PRACTICAL PIPING COURSE

OUTLINE

Disclaimer !

This short course is not a substitute for accessing and using the Codes directly in conformance to generally accepted engineering practice.

Consult the appropriate Codes and references prior to designing and engineering any piping systems.

In some jurisdictions, a Professional Engineer must design pressure piping.

1.0 Introduction

1.1 Definition of Piping

Pipe is a pressure tight cylinder used to convey a fluid or to transmit a fluid pressure, ordinarily designated pipe in applicable material specifications. Materials designated tube or tubing in the specifications are treated as pipe when intended for pressure service.

Piping is an assembly of piping components used to convey, distribute, mix, separate, discharge, meter, control or snub fluid flows. Piping also includes pipe-supporting elements but does not include support structures, such as building frames, bents, foundations, or any equipment excluded from Code definitions.

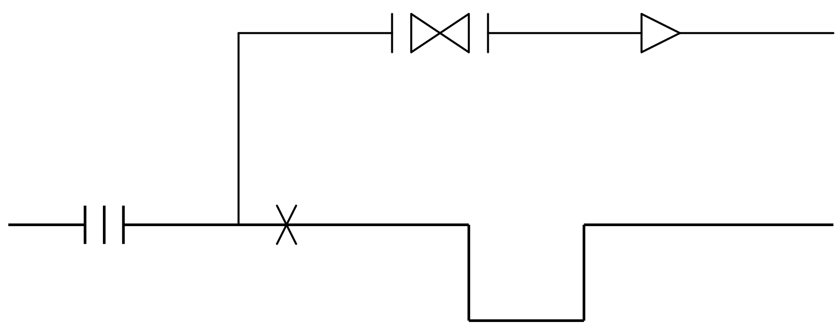
Piping components are mechanical elements suitable for joining or assembly into pressure-tight fluid containing piping systems. Components include pipe, tubing, fittings, flanges, gaskets, bolting, valves and devices such as expansion joints, flexible joints, pressure hoses, traps, strainers, in-line portions of instruments and separators.

Piping is typically round.

1.2 Piping Nomenclature, Components

Graphic of piping system illustrating

- header
- branch connection
- valve
- flange
- expansion joint
- expansion loop
- pipe support
- reducer
- elbow



Pipe system essentials:

Header	• Main run of piping
Take off	• Branch run
Stub in	• Branch fitting connection made to header by direct attachment of branch •
Branch reinforcement	• Material added in the vicinity of a branch opening to restore the mechanical integrity of the pipe
NPS	• Nominal pipe size
Pipe support	• Support elements which serve to maintain the structural integrity of the piping system, these are typically non-linear elements
Spring support	• Support provided by an element composed of a spring assembly, these are linear support elements
Snubber	• Support provided by an element composed of a non-linear, damping element
Category D	• Within reference of B31.3, a service classification
Category M	• Within reference of B31.3, a service classification
Expansible fluid	• Any vapour or gaseous substance, any liquid under such pressure and temperature such that when pressure is reduced to atmospheric, will change to a gas
Hydro test	• Test pressure = 1.5 x MAWP (some of the time)
MAWP	• Maximum allowable working pressure
MDMT	• Minimum design metal temperature
Fracture toughness	• Typically measured by CVN (Charpy V Number) at MDMT

1.3 Regulatory Acts, Codes & Standards

Codes

Codes are rules for the design of prescribed systems which are given the force of law through provincial, state and federal legislation. In Canada, provincial governments have the responsibility for public safety which includes these facilities, among others:

- Pressure piping
- Pressure vessels
- Boilers
- Pipelines
- Plumbing systems
- Gas piping

Alberta Safety Codes Acts and Codes of Practice

The following are applicable to the first four facilities listed above.

Boilers and Pressure Vessels Regulation

- Prescribes requirements for registration of pressure vessels, boilers, pressure piping and fittings

Design, Construction and Installation of Boilers and Pressure Vessels Regulations

- Cites the codes and “bodies of rules” that form part of the regulations
- CSA B51 Boiler, Pressure Vessel and Pressure Piping Code
- CSA B52 Mechanical Refrigeration Code
- CAN/CSA Z184 Gas Pipeline Systems
- ASME Boiler & Pressure Vessel Code
- ASME B31 Pressure Piping Codes
  - B31.1 Power Piping
  - B31.3 Process Piping
  - B31.4 Liquid Transportation Systems for Hydrocarbons, Liquid Petroleum Gas, Anhydrous Ammonia and Alcohols
  - B31.5 Refrigeration Piping
- ANSI K61.1 Safety Requirements for the Storage and Handling of Anhydrous Ammonia
- NFPA 58 Standard for the Storage and Handling of Liquefied Petroleum Gases
- DOT Regulations of the Department of Transportation Governing the Transportation of Hazardous Materials in Tank Motor Vehicles
- MSS Standard Practice SP 25 Standard Marking System for Valves, Fittings, Flanges and Unions
- TEMA Standards of Tubular Exchanger Manufacturers Association

