and the electrodes, allowing the weld

metal to form a continuously cast ingot between the joint faces. Used in pressure vessel construction when back of the welding is not accessible. All butt welds joined by electroslag welding shall be examined radiographically for their full length. (Code UW-11) (a) (6)

**Endurance Limit (Fatigue Strength)** — By endurance limit of a material is usually meant the maximum stress which can be reversed an indefinitely large number of times without producing fracture.

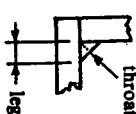
**Erosion-Corrosion** — Attack on a metal surface resulting from the combined effects of erosion and corrosion.

**Expansion Joint** — A joint whose primary purpose is not to join pipe but to absorb that longitudinal expansion in the pipe line due to heat.

**Factor of Safety** — The ratio of the load that would cause failure of a member or structure, to the load that is imposed upon it in service.

**Fatigue** — Tendency of materials to fracture under many repetitions of a stress considerably less than the ultimate static strength.

**Fiber Stress** — A term used for convenience to denote the longitudinal tensile or compressive stress in a beam or other member subject to bending. It is sometimes used to denote this stress at the point or points most remote from the neutral axis, but the term *stress in extreme fiber* is preferable for this purpose. Also, for convenience, the longitudinal elements or filaments of which a beam may be imagined as composed are called *fibers*.



**Fillet Weld** — A weld of approximately triangular cross section joining two surfaces approximately at right angles to each other. The effective stress-carrying area of a fillet weld is assumed to be the product of the throat dimension and the length of the weld. Fillet welds are specified by their leg dimension.



The throat dimension of an equal legged fillet weld is 0.707 times the leg dimension.

Fillet welds may be employed as strength welds for pressure parts of vessels within the limitations given in Table UW-12 of the Code. The allowable load on fillet welds shall equal the product of the weld area (based on minimum leg dimension), the allowable stress value in tension of the material being welded, and a joint efficiency of 55%. (Code UW-18) The allowable stress values for fillet welds attaching nozzles and their reinforcements to vessels are (in shear) 49% of stress value for the vessel material. (Code UW-15)

**Filler Metal** — Material to be added in making a weld.

**Full Fillet Weld** — A fillet weld whose size is equal to the thickness of the thinner member joined.

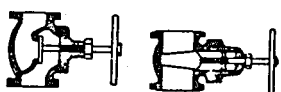
**Gage Pressure** — The amount by which the total absolute pressure exceeds the ambient atmospheric pressure.

**Galvanizing** — Applying a coating of zinc to ferrous articles. Application may be by hot dip process or electrolysis.

**Gas Welding** — A group of welding processes wherein coalescence is produced by heating with a gas flame with or without application of pressure and with or without the use of filler metal.

**Gate Valve** — A valve employing a gate, often wedge-shaped, allowing fluid to flow when the gate is lifted from the seat. Such valves have less resistance to flow than globe valves.

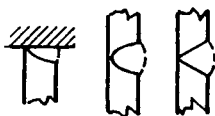
**Globe Valve** — One with a somewhat globe shaped body with a manually raised or lowered disc which when closed rests on a seat so as to prevent passage of a fluid.



**Graphitization** — Precipitation of carbon in the form of graphite at grain boundaries, as occurs if carbon steel is in service long enough above 775°F, and C-Mn steel above 875°F.

Graphitization appears to lower steel strength by removing the strengthening effect of finely disperse iron carbides (cementite) from grains. Fine-grained, aluminum-killed steels seem to be particularly susceptible to graphitization.

**Groove Weld** — A weld made by depositing filler metal in a groove between two members to be joined.



Standard shapes of grooves: V, U and J. Each may be single or double. Stress values for groove welds in tension 74% and in shear 60% of the stress value of vessel material joined by the weld. (Code UW-15)

**Head** — The end (enclosure) of a cylindrical shell. The most commonly used types of heads are hemispherical, ellipsoidal, flanged and dished (torispherical), conical and flat.

