OVERVIEW OF PROCESS PLANT PIPING SYSTEM DESIGN

By: **Vincent A. Carucci**
Carmagen Engineering, Inc.

Piping System

Piping system: conveys fluid between locations

Piping system includes:

- Pipe
- Fittings (e.g. elbows, reducers, branch connections, etc.)
- Flanges, gaskets, bolting
- Valves
- Pipe supports

ASME B31.3

- **Provides requirements for:**
  - Design
  - Materials
  - Fabrication
  - Erection
  - Inspection
  - Testing
- **For process plants including**
  - Petroleum refineries
  - Chemical plants
  - Pharmaceutical plants
  - Textile plants
  - Paper plants
  - Semiconductor plants
  - Cryogenic plants

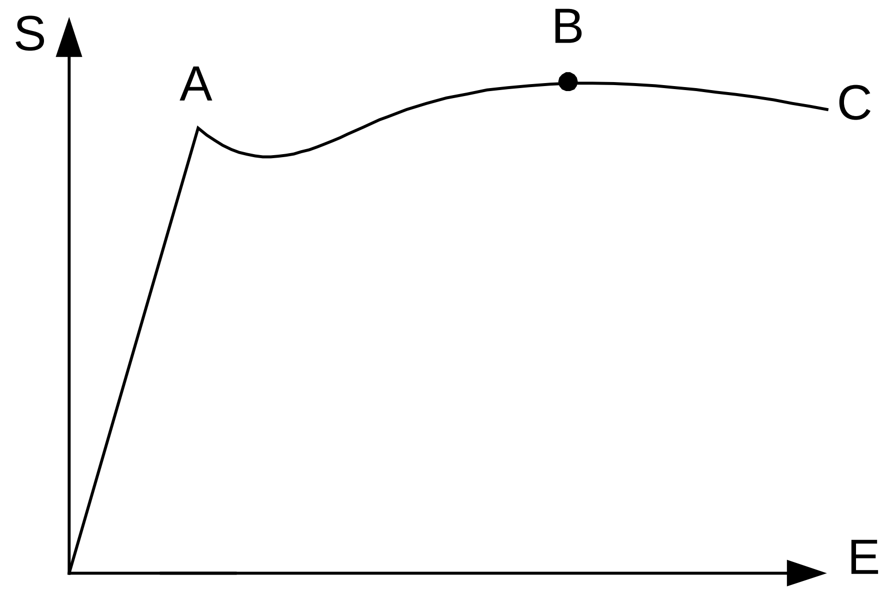
Scope of ASME B31.3

- Piping and piping components, all fluid services:
  - Raw, intermediate, and finished chemicals
  - Petroleum products
  - Gas, steam, air, and water
  - Fluidized solids
  - Refrigerants
  - Cryogenic fluids
- Interconnections within packaged equipment
- Scope exclusions specified

Strength

- Yield and Tensile Strength
- Creep Strength
- Fatigue Strength
- Alloy Content
- Material Grain size
- Steel Production Process

Stress - Strain Diagram



Corrosion Resistance

- Deterioration of metal by chemical or electrochemical action
- Most important factor to consider
- Corrosion allowance $\longrightarrow$ added thickness
- Alloying increases corrosion resistance

Piping System Corrosion

General or Uniform Corrosion	Uniform metal loss. May be combined with erosion if high-velocity fluids, or moving fluids containing abrasives.
Pitting Corrosion	Localized metal loss randomly located on material surface. Occurs most often in stagnant areas or areas of low-flow velocity.
Galvanic Corrosion	Occurs when two dissimilar metals contact each other in corrosive electrolytic environment. Anodic metal develops deep pits or grooves as current flows from it to cathodic metal.
Crevice Corrosion	Localized corrosion similar to pitting. Occurs at places such as gaskets, lap joints, and bolts where crevice exists.
Concentration Cell Corrosion	Occurs when different concentration of either a corrosive fluid or dissolved oxygen contacts areas of same metal. Usually associated with stagnant fluid.
Graphitic Corrosion	Occurs in cast iron exposed to salt water or weak acids. Reduces iron in cast iron, and leaves graphite in place. Result is extremely soft material with no metal loss.

Material Toughness

- Energy necessary to initiate and propagate a crack
- Decreases as temperature decreases
- Factors affecting fracture toughness include:
  – Chemical composition or alloying elements
  – Heat treatment
  – Grain size

Fabricability

- Ease of construction
- Material must be weldable
- Common shapes and forms include:
  - Seamless pipe
  - Plate welded pipe
  - Wrought or forged elbows, tees, reducers, crosses
  - Forged flanges, couplings, valves
  - Cast valves

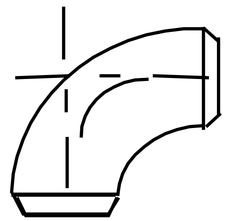
Availability and Cost

- Consider economics
- Compare acceptable options based on:
  - – Availability
  - – Relative cost

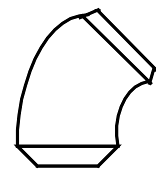
Pipe Fittings

- Produce change in geometry
  - Modify flow direction
  - Bring pipes together
  - Alter pipe diameter
  - Terminate pipe