Pipeline Act

Cites the "minimum requirements for the design, construction, testing, operation, maintenance and repair of pipelines":

- CSA Z662 Oil and Gas Pipeline Systems
- CAN/CSA Z183 Oil Pipeline Systems (superceded)
- CAN/CSA Z184 Gas Pipeline Systems (superceded)
- CSA Z169 Aluminum Pipe and Pressure Piping Systems
- Canadian Petroleum Association Recommended Practice for Liquid Petroleum Pipeline Leak Prevention and Detection in the Province of Alberta

In the US:

As in Canada, some facilities are governed by federal regulations. Interstate pipeline facilities are defined by the:

- Code of Federal Regulations, Title 49
  - Part 192 Transportation of Natural and Other Gas by Pipeline – Minimum Federal Safety Standards
  - Part 193 Liquefied Natural Gas Facilities
  - Part 195 Transportation of Hazardous Liquids by Pipeline

Other pipeline pressure piping codes include:

- ASME B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
- ASME B31.8 Gas Transmission and Distribution Systems

1.4 Line Designation Tables

The Province of Alberta Safety Codes Act "Design, Construction and Installation of Boilers & Pressure Vessels Regulations" par 7(2) requires that construction of a pressure piping system must include submission of drawings, specifications and other information and include:

(a) flow or line diagrams showing the general arrangement of all boilers, pressure vessels, pressure piping systems and fittings

(b) pipeline identification lists showing the maximum pressures and temperatures for each pressure piping system

(c) a list of pressure relief devices, including the set pressure

(d) material specifications, size, schedule and primary service rating of all pressure piping and fittings

(e) the welding procedure registration number

(f) the pressure pipe test procedure outlining the type, method, test media , test pressure, test temperature, duration and safety precautions

(g) a form, provided by the Administrator, completed by the engineering designer or contractor which relates to the general engineering requirements for design and field construction of pressure piping systems

(h) such other information as is necessary for a safety codes officer to survey the design and determine whether it is suitable for approval and registration

Problem Set 1

1 Which Act governs the design of plant pressure piping systems in Alberta?

2 Are process plant water lines considered pressure piping systems?

3 For what fluid service category may a hydro test be waived per B31.3?

4 What is the difference between a pipe elbow and a bend?

2.0 Codes and Standards

The following codes are used for the design, construction and inspection of piping systems.

2.1 The ASME B31 Piping Codes

Piping codes developed by the American Society of Mechanical Engineers:

B31.1 Power Piping

Piping typically found in electric power generating stations, in industrial and institutional plants, geothermal heating systems and central and district heating and cooling plants.

B31.3 Process Piping

Piping typically found in petroleum refineries, chemical, pharmaceutical, textile, per, semiconductor and cryogenic plants and related processing plants and terminals.

B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids

Piping transporting products which are predominately quid between plants and terminals and within terminals, pumping, regulating, and metering stations.

B31.5 Refrigeration Piping

Piping for refrigerants and secondary coolants.

B31.8 Gas Transportation and Distribution Piping Systems

Piping transporting products which are predominately gas between sources and terminals including compressor, regulating and metering stations, gas gathering pipelines.

B31.9 Building Services Piping

Piping typically found in industrial, institutional, commercial and public buildings and in multi-unit residences which does not require the range of sizes, pressures and temperatures covered in B311.1

B31.11 Slurry Transportation Piping Systems

Piping transporting aqueous slurries between plants and terminals within terminals, pumping and regulating stations.

The following codes are used to specify the geometric, material and strength of piping and components:

ASME B16 Dimensional Codes

The ASME B16 Piping Component Standards

Piping component standard developed by the American Society of Mechanical Engineers or the American National Standards Institute (ANSI)