**Heat Treatment** — Heat treating operation performed either to produce changes in mechanical properties of the material or to restore its maximum corrosion resistance. There are three principal types of heat treatment: annealing, normalizing, and post-weld heat treatment.

**High-Alloy Steel** — Steel containing large percentages of elements other than carbon.

**Hydrogen Brittleness** — Low ductility of a metal due to its absorption of hydrogen gas, which may occur during an electrolytic process or during cleaning. Also known as acid brittleness.

**Hydrostatic Test** — The completed vessel filled with water shall be subjected to a test pressure which is equal to 1½ times the maximum allowable working pressure to be marked on the vessel or 1½ times the design pressure by agreement between the user and the manufacturer. (Code UG-99)

**Impact Stress** — Force per unit area imposed to material by a suddenly applied force.

**Impact Test** — Determination of the degree of

resistance of a material to breaking by impact, under bending, tensile and torsion loads; the energy absorbed is measured by breaking the material by a single blow.

**Intermittent Weld** — A weld whose continuity is broken by unwelded spaces.

**Isotropic** — Having the same properties in all directions. In discussions pertaining to strength of materials, isotropic usually means having the same strength and elastic properties (modulus of elasticity, modulus of rigidity, Poisson's ratio) in all directions.

**Joint Efficiency** — A numerical value expressed as the ratio of the strength of a riveted, welded, or brazed joint to the strength of the parent metal.

**Joint Penetration** — The minimum depth a groove weld extends from its face into a joint, exclusive of reinforcement.

**Killed Steel** — Thoroughly deoxidized steel, (for example, by addition of aluminum or silicon), in which the reaction between carbon and oxygen during solidification is suppressed. This type of steel has more uniform chemical composition and properties as compared to other types.

**Lap Joint** — A welded joint in which two overlapping metal parts are joined by means of a fillet, plug or slot welds.



**Layer or Laminated Vessel** — A vessel having a shell which is made up of two or more separate layers. (Code UA-60)

**Lag** — See under Fillet Weld.

**Lethal Substances** — Poisonous gases or liquids of such a nature that a very small amount of the gas or of the vapor of the liquid is dangerous to life when inhaled. It is the responsibility of the user of the vessel to determine that the gas or liquid is lethal. (Code UW-2)

**Ligament** — The section of solid material in a tube sheet or shell between adjacent holes.

**Lined Vessel** — A vessel having a corrosion resistant lining attached intermittently to the

vessel wall. (Code UA-60)

**Liquid Penetrant Examination (PT)** — A method of nondestructive examination which provides for the detection of discontinuities open to the surface in ferrous and nonferrous materials which are nonporous. Typical discontinuities detectable by this method are cracks, seams, laps, cold shuts, and laminations. (Code UA-60)

**Loading** — Loadings (loads) are the results of various forces. The loadings to be considered in designing a vessel: internal or external pressure, impact loads, weight of the vessel, superimposed loads, wind and earthquake, local load, effect of temperature gradients. (Code UG-22)

**Low-Alloy Steel** — A hardenable carbon steel generally containing not more than about 1% carbon and one or more of the following alloyed components: < (less than) 2% manganese, < 4% nickel, < 2% chromium, 0.6% molybdenum, and < 0.2% vanadium.

**Magnetic Particle Examination (MT)** — A method of detecting cracks and similar discontinuities at or near the surface in iron and the magnetic alloys of

**Malleable Iron** — Cast iron heat-treated to reduce its brittleness. The process enables the material to stretch to some extent and to stand greater shock.

**Material Test Report** — A document on which the material manufacturer records the results of tests examinations, repairs, or treatments required by the basic material specification to be reported. (Code UA-60)

**Maximum Allowable Stress Value** — The maximum unit stress permissible for any specified material that may be used in the design formulas given in the Code. (UG-23)

**Maximum Allowable Working Pressure** — The maximum gage pressure permissible at the top of a completed vessel in its operating position for a designated temperature. This pressure is based on the weakest element of the vessel using nominal thicknesses exclusive of allowances for corrosion and thickness required for loadings other than pressure. (Code UA-60)

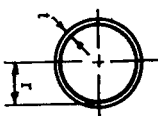


**Membrane Stress** — The component of normal stress which is uniformly distributed and equal to the average value of stress across the thickness of the section under consideration.