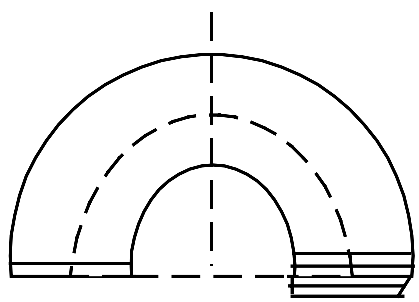
Elbow and Return



90°



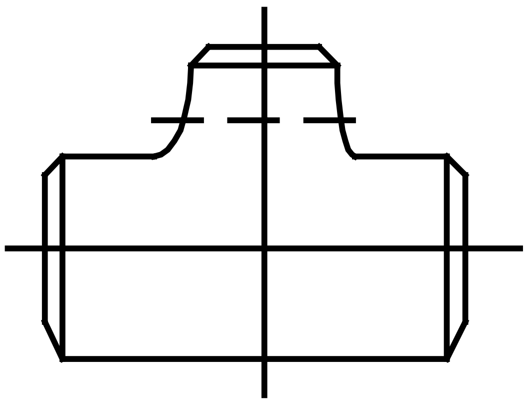
45°



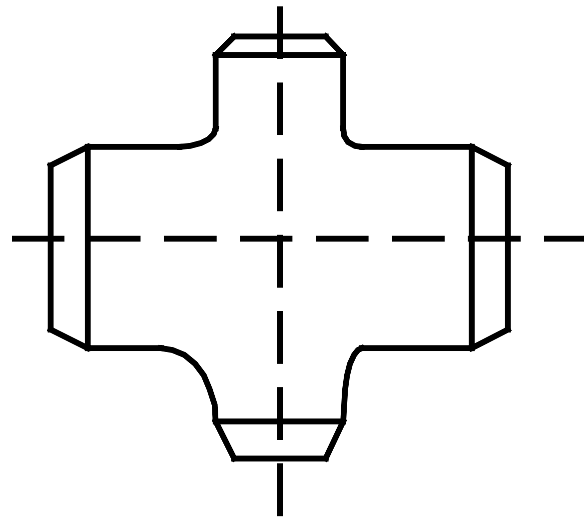
180° Return

Figure 4.1

Tee



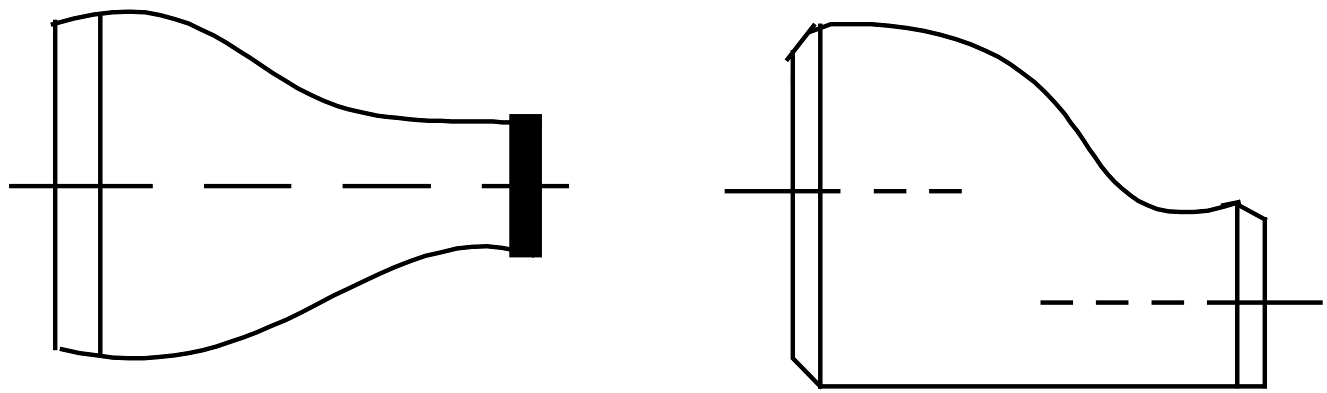
Reducing Outlet Tee



Cross Tee

Figure 4.2

Reducer



Concentric Eccentric

Figure 4.3

Welding Outlet Fitting

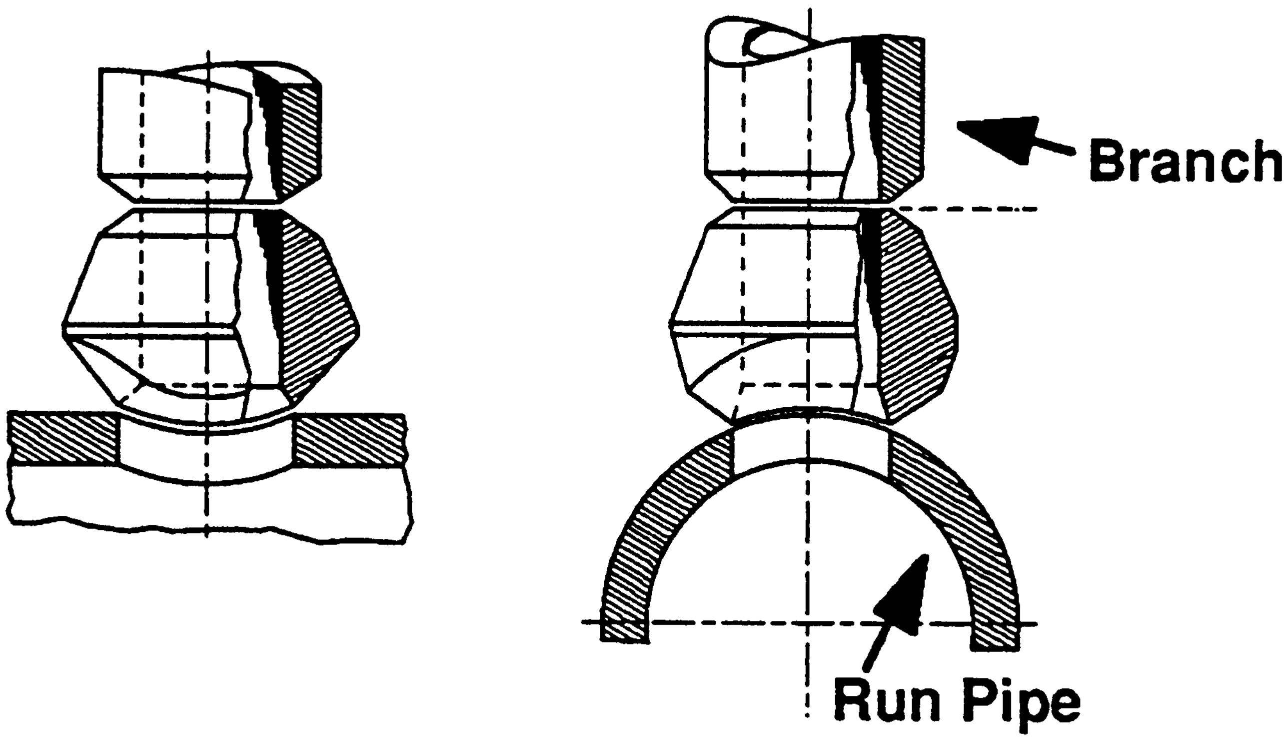


Figure 4.4

Cap

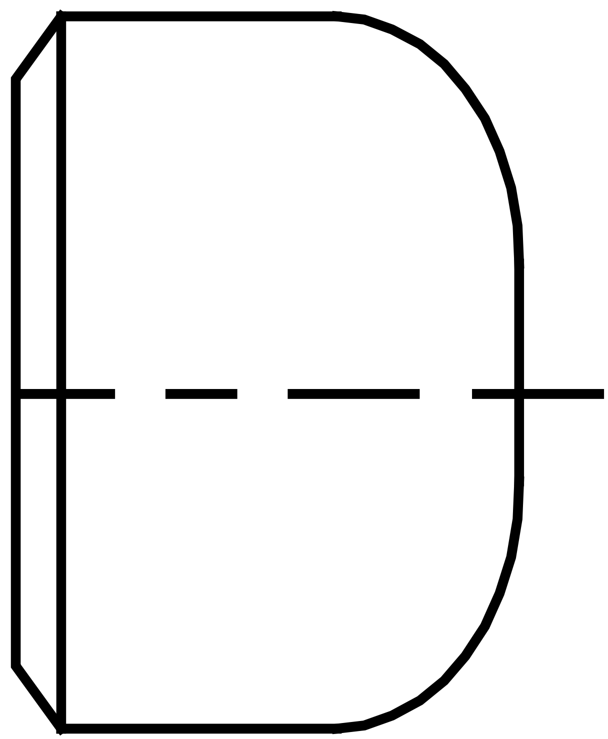


Figure 4.5

Lap-joint Stub End

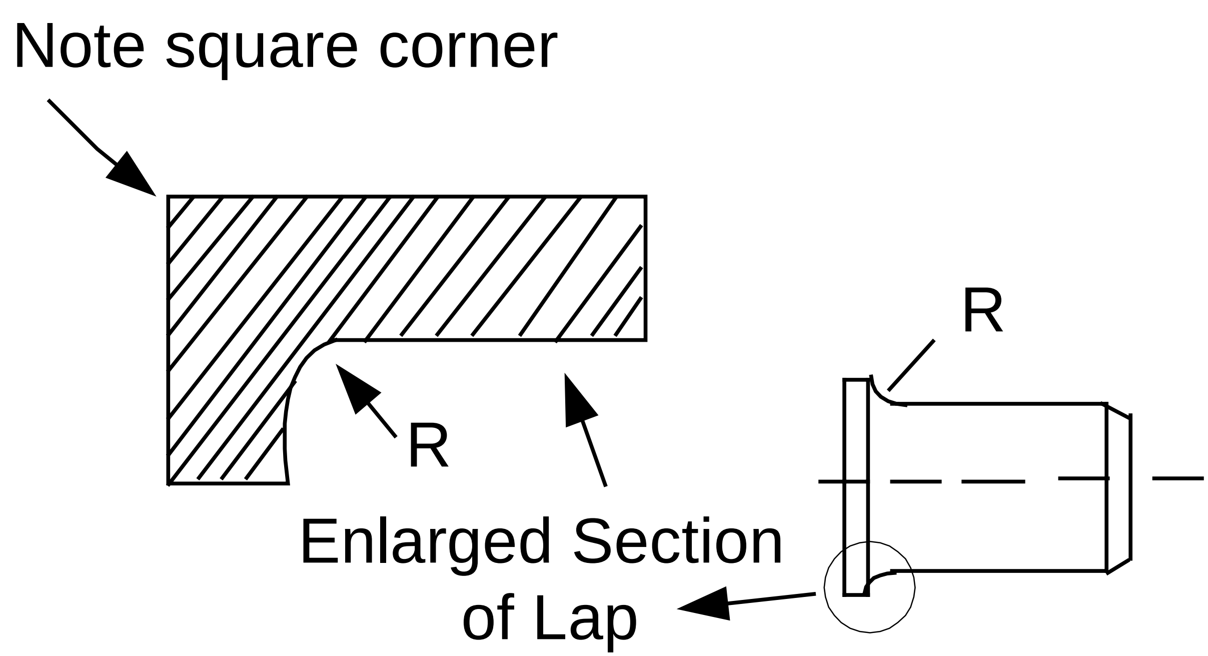


Figure 4.6

Typical Flange Assembly

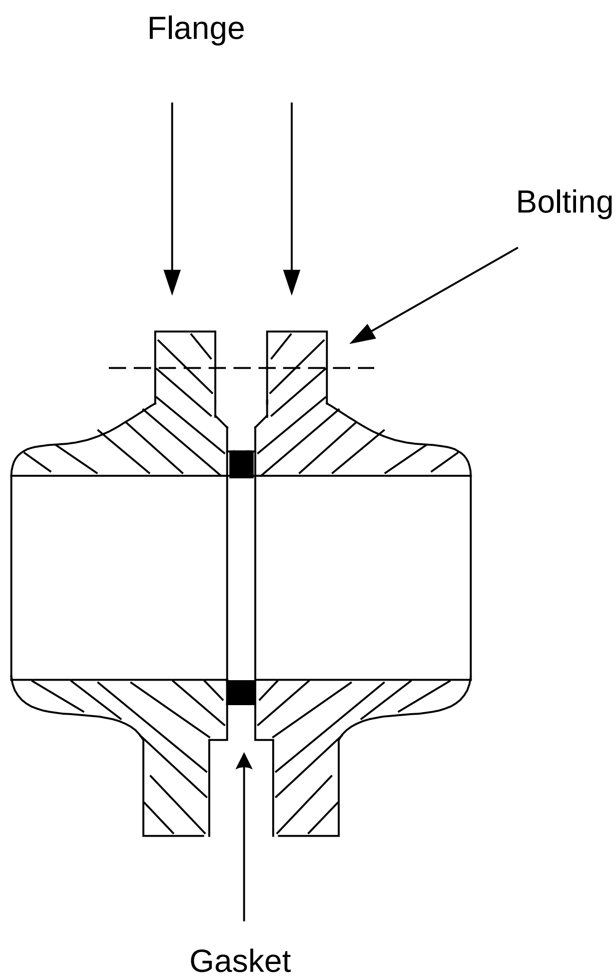


Figure 4.7

Types of Flange Attachment and Facing

Flange Attachment Types	Flange Facing Types
Threaded Flanges	Flat Faced
Socket-Welded Flanges	
Blind Flanges	Raised Face
Slip-On Flanges	
Lapped Flanges	Ring Joint
Weld Neck Flanges	

Table 4.1

Flange Facing Types

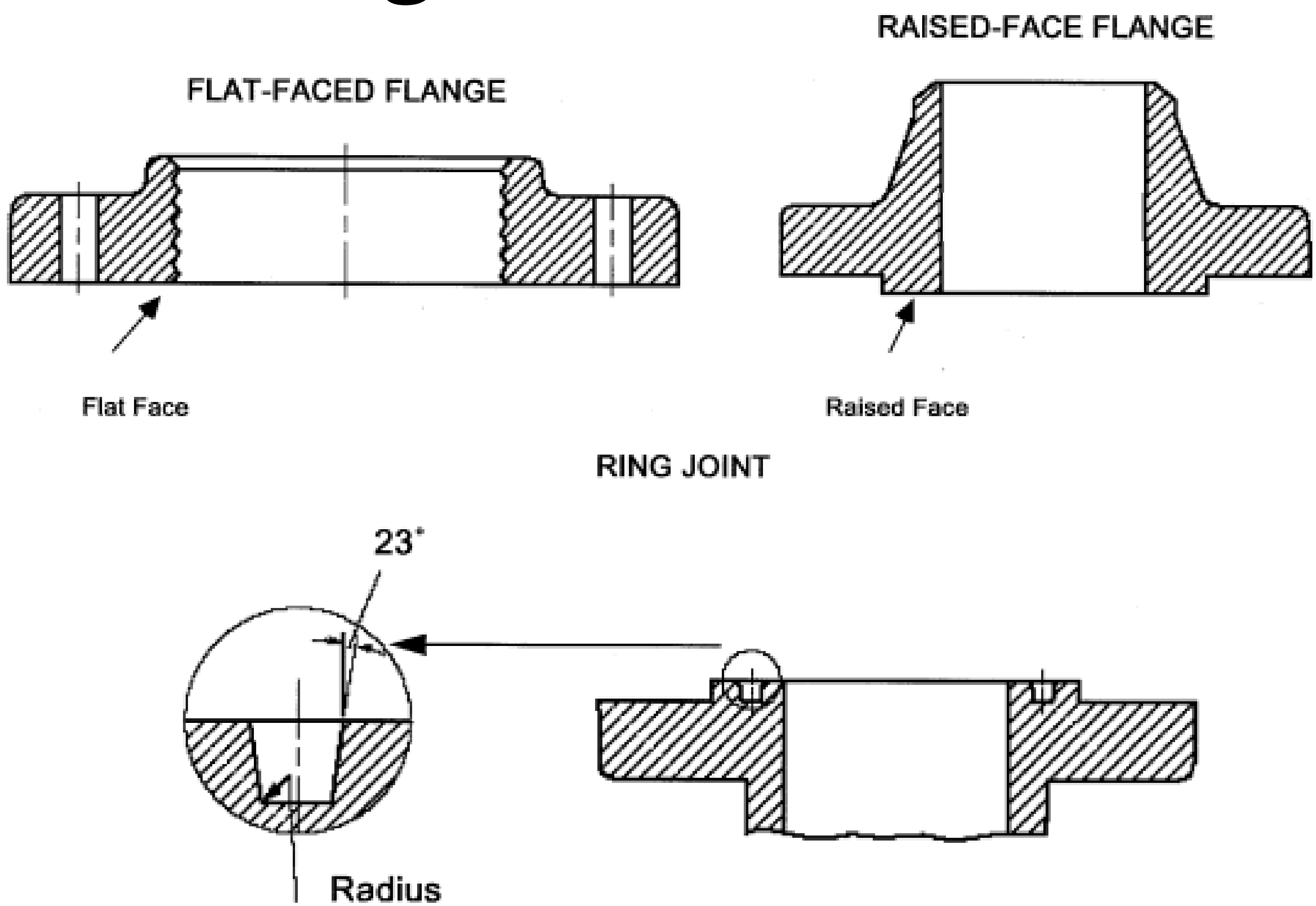


Figure 4.8

Gaskets

- Resilient material
- Inserted between flanges
- Compressed by bolts to create seal
- Commonly used types
  - Sheet
  - Spiral wound
  - Solid metal ring

Flange Rating Class

- **Based on ASME B16.5**
- **Acceptable pressure/temperature combinations**
- **Seven classes (150, 300, 400, 600, 900, 1,500, 2,500)**
- **Flange strength increases with class number**
- **Material and design temperature combinations without pressure indicated not acceptable**

Material Specification List

Material Groups		Product Forms					
Material Group Number	Nominal Designation Steel	Forgings		Castings		Plates	
		Spec. No.	Grade	Spec. No.	Grade	Spec. No.	Grade
1.1	Carbon	A105	--	A216	WCB	A515	70
		A350	LF2	--	--	A516	70
	C-Mn-Si	--	--	--	--	A537	Cl.1
1.2	Carbon	--	--	A216	WCC	--	--
		--	--	A352	LCC	--	--
	2½ Ni	--	--	A352	LC2	A203	B
	3½ Ni	A350	LF3	A352	LC3	A203	E
1.9	1Cr – ½Mo	A182	F12	--	--	--	--
	1¼ Cr – ½Mo	--	--	A217	WC6	--	--
	1¼ Cr – ½Mo - Si	A182	F11	--	--	A387	11
1.10	2¼ Cr – 1Mo	A182	F22	A217	WC9	A387	22

Table 4.2

Pressure - Temperature Ratings

Material Group No.	1.8			1.9			1.10		
Classes	150	300	400	150	300	400	150	300	400
Temp., °F									
-20 to 100	235	620	825	290	750	1000	290	750	1000
200	220	570	765	260	750	1000	260	750	1000
300	215	555	745	230	720	965	230	730	970
400	200	555	740	200	695	885	200	705	940
500	170	555	740	170	695	805	170	665	885
600	140	555	740	140	605	785	140	605	805
650	125	555	740	125	590	785	125	590	785
700	110	545	725	110	570	710	110	570	755
750	95	515	685	95	530	675	95	530	710
800	80	510	675	80	510	650	80	510	675
850	65	485	650	65	485	600	65	485	650
900	50	450	600	50	450	425	50	450	600
950	35	320	425	35	320	290	35	375	505
1000	20	215	290	20	215	190	20	260	345

Table 4.3

Sample Problem 1
Flange Rating

New piping system to be installed at existing plant.