B16.1	Cast Iron Pipe Flanges and Flanged Fittings
B16.3	Malleable Iron Threaded Fittings, Class 150 and 300
B16.4	Cast Iron Threaded Fittings, Classes 125 and 250
B16.5	Pipe Flanges and Flanged Fittings
B16.9	Factory Made Wrought Steel Buttwelding Fittings
B16.10	Face to Face and End to End Dimensions of Valves
B16.11	Forged Fittings, Socket Welding and Threaded
B16.12	Cast Iron Threaded Drainage Fittings
B16.14	Ferrous Pipe Plugs, Bushings and Locknuts with Pipe Threads
B16.15	Cast Bronze Threaded Fittings Class 125 and 250
B16.18	Cast Copper Alloy Solder Joint Pressure Fittings
B16.20	Ring Joint Gaskets and Grooves for Steel Pipe Flanges
B16.21	Nonmetallic Flat Gaskets for Pipe Flanges
B16.22	Wrought Copper and Copper Alloy Solder Joint Pressure Fittings
B16.23	Cast Copper Alloy Solder Joint Drainage Fittings – DWV
B16.24	Cast Copper Alloy Pipe Flanges and Flanged Fittings Class 150, 300, 400,600, 900, 1500 and 2500
B16.25	Buttwelding Ends
B16.26	Cast Copper Alloy Fittings for Flared Copper Tubes
B16.28	Wrought Steel Buttwelding Short Radius Elbows and Returns
B16.29	Wrought Copper and Wrought Copper Alloy Solder Joint Drainage Fittings – DWV
B16.32	Cast Copper Alloy Solder Joint Fittings for Sovent Drainage Systems
B16.33	Manually Operated Metallic Gas Valves for Use in Gas Piping systems Up to 125 psig (sizes ½ through 2)
B16.34	Valves – Flanged, Threaded and Welding End
B16.36	Orifice Flanges
B16.37	Hydrostatic Testing of Control Valves
B16.38	Large Metallic Valves for Gas Distribution (Manually Operated, NPS 2 ½ to 12, 125 psig maximum)
B16.39	Malleable Iron Threaded Pipe Unions, Classes 1150, 250 and 300
B16.40	Manually Operated Thermoplastic Gs Shutoffs and Valves in Gas Distribution Systems
B16.42	Ductile Iron Pipe Flanges and Flanged Fittings, Class 150 and 300
B16.47	Large Diameter Steel Flanges (NPS 26 through NPS 60)

ASME B36 Piping Component Standards

Piping standards developed by the American Society of Mechanical Engineers / American National Standards Institute:

B36.10	Welded and Seamless Wrought Steel Pipe
B36.19	Stainless Steel Pipe

Other ASME or ANSI

B73.1	Horizontal, End Suction Centrifugal Pumps
B73.2	Vertical In-line Centrifugal Pumps
B133.2	Basic Gas Turbine

2.2 NEPA Codes

National Electrical Protection Association

Piping covering fire protection systems using water, carbon dioxide, halon, foam, dry chemical and wet chemicals.

NFC - NFPA Codes

National Fire Code / National Fire Protection Association

NFPA 99 Health Care Facilities Code

2.3 CSA Standards

Canadian Standards Association

CSA Z662 - 94 Oil & Gas Pipeline Systems

This standard supercedes these standards:

- CAN/CSA Z183 Oil Pipeline Systems
- CAN/CSA Z184 Gas Pipeline Systems
- CAN/CSA Z187 Offshore Pipelines

Other CSA Piping and Component Codes:

B 51	Boilers and Pressure Vessels
B 53	Identification of Piping Systems
B 52	Mechanical Refrigeration Code
B 63	Welded and Seamless Steel Pipe
B 137.3	Rigid Poly-Vinyl Chloride (PVC) Pipe
B 137.4	Polyethylene Piping Systems for Gas Service
W 48.1	Mild Steel Covered Arc-Welding Electrodes
W 48.3	Low-Alloy Steel Arc-Welding Electrodes
Z 245.1	Steel Line Pipe
Z 245.11	Steel Fittings
Z 245.12	Steel Flanges
Z 245.15	Steel Valves
Z 245.20	External Fusion Bond Epoxy Coating for Steel Pipe
Z 245.21	External Polyethylene Coating for Pipe
Z 276	LNG - Production, Storage and Handling

2.4 MSS Standard Practices

These are piping and related component standards developed by the Manufacturer's Standardization Society. The MSS standards are directed at general industrial applications. The pipeline industry makes extensive use of these piping component and quality acceptance standards.

SP-6	Standard Finishes for Contact Faces Pipe Flanges and Connecting End Flanges of Valves and Fittings
SP-25	Standard Marking System for Valves, Fittings, Flanges and Union
SP-44	Steel Pipeline Flanges
SP-53	Quality Standards for Steel Castings and Forgings for Valves, Flanges and Fittings and Other Piping Components - Magnetic Particle
SP-54	Quality Standards for Steel Castings and for Valves, Flanges and Fittings and Other Piping Components - Radiographic
SP-55	Quality Standards for Steel Castings and for Valves, Flanges and Fittings and Other Piping Components - Visual
SP-58	Pipe Hangers and Supports - Material, Design and Manufacture
SP-61	Pressure Testing of Steel Valves
SP-69	Pipe Hangers and Supports - Selection and Application
SP-75	High Test Wrought Butt Welding Fittings
SP-82	Valve Pressure Testing Methods
SP-89	Pipe Hangers and Supports - Fabrication and Installation Practices

2.5 API

American Petroleum Institute

The API standards are focused on oil production, refinery and product distribution services. Equipment specified to these standards are typically more robust than general industrial applications.