**Metal Arc Welding** — An arc welding process in which the electrode supplies the filler metal to the weld.

**Modulus of Elasticity (Young's Modulus)** — The rate of change of unit tensile or compressive stress with respect to unit tensile or compressive strain for the condition of uniaxial stress within the proportional limit. For most, but not all materials, the modulus of elasticity is the same for tension and compression. For nonisotropic materials such as wood, it is necessary to distinguish between the modulus of elasticity in different directions.

**Modulus of Rigidity (Modulus of Elasticity in Shear)** — The rate of change of unit shear stress with respect to unit shear strain, for the condition of pure shear within the proportional limit.



**Moment of Inertia of an Area (Second Moment of an Area)** —

The moment of inertia of an area with respect to an axis is the sum of the products obtained by multiplying each element of the area by the square of its distance from the axis.

The Moment of Inertia ( $I$ ) for thin walled cylinder

about its transverse axis;  $I = \pi r^3 t$

where  $r$  = mean radius of cylinder

$t$  = wall thickness

**Needle Valve** — A valve provided with a long tapering point in place of the ordinary valve disk. The tapering point permits fine graduation of the opening.

**Neutral Axis** — The line of zero fiber stress in any given section of a member subject to bending; it is the line formed by the intersection of the neutral surface and the section.

**Neutral Surface** — The longitudinal surface of zero fiber stress in a member subject to bending; it contains the neutral axis of every section.

**Nipple** — A tubular pipe fitting usually threaded on both ends and under 12 inches in length. Pipe over 12 inches long is regarded as cut pipe.

**Non-Pressure Welding** — A group of welding processes in which the weld is made without pressure.

**Normalizing** — Heating to about 100° F. above the critical temperature and cooling to room temperature in still air. Provision is often made in normalizing for controlled cooling at a slower rate, but when the cooling is prolonged the term used is annealing.

**Notch Sensitivity** — A measure of the reduction in strength of a metal caused by the presence of a notch.

**Notch Strength** — The ratio of maximum tensile load required to fracture a notched specimen to the original minimum cross-sectional area.

**Notch Test** — A tensile or creep test of a metal to determine the effect of a surface notch.

**Operating Pressure** — The pressure at the top of a pressure vessel at which it normally operates. It shall not exceed the maximum allowable working pressure and it is usually kept at a suitable level below the setting of the pressure relieving devices to prevent their frequent opening. (Code UA-60)

**Operating or Working Temperature** — The temperature that will be maintained in the metal of the part of the vessel being considered for the specified operation of the vessel (see UG-20 and UG-23). (Code UA-60)

**Oxidation** or scaling of metals occurs at high temperatures and access of air. Scaling of carbon steels from air or steam is negligible up to 1000°F. Chromium increases scaling resistance of carbon steels. Decreasing oxidation resistance makes austenitic stainless steels unsuitable for operating temperatures above 1500°F.

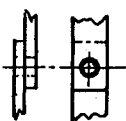
**P-Number** — The number of welding procedure-group. The classification of materials based on hardenability characteristic and the purpose of grouping is to reduce the number of weld procedures. (Code Section IX)

All carbon steel material listed in the Code (with the exception of SA-612) are classified as P-No. 1.

**Pass** — The weld metal deposited by one progression along the axis of a weld.

**Plasticity** — The property of sustaining appreciable (visible to the eye) permanent deformation without rupture. The term is also used to denote the property of yielding or flowing under steady load.

**Plug Valve** — One with a short section of a cone or tapered plug through which a hole is cut so that fluid can flow through when the hole lines up with the inlet and outlet, but when the plug is rotated 90°, flow is blocked.



**Plug Weld** — A weld made in a circular hole in one member of a lap joint. The hole may or may not be partially or completely filled with weld metal.