Determine required flange class.

- **Pipe Material:** $1\frac{1}{4}Cr - \frac{1}{2}Mo$
- **Design Temperature:** 700°F
- **Design Pressure:** 500 psig

Sample Problem 1 Solution

- Determine Material Group Number (Fig. 4.2)

  Group Number = 1.9
- Find allowable design pressure at intersection of design temperature and Group No. Check Class 150.
  - Allowable pressure = 110 psig < design pressure
  - Move to next higher class and repeat steps
- For Class 300, allowable pressure = 570 psig
- Required flange Class: 300

Valves

- Functions
  - Block flow
  - Throttle flow
  - Prevent flow reversal

Full Port Gate Valve

1. Handwheel Nut
2. Handwheel
3. Stem Nut
4. Yoke
5. Yoke Bolting
6. Stem
7. Gland Flange
8. Gland
9. Gland Bolts or
   Gland Eye-bolts and nuts
10. Gland Lug Bolts and Nuts
11. Stem Packing
12. Plug
13. Lantern Ring
14. Backseat Bushing
15. Bonnet
16. Bonnet Gasket
17. Bonnet Bolts and Nuts
18. Gate
19. Seat Ring
20. Body
21. One-Piece Gland (Alternate)
22. Valve Port

Figure 5.1

Globe Valve

- Most economic for throttling flow
- Can be hand-controlled
- Provides “tight” shutoff
- Not suitable for scraping or rodding
- Too costly for on/off block operations

Check Valve

- Prevents flow reversal
- Does not completely shut off reverse flow
- Available in all sizes, ratings, materials
- Valve type selection determined by
  - Size limitations
  - Cost
  - Availability
  - Service

Swing Check Valve

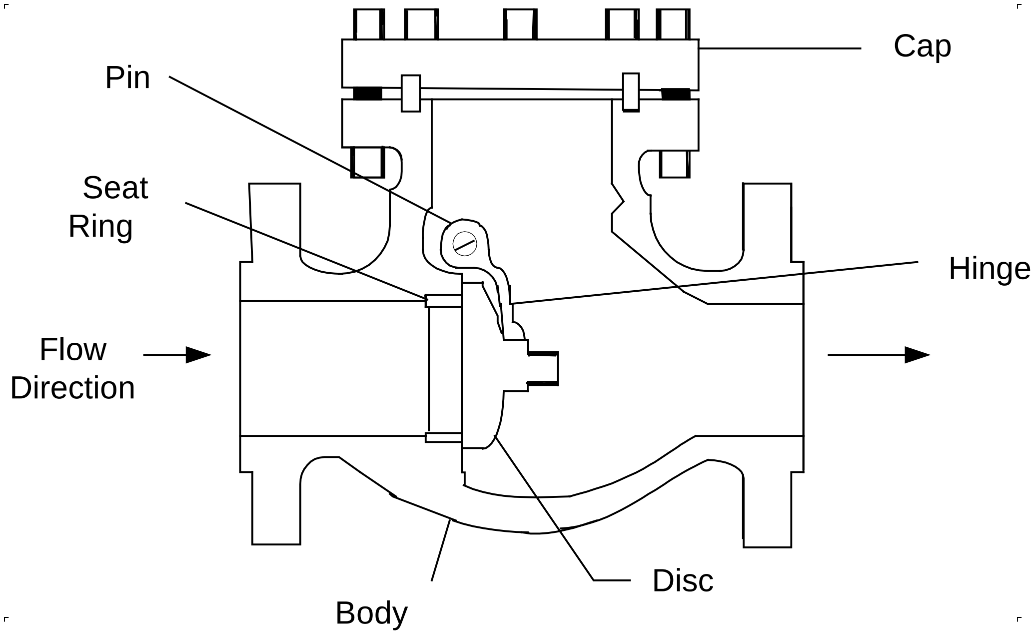


Figure 5.2

Ball Check Valve

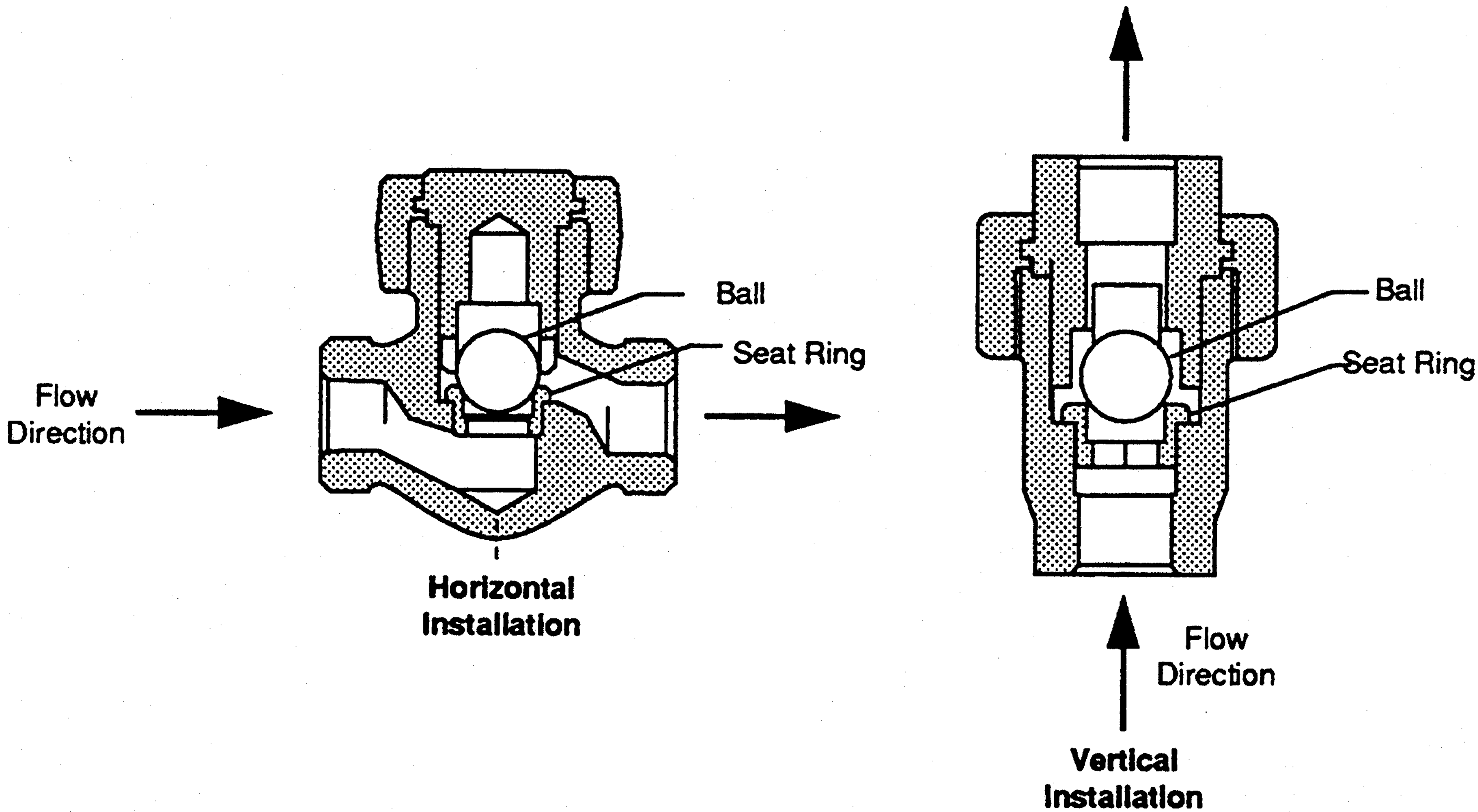


Figure 5.3

Lift Check Valve

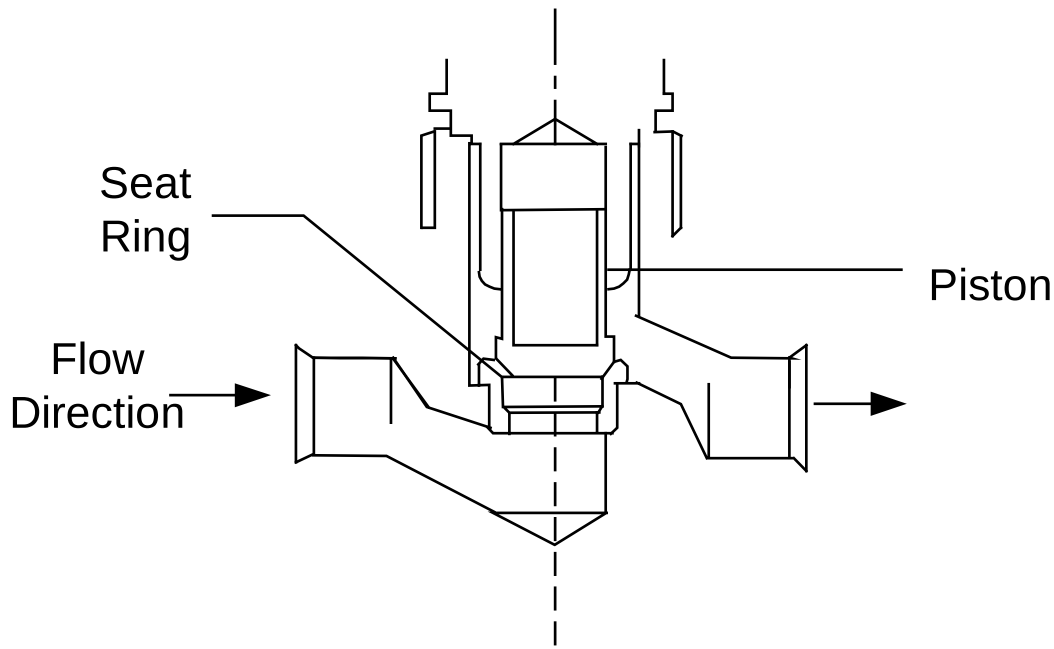
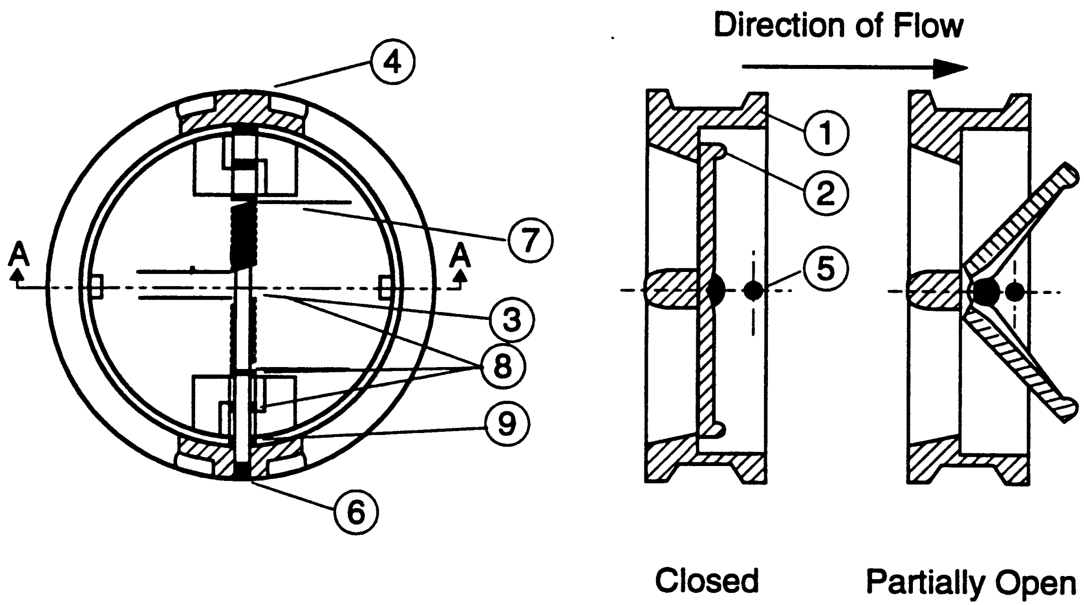


Figure 5.4

Wafer Check Valve



Part Names:
1. Body
2. Plates
3. Hingle Pin
4. Hinge Pin Retainers
5. Stop Pin
6. Stop Pin Retainers
7. Spring
8. Plate Lug Bearings
9. Body Lug Bearings

Section A-A

Figure 5.5

Ball Valve

No.	Part Names
1	Body
2	Body Cap
3	Ball
4	Body Seal Gasket
5	Seat
6	Stem
7	Gland Flange
8	Stem Packing
9	Gland Follower
10	Thrust Bearing
11	Thrust Washer
12	Indicator Stop
13	Snap Ring
14	Gland Bolt
15	Stem Bearing
16	Body Stud Bolt & Nuts
17	Gland Cover
18	Gland Cover Bolts
19	Handle

Figure 5.6

Plug Valve

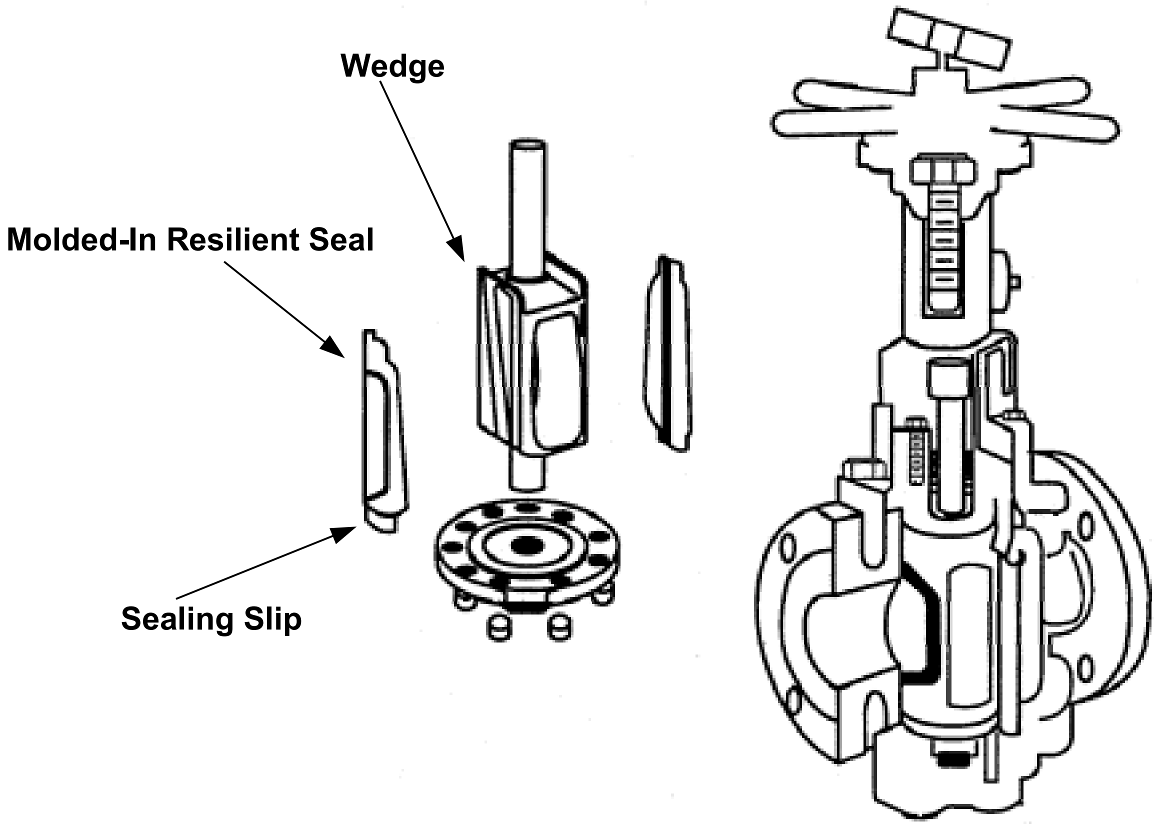


Figure 5.7

Valve Selection Process

General procedure for valve selection.

1. Identify design information including pressure and temperature, valve function, material, etc.
2. Identify potentially appropriate valve types and components based on application and function (i.e., block, throttle, or reverse flow prevention).

Valve Selection Process, cont'd

3. Determine valve application requirements (i.e., design or service limitations).
4. Finalize valve selection. Check factors to consider if two or more valves are suitable.
5. Provide full technical description specifying type, material, flange rating, etc.

Exercise 1 - Determine Required Flange Rating

- Pipe: $1\frac{1}{4}Cr - \frac{1}{2}Mo$
- Flanges: A-182 Gr. F11
- Design Temperature: 900°F
- Design Pressure: 375 psig

Exercise 1 - Solution

1. Identify material specification of flange

   A-182 Gr, F11

2. Determine Material Group No. (Table 4.2)

   Group 1.9

3. Determine class using Table 4.3 with design temperature and Material Group No.
   - *The lowest Class for design pressure of 375 psig is Class 300.*
   - *Class 300 has 450 psig maximum pressure at 900°F*

Design Conditions

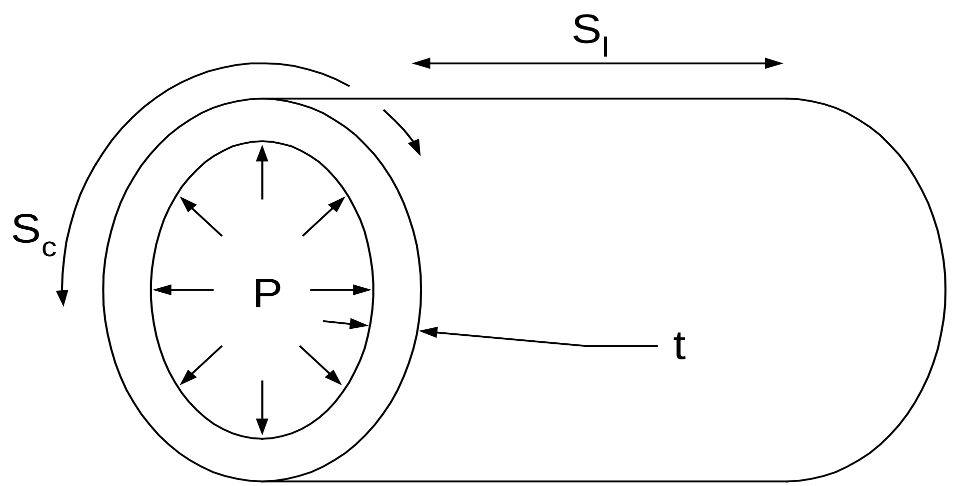
- General
  - Normal operating conditions
  - Design conditions
- Design pressure and temperature
  - Identify connected equipment and associated design conditions
  - Consider contingent conditions
  - Consider flow direction
  - Verify conditions with process engineer

Loading Conditions

Principal pipe load types

- Sustained loads
  - – Act on system all or most of time
  - – Consist of pressure and total weight load
- Thermal expansion loads
  - – Caused by thermal displacements
  - – Result from restrained movement
- Occasional loads
  - – Act for short portion of operating time
  - – Seismic and/or dynamic loading

Stresses Produced By Internal Pressure



S_l	=	Longitudinal Stress
S_c	=	Circumferential (Hoop) Stress
t	=	Wall Thickness
P	=	Internal Pressure

Figure 6.1

Stress Categorization

- Primary Stresses
  – Direct
  – Shear
  – Bending
- Secondary stresses
  – Act across pipe wall thickness
  – Cause local yielding and minor distortions
  – Not a source of direct failure

Stress Categorization, cont'd

- Peak stresses
  - More localized
  - Rapidly decrease within short distance of origin
  - Occur where stress concentrations and fatigue failure might occur
  - Significance equivalent to secondary stresses
  - Do not cause significant distortion

Allowable Stresses

Function of
- – Material properties
- – Temperature
- – Safety factors

Established to avoid:
- – General collapse or excessive distortion from sustained loads
- – Localized fatigue failure from thermal expansion loads
- – Collapse or distortion from occasional loads

B31.3 Allowable Stresses in Tension

Material	Spec. No/Grade		Basic Allowable Stress *S*, ksi. At Metal Temperature, °F.														
			100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
Carbon Steel	A 106	B	20.0	20.0	20.0	20.0	18.9	17.3	16.5	10.8	6.5	2.5	1.0				
C - ½Mo	A 335	P1	18.3	18.3	17.5	16.9	16.3	15.7	15.1	13.5	12.7	4.	2.4				
1¼ - ½Mo	A 335	P11	20.0	18.7	18.0	17.5	17.2	16.7	15.6	15.0	12.8	6.3	2.8	1.2			
18Cr - 8Ni pipe	A 312	TP304	20.0	20.0	20.0	18.7	17.5	16.4	16.0	15.2	14.6	13.8	9.7	6.0	3.7	2.3	1.4
16Cr - 12Ni-2Mo pipe	A 312	TP316	20.0	20.0	20.0	19.3	17.9	17.0	16.3	15.9	15.5	15.3	12.4	7.4	4.1	2.3	1.3

Table 6.1

Pipe Thickness Required For Internal Pressure

- $$t = \frac{PD}{2(SE + PY)}$$

P = Design pressure, psig

D = Pipe outside diameter, in.

S = Allowable stress in tension, psi

E = Longitudinal-joint quality factor

Y = Wall thickness correction factor

- $t_m = t + CA$
- $t_{nom} = \frac{t_m}{0.875}$

Spec. No.	Class (or Type)	Description	E_j
		Carbon Steel	
API	. . .	Seamless pipe	1.00
5L	. . .	Electric resistance welded pipe	0.85
	. . .	Electric fusion welded pipe, double butt, straight or spiral seam	0.95
		Furnace butt welded	
A 53	Type S	Seamless pipe	1.00
	Type E	Electric resistance welded pipe	0.85
	Type F	Furnace butt welded pipe	0.60
A 106	. . .	Seamless pipe	1.00
		Low and Intermediate Alloy Steel	
A 333	. . .	Seamless pipe	1.00
	. . .	Electric resistance welded pipe	0.85
A 335	. . .	Seamless pipe	1.00
		Stainless Steel	
A 312	. . .	Seamless pipe	1.00
	. . .	Electric fusion welded pipe, double butt seam	0.85
	. . .	Electric fusion welded pipe, single butt seam	0.80
A 358	1, 3, 4	Electric fusion welded pipe, 100% radiographed	1.00
	5	Electric fusion welded pipe, spot radiographed	0.90
	2	Electric fusion welded pipe, double butt seam	0.85
		Nickel and Nickel Alloy	
B 161	. . .	Seamless pipe and tube	1.00
B 514	. . .	Welded pipe	0.80
B 675	All	Welded pipe	0.80

Table 6.2

	Temperature, °F					
Materials	900 & lower	950	1000	1050	1100	1150 & up
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
Other Ductile Metals	0.4	0.4	0.4	0.4	0.4	0.4
Cast iron	0.0	. . .	. . .	. . .	. . .	. . .