For pressure vessel construction plug welds may be used in lap joints in reinforcements around openings, in non pressure structural attachments (Code UW-17) and for attachment of heads with certain restrictions. (Code Table UW-12)

**Pneumatic Test** — The completed vessel may be tested by air pressure in lieu of hydrostatic test when the vessel cannot safely be filled with water or the traces of testing liquid cannot be tolerated (in certain services). The pneumatic test pressure shall be 1.25 times the maximum allowable working pressure to be stamped on the vessel. (Code UG-100)

**Poisson's Ratio** — The ratio of lateral unit strain to longitudinal unit strain, under the

condition of uniform and uniaxial longitudinal stress within the proportional limit.

**Porosity** — Gas pockets or voids in metal. (Code UA-60)

**Postweld Heat Treatment** — Heating a vessel to a sufficient temperature to relieve the residual stresses which are the result of mechanical treatment and welding.

Pressure vessels and parts shall be postweld heat treated:

When the vessels are to contain lethal substances, (Code UW-2)

Unfired Steam Boilers (UW-2)

Pressure vessels and parts subject to direct firing when the thickness of welded joints exceeds 5/8 in. (UW-2)

When the carbon (P-No. 1) steel material thickness exceeds 1½ in. at welded connections and attachments (see Code Table UCS-56 for exceptions).

**Preheating** — Heat applied to base metal prior to welding operations.

**Pressure Relief Valve** — A valve which relieves pressure beyond a specified limit and recloses upon return to normal operating conditions.

**Pressure Vessel** — A metal container generally cylindrical or spheroidal, capable of withstanding various loadings.

**Pressure Welding** — A group of welding processes wherein the weld is completed by use of pressure.

**Primary Stress** — A normal stress or a shear stress developed by the imposed loading which is necessary to satisfy the simple laws of equilibrium of external and internal forces and moments. The basic characteristics of a primary stress is that it is not self-limiting. Primary stresses which considerably exceed the yield strength will result in failure or at least, in gross distortion. A thermal stress is not classified as a primary stress. Primary membrane stress is divided into "general" and "local" categories. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding. Examples of primary stress are: general



membrane stress in a circular cylindrical or a spherical shell due to internal pressure or to distributed live loads; bending stress in the central portion of a flat head due to pressure.

**Quench Annealing** — Annealing an austenitic ferrous alloy by heating followed by quenching from solution temperatures. Liquids used for quenching are oil, fused salt or water, into which a material is plunged.

**Radiographing** — The process of passing electronic radiations through an object and obtaining a record of its soundness upon a sensitized film. (Code U/A-60)

**Radius of Gyration** — The radius of gyration of an area with respect to a given axis is the square root of the quantity obtained by dividing the moment of inertia of the area with respect to that axis by the area.

**Random Lengths** — A term indicating no specified minimum or maximum length with lengths falling within the range indicated.

**Refractory** — A material of very high melting point with properties that make it suitable for such uses as high-temperature lining.

**Residual Stress** — Stress remaining in a structure or member as a result of thermal or mechanical treatment, or both.

**Resistance Welding** — A pressure welding process wherein the heat is produced by the resistance to the flow of an electric current.

**Root of Weld** — The bottom of the weld.

**Scale** — An iron oxide formed on the surface of hot steel, sometimes in the form of large sheets which fall off when the sheet is rolled.

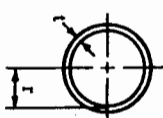
**Searf** — Edge preparation; preparing the contour on the edge of a member for welding.

**Seal Weld** — Seal weld used primarily to obtain tightness.

**Secondary Stress** — A normal stress or a shear stress developed by the constraint of adjacent parts or by self-constraint of a structure. The basic charac-

teristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur and failure from one application of the stress is not to be expected. Examples of secondary stress are: general thermal stress, bending stress at a gross structural discontinuity.

**Section Modulus** — The term pertains to the cross section of a beam. The *section modulus* with respect to either principal central axis is the moment of inertia with respect to that axis divided by the distance from that axis to the most remote point of the section. The section modulus largely determines the flexural strength of a beam of given material.