Table 6.3

Curved and Mitered Pipe

- Curved pipe
  - Elbows or bends
  - Same thickness as straight pipe
- Mitered bend
  - Straight pipe sections welded together
  - Often used in large diameter pipe
  - May require larger thickness
    - Function of number of welds, conditions, size

Sample Problem 2 - Determine Pipe Wall Thickness

Design temperature: 650˚F

Design pressure: 1,380 psig.

Pipe outside diameter: 14 in.

Material: ASTM A335, Gr. P11 ($1\frac{1}{4}$**Cr** – $\frac{1}{2}$**Mo**), seamless

Corrosion allowance: 0.0625 in.

Sample Problem 2 - Solution

$$t = \frac{PD}{2(SE + PY)}$$

$$t = \frac{1{,}380 \times 14}{2\left[\left(16{,}200 \times 1\right) + \left(1{,}380 \times 0.4\right)\right]}$$

$$t = 0.577 \text{ in.}$$

Sample Problem 2 - Solution, cont'd

$t_m = t + c = 0.577 + 0.0625 = 0.6395$ in.

$$\mathbf{t_{nom} = \frac{0.6395}{0.875} = 0.731 \text{ in.}}$$

Welded Branch Connection

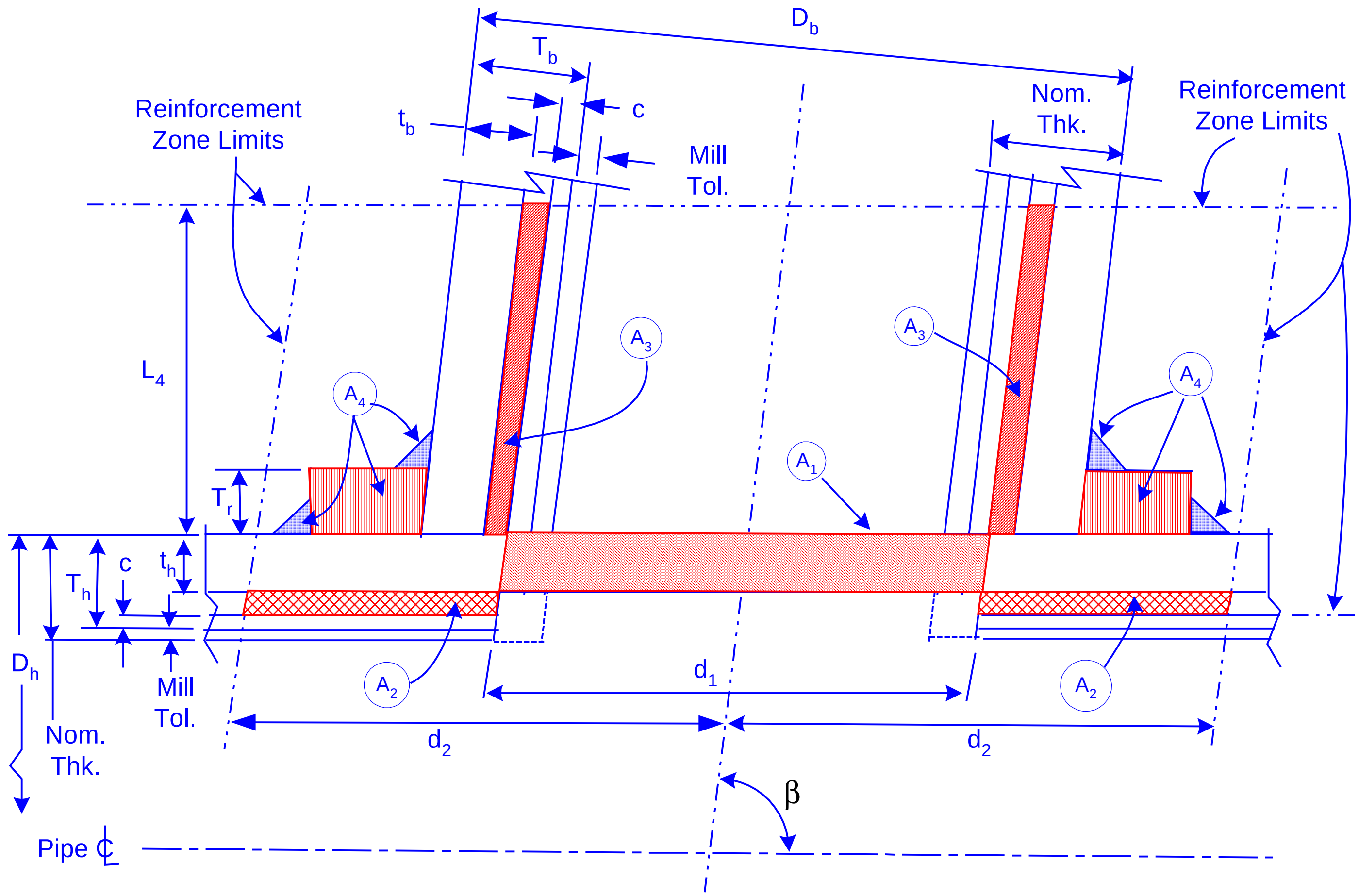


Figure 6.2

Reinforcement Area

$$\mathbf{d_1 = \frac{D_b - 2(T_b - c)}{\sin\beta}}$$

d_1 = Effective length removed from run pipe, in.

D_b = Branch outside diameter, in.

T_b = Minimum branch thickness, in.

c = Corrosion allowance, in.

β = Acute angle between branch and header

Required Reinforcement Area

Required reinforcement area, A_1:

$$\mathbf{A_1 = t_h d_1 (2 - \sin\beta)}$$

Where: t_h = Minimum required header thickness, in.

Reinforcement Pad

- Provides additional reinforcement
- Usually more economical than increasing wall thickness
- Selection variables
  - Material
  - Outside diameter
  - Wall thickness

$$A_4 = \left(\frac{(D_p - D_b)}{\sin\beta} \right) T_r$$

Sample Problem 3

- Pipe material: Seamless, A 106/Gr. B for branch and header, S = 16,500 psi
- Design conditions: 550 psig @ 700°F
- c = 0.0625 in.
- Mill tolerance: 12.5%

Sample Problem 3, cont'd

- Nominal Pipe Thicknesses: Header: 0.562 in. Branch: 0.375 in.
- Required Pipe Thicknesses: Header: 0.395 in. Branch: 0.263 in.
- Branch connection at 90° angle

Sample Problem 3 - Solution

$$d_1 = \frac{D_b - 2(T_b - c)}{\sin\beta}$$

$$d_1 = \frac{16 - 2\left(0.375 \times 0.875 - 0.0625\right)}{\sin 90^\circ} = 15.469\,\text{in.}$$

$$A_1 = t_h d_1 (2 - \sin\beta)$$

$$A_1 = 0.395 \times 15.469\,(2 - \sin 90^\circ) = 6.11\,\text{in.}^2$$

Sample Problem 3 - Solution, cont'd

- Calculate excess area available in header, A_2.

$$\mathbf{A_2 = (2d_2 - d_1)(T_h - t_h - c)}$$

$d_2 = d_1 = 15.469$ in. $< D_h = 24$ in.

$A_2 = (2 \times 15.469 - 15.469)\,(0.875 \times 0.562 - 0.395 - 0.0625)$

$A_2 = 0.53$ in.^{2}

Sample Problem 3 - Solution, cont'd

- Calculate excess area available in branch,
- A_3.

$$A_3 = \frac{2L_4\left(T_b - t_b - c\right)}{\sin\beta}$$

$$L_4 = 2.5\,(0.875 \times 0.375 - 0.0625) = 0.664\,\text{in.}$$

$$A_3 = \frac{2 \times 0.664\left(0.875 \times 0.375 - 0.263 - 0.0625\right)}{\sin 90^\circ} = 0.003\ \text{in.}^2$$

Sample Problem 3 - Solution, cont'd

- Calculate other excess area available, A_4.

  $A_4 = 0$.

- Total Available Area:

  $A_T = A_2 + A_3 + A_4$

  $A_T = 0.53 + 0.003 + 0 = 0.533$ in.^{2} available reinforcement.

  $A_T < A_1$

  $\therefore$ Pad needed

Sample Problem 3 - Solution, cont'd

- Reinforcement pad: A106, Gr. B, 0.562 in. thick
- Recalculate Available Reinforcement

$L_{41} = 2.5\ (T_h - c) = 2.5\ (0.875 \times 0.562 - 0.0625) =$
1.073 in.

$L_{42} = 2.5\ (T_b - c) + T_r$
$= 2.5\ (0.875 \times 0.375 - 0.0625) + 0.562\ (0.875) =$
1.16 in

Sample Problem 3 - Solution, cont'd

Therefore, L_4 = 1.073 in.

$$A_3 = \frac{2L_4(T_b - t_b - c)}{\sin\beta}$$

$$A_3 = \frac{2 \times 1.073\,(0.875 \times 0.375 - 0.263 - 0.0625)}{\sin 90^\circ}$$

$$A_3 = 0.005\,\text{in.}^2 \quad \text{(vs. the } 0.003\,\text{in.}^2 \text{ previously calculated)}$$

$$A_T = A_2 + A_3 + A_4 = 0.53 + 0.005 + 0 = 0.535\,\text{in.}^2$$

Sample Problem 3 - Solution, cont'd

- Calculate additional reinforcement required and pad dimensions:

$A_4 = 6.11 - 0.535 = 5.575 \text{ in.}^2$

Pad diameter, D_p is:

$T_r = 0.562\ (0.875) = 0.492 \text{ in.}$

$$D_p = \frac{A_4}{T_r} + \frac{D_b}{\sin\beta} = \frac{5.575}{0.492} + 16 = 27.3$$

Since $2d_2 > D_p$, pad diameter is acceptable

Exercise 2 - Determine Required Pipe Wall Thickness

- Design Temperature: 260°F
- Design Pressure: 150 psig
- Pipe OD: 30 in.
- Pipe material: A 106, Gr. B seamless
- Corrosion allowance: 0.125
- Mill tolerance: 12.5%
- Thickness for internal pressure and nominal thickness?

Exercise 2 - Solution

- From Tables 6.1, 6.2, and 6.3 obtain values:
  - S = 20,000 psi
  - E = 1.0
  - Y = 0.4
- Thickness calculation:

$$\mathbf{t} = \frac{\mathbf{PD}}{\mathbf{2(SE + PY)}} = \frac{\mathbf{150 \times 30}}{\mathbf{2[(20{,}000 \times 1.0) + (150 \times 0.04)]}}$$

t = 0.112 in.

Exercise 2 - Solution, cont'd

- Corrosion allowance calculation:

$$t_m = t + CA = 0.112 + 0.125$$
$$t = 0.237\,\text{in.}$$

- Mill tolerance calculation:

$$t_{nom} = \frac{t_m}{0.875} = \frac{0.237}{0.875}$$
$$t_{nom} = 0.271\,\text{in.}$$

Layout Considerations

- Operational
  - – Operating and control points easily reached
- Maintenance
  - – Ample clearance for maintenance equipment
  - – Room for equipment removal
  - – Sufficient space for access to supports
- Safety
  - – Consider personnel safety
  - – Access to fire fighting equipment

Pipe Supports and Restraints

- Supports
  - Absorb system weight
  - Reduce:
    - + longitudinal pipe stress
    - + pipe sag
    - + end point reaction loads
- Restraints
  - Control or direct thermal movement due to:
    - + thermal expansion
    - + imposed loads

Support and Restraint Selection Factors

- Weight load
- Available attachment clearance
- Availability of structural steel
- Direction of loads and/or movement
- Design temperature
- Vertical thermal movement at supports

Rigid Supports

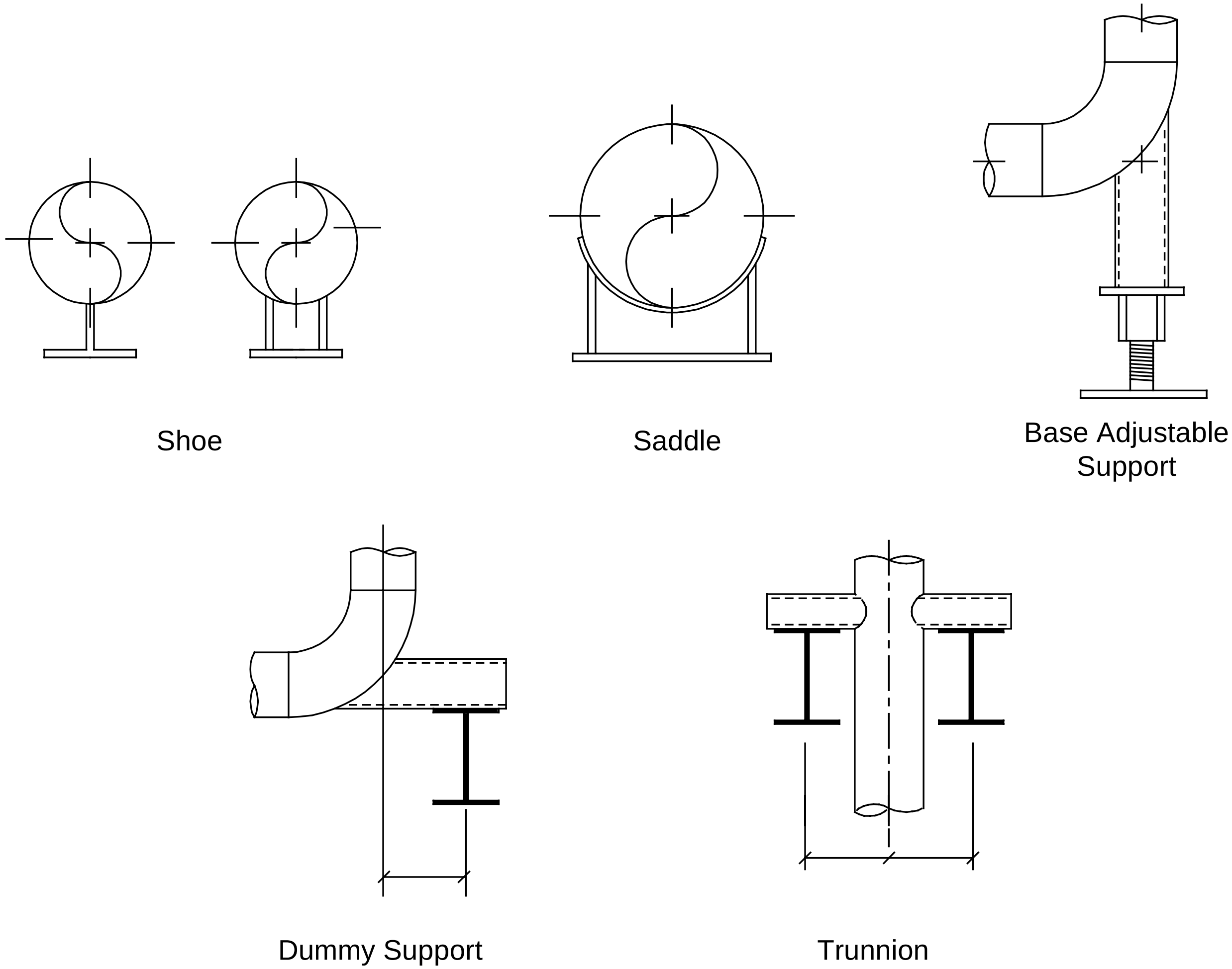


Figure 7.1

Hangers

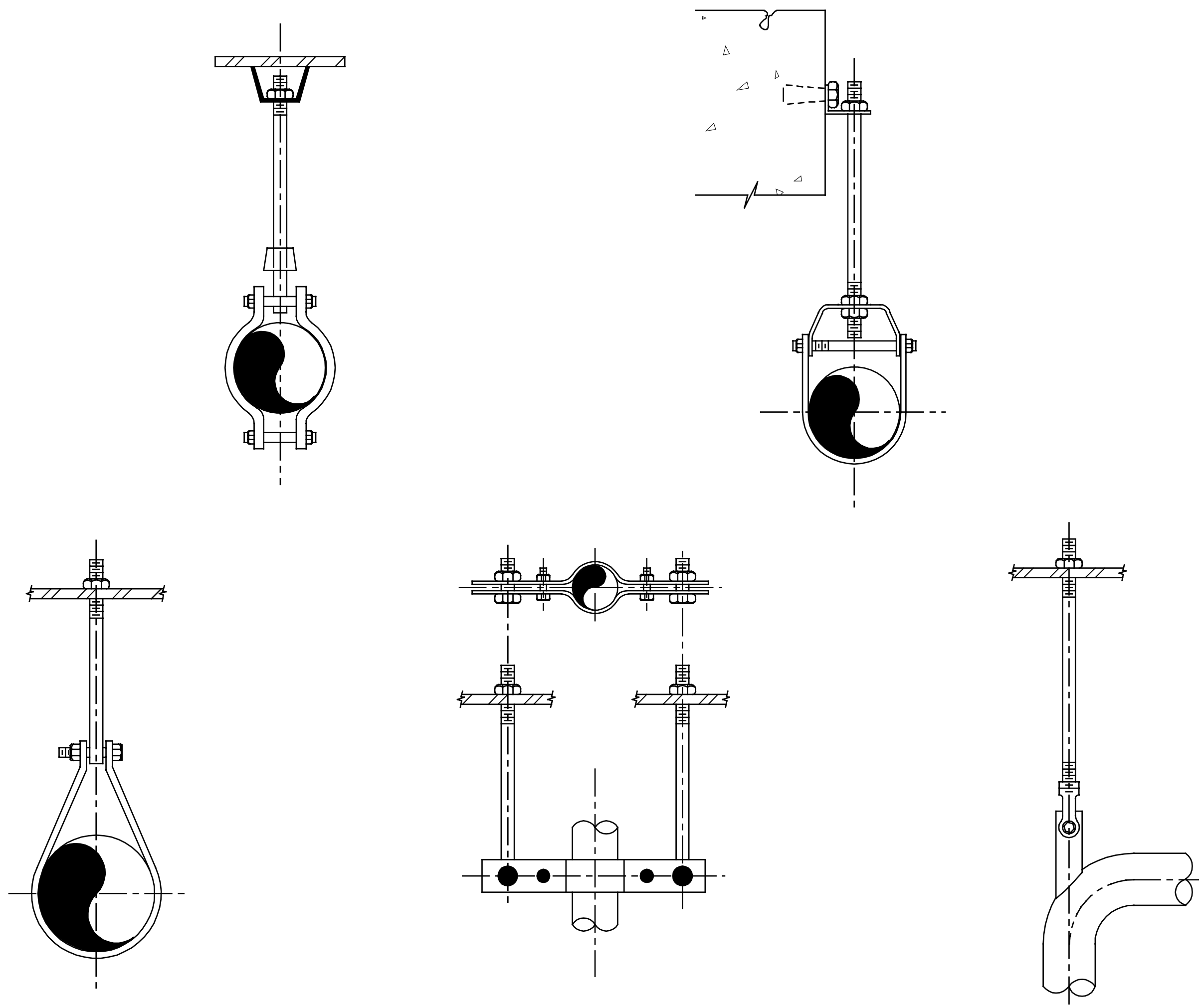
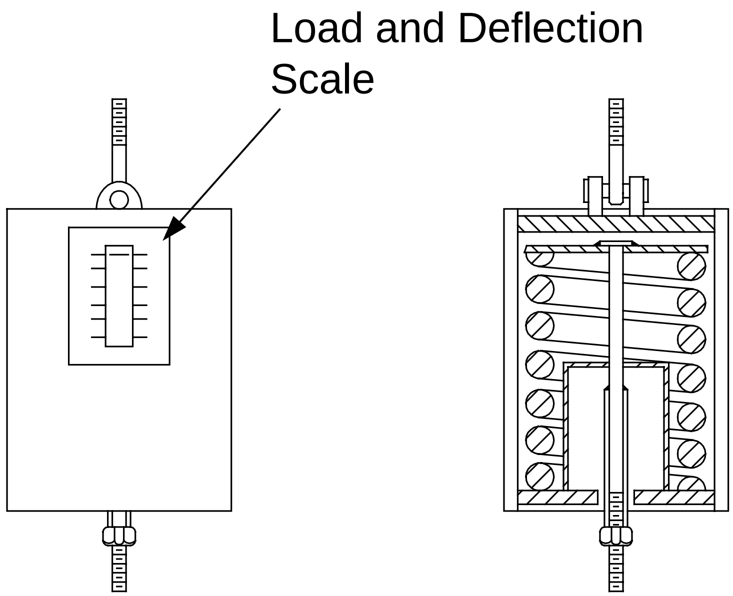
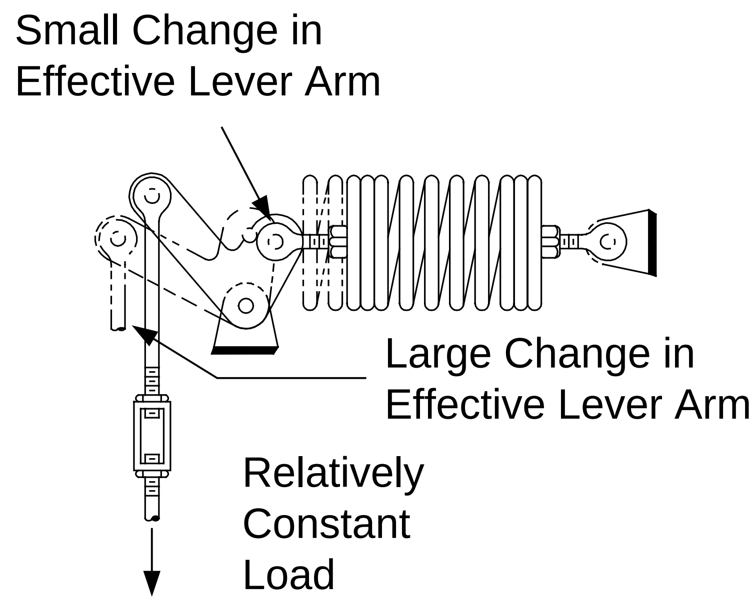


Figure 7.2

Flexible Supports



Typical Variable-Load
Spring Support



Typical Constant-Load
Spring Support Mechanism

Figure 7.3

Restraints

- Control, limit, redirect thermal movement
  - Reduce thermal stress
  - Reduce loads on equipment connections
- Absorb imposed loads
  - Wind
  - Earthquake
  - Slug flow
  - Water hammer
  - Flow induced-vibration