Section Modulus ( $Z$ ) of a thin walled cylinder ( $t \gg 10t$ ) about its transverse axis:  

$$Z = I^2 \pi t$$
 where  $r$  = mean radius of cylinder, in.  
 $t$  = wall thickness, in.

**Shell** — Structural element made to enclose some space. Most of the shells are generated by the revolution of a plane curve. In the terminology of this book shell is the cylindrical part of a vessel or a spherical vessel is called also a spherical shell.

**Shear Stress** — The component of stress tangent to the plane of reference.

**Shielded Metal-Arc Welding** — An arc welding process wherein coalescence is produced by heating with an electric arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

**Single-Welded Butt Joint** — A butt joint welded from one side only.

**Single-Welded Lap Joint** — A lap joint in which the overlapped edges of the members to be joined are welded along the edge of one member.

**Size of Weld** — Groove Weld: The depth of penetration.

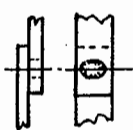


**Equal Leg Fillet Weld:** the leg length of the largest isosceles right-triangle which can be inscribed within the fillet weld cross section.

**Unequal Leg Fillet Weld:** The leg length of the largest right triangle which can be inscribed within the fillet weld cross section.

**Slag** — A result of the action of a flux on non-metallic constituents of a processed ore, or on the oxidized metallic constituents that are undesirable. Usually consist of combinations of acid oxides and basic oxides with neutral oxides added to aid fusibility.

**Slenderness Ratio** — The ratio of the length of a uniform column to the least radius of gyration of the cross section.



**Slot Weld** — A weld made in an elongated hole (slot) in one member of a lap joint, joining that member to that portion of the surface of the other member which is exposed through the hole. The hole may or may not be filled completely with weld metal.

**Specific Gravity** — The ratio of the density of a material to the density of some standard material, such as water at a specified temperature, for example, 4°C or 60°F, or (for gases) air at standard conditions of pressure and temperature.

**Spot Welding** — Electric-resistance welding in which fusion is limited to a small area directly between the electrode tips.

**Stability of Vessels** — (Elastic Stability) The strength of a vessel to resist buckling or wrinkling due to axial compressive stress. The stability of a vessel is severely affected by out of roundness.

**Staggered Intermittent Fillet Welds** — Two lines of intermittent fillet welding in a tee or lap joint, in which the increments of



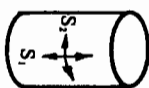
welding in one line are staggered with respect to those in the other line.

**Static Head** — The pressure of liquids that is not moving, against the vessel wall, is due solely to the "Static Head", or height of the liquid. This pressure shall be taken into consideration in designing vessels.

**Strain** — Any forced change in the dimensions of a body. A stretch is a *tensile strain*; a shortening is a *compressive strain*; an angular distortion is a *shear strain*. The word *strain* is commonly used to connote *unit strain*.

**Stress** — Internal force exerted by either of two adjacent parts of a body upon the other across an imagined plane of separation. When the forces are parallel to the plane, the stress is called *shear stress*; when the forces are normal to the plane the stress is called *normal stress*; when the normal stress is directed toward the part on which it acts it is called *compressive stress*; when it is directed away from the part on which it acts it is called *tensile stress*.

**Stresses in Pressure Vessels** — Longitudinal (meridional)  $S_L$  stress, Circumferential (hoop)  $S_C$  stress, and  $S_R$  called membrane (diaphragm) stress for vessels having a figure of revolution.



Bending stress  
 Shear stress  
 Discontinuity stresses at an abrupt change in thickness or shape of the vessel.

**Stud** — A threaded fastener without a head, with threads on one end or both ends, or threaded full length. (Code U/A-60)

**Submerged Arc Welding** — An arc welding process wherein coalescence is produced by heating with an arc or arcs between a bare metal electrode or electrodes and the work. The welding is shielded by a blanket of granular, fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplementary



welding rod.

**Tack Weld** — A weld made to hold parts of a weldment in proper alignment until the final welds are made.

**Tea Joint** — A welded joint at the junction of two parts located approximately at right angles to each other in the form of a T.