Restraints, cont'd

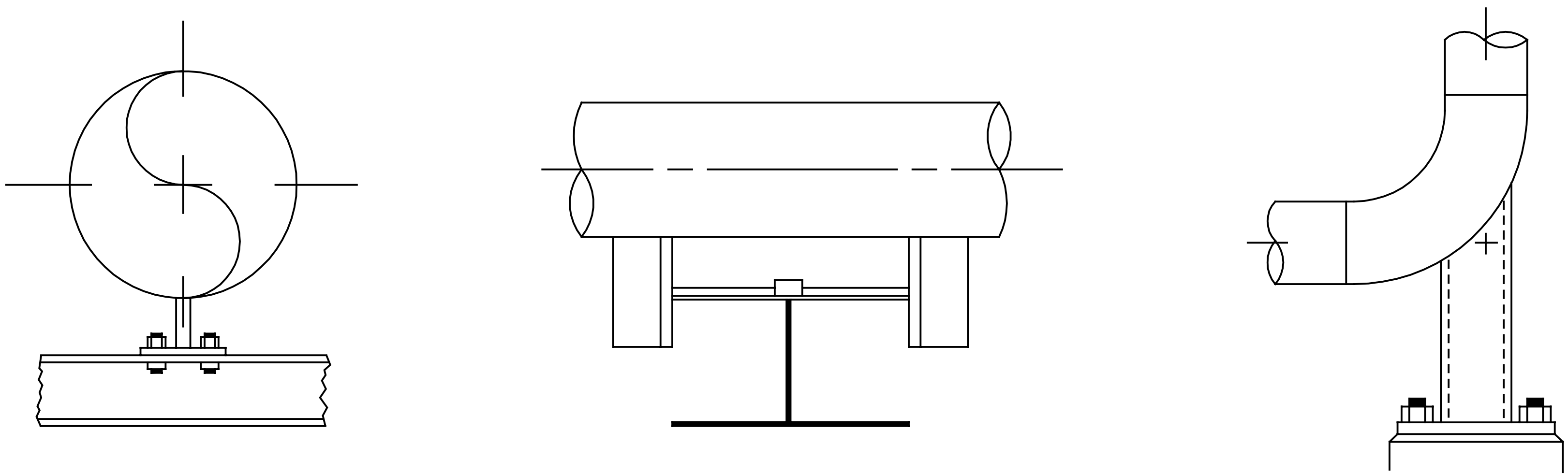
- Restraint Selection
  - Direction of pipe movement
  - Location of restraint point
  - Magnitude of load

Anchors and Guides

- Anchor
  - Full fixation
  - Permits very limited (if any) translation or rotation

- Guide
  - Permits movement along pipe axis
  - Prevents lateral movement
  - May permit pipe rotation

Restraints - Anchors



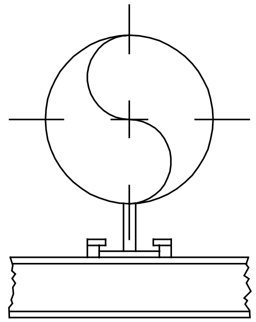
Anchor

Anchor

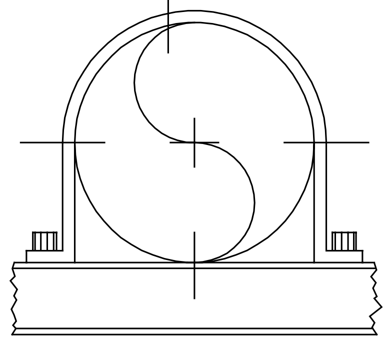
Partial Anchor

Figure 7.4

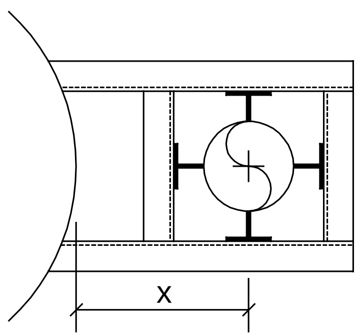
Restraints - Guides



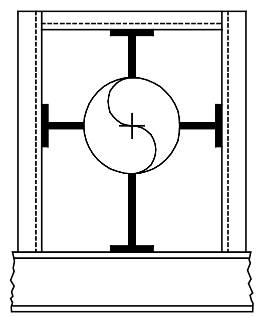
Guide



Guide



Vertical Guide



Guide

Figure 7.5

Piping Flexibility

- Inadequate flexibility
  - Leaky flanges
  - Fatigue failure
  - Excessive maintenance
  - Operations problems
  - Damaged equipment

- System must accommodate thermal movement

Flexibility Analysis

- Considers layout, support, restraint
- Ensures thermal stresses and reaction loads are within allowable limits
- Anticipates stresses due to:
  - Elevated design temperatures
    - Increases pipe thermal stress and reaction loads
    - Reduces material strength
  - Pipe movement
  - Supports and restraints

Flexibility Analysis, cont'd

- Evaluates loads imposed on equipment
- Determines imposed loads on piping system and associated structures
- Loads compared to industry standards
  - Based on tables
  - Calculated

Design Factors

- Layout
- Component design details
- Fluid service
- Connected equipment type
- Operating scenarios
- Pipe diameter, thickness
- Design temperature and pressure
- End-point movements
- Existing structural steel locations
- Special design considerations

Equipment Nozzle Load Standards and Parameters

Equipment Item	Industry Standard	Parameters Used To Determine Acceptable Loads
Centrifugal Pumps	API 610	Nozzle size
Centrifugal Compressors	API 617, 1.85 times NEMA SM-23 allowable	Nozzle size, material
Air-Cooled Heat Exchangers	API 661	Nozzle size
Pressure Vessels, Shell-and-Tube Heat Exchanger Nozzles	ASME Code Section VIII, WRC 107, WRC 297	Nozzle size, thickness, reinforcement details, vessel/exchanger diameter, and wall thickness. Stress analysis required.
Tank Nozzles	API 650	Nozzle size, tank diameter, height, shell thickness, nozzle elevation.
Steam Turbines	NEMA SM-23	Nozzle size

Table 7.1

Computer Analysis

- Used to perform detailed piping stress analysis
- Can perform numerous analyses
- Accurately completes unique and difficult functions
  - Time-history analyses
  - Seismic and wind motion
  - Support motion
  - Finite element analysis
  - Animation effects

Computer Analysis Guidelines

Type Of Piping	Pipe Size, NPS	Maximum Differential Flexibility Temp.
General piping	$\geq$ 4 $\geq$ 8 $\geq$ 12 $\geq$ 20	$\geq$ 400°F $\geq$ 300°F $\geq$ 200°F any
For rotating equipment	$\geq$ 3	Any
For air-fin heat exchangers	$\geq$ 4	Any
For tankage	$\geq$ 12	Any

Table 7.2

Piping Flexibility Temperature

- Analysis based on largest temperature difference imposed by normal and abnormal operating conditions
- Results give:
  - Largest pipe stress range
  - Largest reaction loads on connections, supports, and restraints
- Extent of analysis depends on situation

Normal Temperature Conditions To Consider

Stable Operation	Temperature range expected for most of time plant is in operation. Margin above operating temperature (i.e., use of design temperature rather than operating temperature) allows for process flexibility.
Startup and Shutdown	Determine if heating or cooling cycles pose flexibility problems. For example, if tower is heated while attached piping remains cold, piping flexibility should be checked.
Regeneration and Decoking Piping	Design for normal operation, regeneration, or decoking, and switching from one service to the other. An example is furnace decoking.
Spared Equipment	Requires multiple analyses to evaluate expected temperature variations, for no flow in some of piping, and for switching from one piece of equipment to another. Common example is piping for two or more pumps with one or more spares.

Table 7.3

Abnormal Temperature Conditions To Consider

Loss of Cooling Medium Flow	Temperature changes due to loss of cooling medium flow should be considered. Includes pipe that is normally at ambient temperature but can be blocked in, while subject to solar radiation.
Steamout for Air or Gas Freeing	Most on-site equipment and lines, and many off-site lines, are freed of gas or air by using steam. For 125 psig steam, 300°F is typically used for metal temperature. Piping connected to equipment which will be steamed out, especially piping connected to upper parts of towers, should be checked for tower at 300°F and piping at ambient plus 50°F. This may govern flexibility of lines connected to towers that operate at less than 300°F or that have a smaller temperature variation from top to bottom.
No Process Flow While Heating Continues	If process flow can be stopped while heat is still being applied, flexibility should be checked for maximum metal temperature. Such situations can occur with steam tracing and steam jacketing.

Table 7.4

Extent of Analysis

- Extent depends on situation
- Analyze right combination of conditions
- Not necessary to include system sections that are irrelevant to analysis results

Modifying System Design

- Provide more offsets or bends
- Use more expansion loops
- Install expansion joints
- Locate restraints to:
  - Minimize thermal and friction loads
  - Redirect thermal expansion
- Use spring supports to reduce large vertical thermal loads
- Use Teflon bearing pads to reduce friction loads

System Design Considerations

- Pump systems
  - Operating vs. spared pumps

- Heat traced piping systems
  - Heat tracing
    - + Reduces liquid viscosity
    - + Prevents condensate accumulation
  - Tracing on with process off

System Design Considerations, cont'd

- Atmospheric storage tank
  - Movement at nozzles
  - Tank settlement
- Friction loads at supports and restraints
  - Can act as anchors or restraints
  - May cause high pipe stresses or reaction loads
- Air-cooled heat exchangers
  - Consider header box and bundle movement

Tank Nozzle

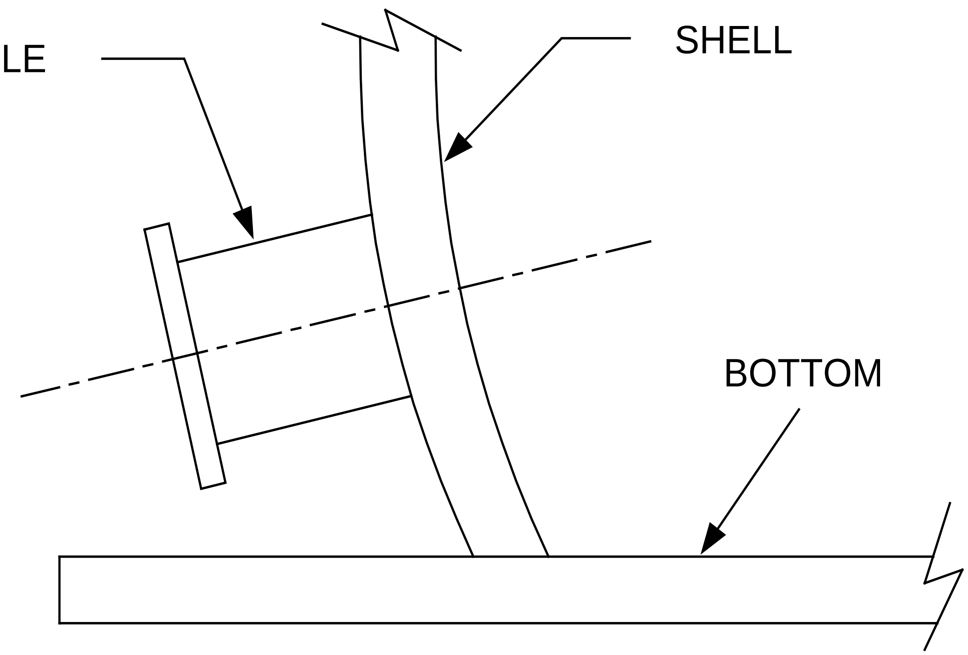
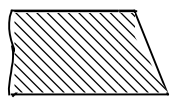


Figure 7.6

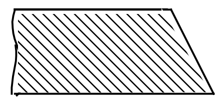
Welding

- Welding is primary way of joining pipe
- Provides safety and reliability
- Qualified welding procedure and welders
- Butt welds used for:
  – Pipe ends
  – Butt-weld-type flanges or fittings to pipe ends
  – Edges of formed plate

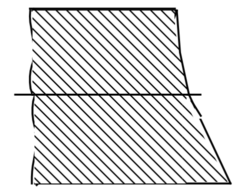
Butt-Welded Joint Designs Equal Thickness



(a) Standard End Preparation of Pipe



(b) Standard End Preparation of Butt-Welding Fittings and Optional End Preparation of Pipe 7/8 in. and Thinner