**Tensile Strength** — The maximum stress a material subjected to a stretching load can withstand without tearing.

**Tensile Stress** — Stress developed by a material bearing tensile load.

**Test** — Trial to prove that the vessel is suitable for the design pressure.

See Hydrostatic test, Pneumatic test.

**Test Pressure** — The requirements for determining the test pressure based on calculations are outlined in UG-99(c) for the hydrostatic test and in UG-100(b) for the pneumatic test. The basis for calculated test pressure in either of these paragraphs is the highest permissible internal pressure as determined by the design formulas, for each element of the vessel using nominal thicknesses with corrosion allowances included and using the allowable stress values for the temperature of the test. (Code U-A-60)

**Thermal Fatigue** — The development of cyclic thermal gradients producing high cyclic thermal stresses and subsequent local cracking of material.

**Thermal Stress** — A self-balancing stress produced by a nonuniform distribution of temperature or by differing thermal coefficients of expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature.

#### Thickness of Vessel Wall

1. The "required thickness" is that computed by the formulas in this Division, before corrosion allowance is added (see UG-22).
2. The "design thickness" is the sum of the required thickness and the corrosion allowance

(see UG-25).

3. The "nominal thickness" is the thickness selected as commercially available, and as supplied to the manufacturer; it may exceed the design thickness. (Code U-A-60)

**Throat** — See under Fillet Weld.

**Tolerances** — For plates the maximum permissible under-tolerance is the smaller value of 0.01 in. or 6% of the design thickness. (Code UG-16)

The manufacturing under-tolerance on wall thickness of heads, pipes and pipefittings shall be taken into account and the next heavier commercial wall thickness may then be used.

**U.M. Plate** — Universal Mill Plate or plate rolled to width by vertical rolls as well as to thickness by horizontal rolls.

**Ultrasonic Examination (UT)** — a nondestructive means for locating and identifying internal discontinuities by detecting the reflections they produce of a beam of ultrasonic vibrations (Code U-A-60)

**Undercut** — A groove melted into the base metal adjacent to the toe of a weld and left unfilled by weld metal.

**Unit Strain** — Unit tensile strain is the elongation per unit length; unit compressive strain is the shortening per unit length; unit shear strain is the change in angle (radians) between two lines originally at right angles to each other.

**Unit Stress** — The amount of stress per unit of area.

**Vessel** — A container or structural envelope in which materials are processed, treated, or stored; for example, pressure vessels, reactor vessels, agitator vessels, and storage vessels (tanks).

**Weaving** — A technique of depositing weld metal in which the electrode is oscillated from side to side.

**Weld** — A localized coalescence of metal produced by fusion with or without use of filler metal, and with or without application of pressure.

**Weld Metal** — The metal resulting from the fusion of the base metal and the filler metal.

**Welding** — The metal joining process used in making welds.

In the construction of vessels the welding processes are restricted by the Code (UW-27) as follows:

1. Shielded metal arc, submerged arc, gas metal arc, gas tungsten arc, plasma arc, atomic hydrogen metal arc, oxyfuel gas welding, electroslag, and electron beam.

2. Pressure welding processes: flash, induction, resistance, pressure thermal, and pressure gas.

**Welding Procedure** — The materials, detailed methods and practices involved in the production of a welded joint.

**Welding Rod** — Filler metal, in wire or rod

form, used in the gas welding process, and in those arc welding processes wherein the electrode does not furnish the deposited metal.

**Wrought Iron** — Iron refined to a plastic state in a puddling furnace. It is characterized by the presence of about 3 per cent of slag irregularly mixed with pure iron and about 0.5 per cent carbon.

**Yield Point** — The lowest stress at which strain increases without increase in stress. For some purposes it is important to distinguish between the upper yield point, which is the stress at which the stress-strain diagram first becomes horizontal, and the lower yield point, which is the somewhat lower and almost constant stress under which the metal continues to deform. Only a few materials exhibit a true yield point; for some materials the term is sometimes used as synonymous with yield strength.



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