(c) Suggested End Preparation, Pipe and Fittings Over 7/8 in. Thickness

Figure 8.1

Butt-Welded Joint Designs Unequal Thickness

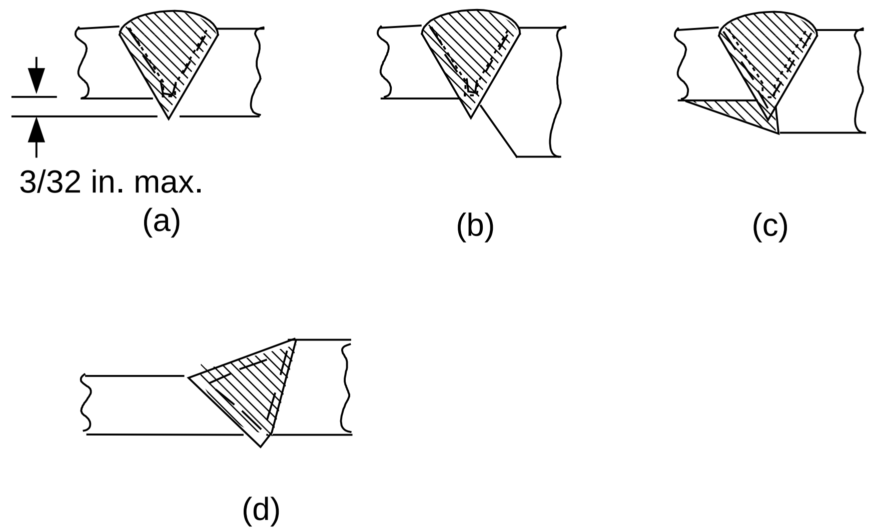


Figure 8.2

Fillet Welds

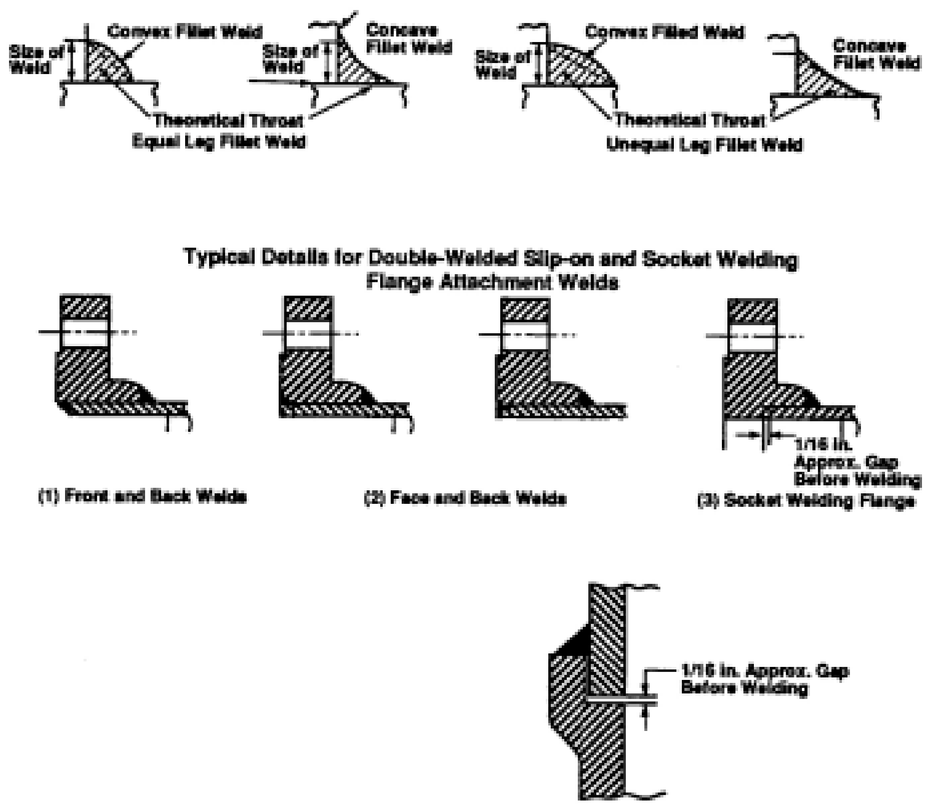


Figure 8.3

Weld Preparation

- Welder and equipment must be qualified
- Internal and external surfaces must be clean and free of paint, oil, rust, scale, etc.
- Ends must be:
  - Suitably shaped for material, wall thickness, welding process
  - Smooth with no slag from oxygen or arc cutting

Preheating

- Minimizes detrimental effects of:
  - High temperature
  - Severe thermal gradients
- Benefits include:
  - Dries metal and removes surface moisture
  - Reduces temperature difference between base metal and weld
  - Helps maintain molten weld pool
  - Helps drive off absorbed gases

Postweld Heat Treatment (PWHT)

- Primarily for stress relief
  - Only reason considered in B31.3
- Averts or relieves detrimental effects
  - Residual stresses
    - + Shrinkage during cooldown
    - + Bending or forming processes
  - High temperature
  - Severe thermal gradients

Postweld Heat Treatment (PWHT), cont'd

- Other reasons for PWHT to be specified by user
  - Process considerations
  - Restore corrosion resistance of normal grades of stainless steel
  - Prevent caustic embrittlement of carbon steel
  - Reduce weld hardness

Storage and Handling

- Store piping on mounds or sleepers
- Stacking not too high
- Store fittings and valves in shipping crates or on racks
- End protectors firmly attached
- Lift lined and coated pipes and fittings with fabric or rubber covered slings and padding

Pipe Fitup and Tolerances

- Good fitup essential
  - Sound weld
  - Minimize loads
- Dimensional tolerances
- Flange tolerances

Pipe Alignment
Load Sensitive Equipment

- Special care and tighter tolerances needed
- Piping should start at nozzle flange
  - Initial section loosely bolted
  - Gaskets used during fabrication to be replaced
- Succeeding pipe sections bolted on
- Field welds to join piping located near machine

Load Sensitive Equipment, cont’d

- Spring supports locked in cold position during installation and adjusted in locked position later
- Final bolt tensioning follows initial alignment of nozzle flanges
- Final nozzle alignment and component flange boltup should be completed after replacing any sections removed

Load Sensitive Equipment, cont'd

- More stringent limits for piping > NPS 3
- Prevent ingress of debris during construction

Flange Joint Assembly

- Primary factors
  - Selection
  - Design
  - Preparation
  - Inspection
  - Installation
- Identify and control causes of leakage

Flange Preparation, Inspection, and Installation

- Redo damaged surfaces
- Clean faces
- Align flanges
- Lubricate threads and nuts
- Place gasket properly
- Use proper flange boltup procedure

"Criss-Cross" Bolt-tightening Sequence

Figure 8.4

Causes of Flange Leakage

- Uneven bolt stress
- Improper flange alignment
- Improper gasket centering
- Dirty or damaged flange faces
- Excessive loads at flange locations
- Thermal shock
- Improper gasket size or material
- Improper flange facing

Inspection

- Defect identification
- Weld inspection
  - Technique
  - Weld type
  - Anticipated type of defect
  - Location of weld
  - Pipe material

Typical Weld Imperfections

Lack of Fusion Between Weld Bead and Base Metal

a) Side Wall Lack of Fusion

b) Lack of Fusion Between Adjacent Passes

Incomplete Filling at Root on One Side Only

c) Incomplete Penetration Due to Internal Misalignment

Incomplete Filling at Root

d) Incomplete Penetration of Weld Groove

Root Bead Fused to Both Inside Surfaces but Center of Root Slightly Below Inside Surface of Pipe (Not Incomplete Penetration)

e) Concave Root Surface (Suck-Up)

External Undercut

Internal Undercut

f) Undercut

g) Excess External Reinforcement

Figure 9.1

Weld Inspection Guidelines

Type of Inspection	Situation/Weld Type	Defect
Visual	All welds.	• Minor structural welds. • Cracks. • Slag inclusions.
Radiography	• Butt welds. • Girth welds. • Miter groove welds.	• Gas pockets. • Slag inclusions. • Incomplete penetration.
Magnetic Particle	• Ferromagnetic materials. • For flaws up to 6 mm (1/4 in.) beneath the surface.	• Cracks. • Porosity. • Lack of fusion.
Liquid Penetrant	• Ferrous and nonferrous materials. • Intermediate weld passes. • Weld root pass. • Simple and inexpensive.	• Cracks. • Seams. • Porosity. • Folds. • Inclusions. • Shrinkage. • Surface defects.
Ultrasonic	Confirms high weld quality in pressure-containing joints.	• Laminations. • Slag inclusions in thick plates. • Subsurface flaws.

Table 9.1

Testing

- Pressure test system to demonstrate integrity
- Hydrostatic test unless pneumatic approved for special cases
- Hydrostatic test pressure
  - $\geq$ 1½ times design pressure

Testing, cont'd

– For design temperature > test temperature:

$$P_T = \frac{1.5 P S_T}{S}$$

S_T/S must be ≤ 6.5

P_T = Minimum hydrostatic test pressure, psig

P = Internal design pressure, psig

S_T = Allowable stress at test temperature, psi

S = Allowable stress at design temperature, psi

Testing, cont'd

- Pneumatic test at 1.1P
- Instrument take-off piping and sampling piping strength tested with connected equipment

Nonmetallic Piping

- Thermoplastic Piping
  - Can be repeatedly softened and hardened by increasing and decreasing temperature
- Reinforced Thermosetting Resin Piping (RTR)
  - Fabricated from resin which can be treated to become infusible or insoluble

Nonmetallic Piping, cont'd

- No allowances for pressure or temperature variations above design conditions
- Most severe coincident pressure and temperature conditions determine design conditions

Nonmetallic Piping, cont'd

- Designed to prevent movement from causing:
  - Failure at supports
  - Leakage at joints
  - Detrimental stresses or distortions
- Stress-strain relationship inapplicable

Nonmetallic Piping, cont'd

- Flexibility and support requirement same as for piping in normal fluid service. In addition:
  - Piping must be supported, guided, anchored to prevent damage.
  - Point loads and narrow contact areas avoided
  - Padding placed between piping and supports
  - Valves and load transmitting equipment supported independently to prevent excessive loads.

Nonmetallic Piping, cont'd

- Thermoplastics not used in flammable service, and safeguarded in most fluid services.
- Joined by bonding

Category M Fluid Service

Category M Fluid

- Significant potential for personnel exposure

- Single exposure to small quantity can cause irreversible harm to breathing or skin.

Category M Fluid Service, cont'd

- Requirements same as for piping in normal fluid service. In addition:
  - Design, layout, and operation conducted with minimal impact and shock loads.
  - Detrimental vibration, pulsation, resonance effects to be avoided or minimized.
  - No pressure-temperature variation allowances.

Category M Fluid Service, cont'd

– Most severe coincident pressure-temperature conditions determine design temperature and pressure.

– All fabrication and joints visually examined.

– Sensitive leak test required in addition to other required testing.

Category M Fluid Service, cont'd

- Following may not be used
  - – Miter bends not designated as fittings, fabricated laps, nonmetallic fabricated branch connections.
  - – Nonmetallic valves and specialty components.
  - – Threaded nonmetallic flanges.
  - – Expanded, threaded, caulked joints.

High Pressure Piping

- Ambient effects on design conditions
  - Pressure reduction based on cooling of gas or vapor
  - Increased pressure due to heating of a static fluid
  - Moisture condensation

High Pressure Piping, cont'd

- Other considerations
  - Dynamic effects
  - Weight effects
  - Thermal expansion and contraction effects
  - Support, anchor, and terminal movement

High Pressure Piping, cont'd

- Testing
  - Each system hydrostatically or pneumatically leak tested
  - Each weld and piping component tested
  - Post installation pressure test at 110% of design pressure if pre-installation test was performed
- Examination
  - Generally more extensive than normal fluid service

Summary

- Process plant piping much more than just pipe
- ASME B31.3 covers process plant piping
- Covers design, materials, fabrication, erection, inspection, and testing
- Course provided overview of requirements