Spec. 5L	Line Pipe
Spec. 6D	Pipeline Valves
Spec. 6FA	Fire Test for Valves
Spec. 12D	Field Welded Tanks for Storage of Production Liquids
Spec. 12F	Shop Welded Tanks for Storage of Production Liquids
Spec. 12J	Oil and Gas Separators
Spec. 12K	Indirect Type Oil Field Heaters

Std. 594	Wafer and Wafer-Lug Check Valves
Std. 598	Valve Inspection and Testing
Std. 599	Metal Plug Valves - Flanged and Butt-Welding Ends
Std. 600	Steel Gate Valves-Flanged and Butt-Welding Ends
Std. 602	Compact Steel Gate Valves-Flanged Threaded, Welding, and Extended-Body Ends
Std. 603	Class 150, Cast, Corrosion-Resistant, Flanged-End Gate Valves
Std. 607	Fire Test for Soft-Seated Quarter-Turn Valves
Std. 608	Metal Ball Valves-Flanged and Butt-Welding Ends
Std. 609	Lug-and Wafer-Type Butterfly Valves
Std. 610	Centrifugal Pumps For Petroleum, Heavy Duty Chemical and Gas Industry Services
Std. 611	General Purpose Steam Turbines for Refinery Services
Std. 612	Special Purpose Steam Turbines for Refinery Services
Std. 613	Special Purpose Gear Units for Refinery Services
Std. 614	Lubrication, Shaft-Sealing and Control Oil Systems for Special Purpose Application
Std. 615	Sound Control of Mechanical Equipment for Refinery Services
Std. 616	Gas Turbines for Refinery Services
Std. 617	Centrifugal Compressors for General Refinery Services
Std. 618	Reciprocating Compressors for General Refinery Services
Std. 619	Rotary-Type Positive Displacement Compressors for General Refinery Services
Std. 620	Design and Construction of Large, Welded, Low Pressure Storage Tanks
Std. 630	Tube and Header Dimensions for Fired Heaters for Refinery Service
Std. 650	Welded Steel Tanks for Oil Storage
Std. 660	Heat Exchangers for General Refinery Service
Std. 661	Air-Cooled Heat Exchangers for General Refinery Service
Std. 670	Vibrations, Axial Position, and Bearing-Temperature Monitoring Systems
Std. 671	Special Purpose Couplings for Refinery Service
Std. 674	Positive Displacement Pumps-Reciprocating

API (cont'd)

Std. 675	Positive Displacement Pumps-Controlled Volume
Std. 676	Positive Displacement Pumps-Rotary
Std. 677	General Purpose Gear Units for Refineries Services
Std. 678	Accelerometer-Base Vibration Monitoring System
Std. 1104	Welding Pipelines and Related Facilities
Std. 2000	Venting Atmospheric and Low-Pressure Storage Tanks - Non-Refrigerated and Refrigerated
RP 530	Calculation for Heater Tube Thickness in Petroleum Refineries
RP 560	Fired Heater for General Refinery Services
RP 682	Shaft Sealing System for Centrifugal and Rotary Pumps
RP 1110	Pressure Testing of Liquid Petroleum Pipelines
Publ. 941	Steel for Hydrogen Service at Elevated Temperature and Pressures in Petroleum Refineries and Petrochemical Plants
Publ. 2009	Safe Welding and Cutting Practices in Refineries
Publ. 2015	Safe Entry and Cleaning of Petroleum Storage Tanks

2.6 ASTM

There are numerous American Society for Testing and Materials designations cover the specification of wrought materials, forgings and castings used for plate, fittings, pipe and valves. The ASTM standards are directed to dimensional standards, materials and strength considerations.

Some of the more material standards referenced are:

A 36	Specification for Structural Steel
A 53	Specification for Pipe, Steel, Black and Hot –Dipped, Zinc Coated Welded and Seamless
A 105	Specification for Forgings, Carbon Steel, for Piping Components
A 106	Specification for Seamless Carbon Steel Pipe for High Temperature Service
A 181	Specification for Forgings, Carbon Steel for General Purpose Piping
A 182	Specification for Forged or Rolled Alloy Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High Temperature Service
A 193	Specification for Alloy Steel and Stainless Steel Bolting Materials for High Temperature Service
A 194	Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure and High Temperature Service
A 234	Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Moderate and Elevated Temperatures
A 333	Specification for Seamless and Welded Steel Pipe for Low Temperature Service
A 350	Specification for Forgings, Carbon and Low Alloy Steel Requiring Notch Toughness Testing for Piping Components
A 352	Specification for Steel Castings, Ferritic and Martensitic for Pressure Containing Parts Suitable for Low Temperature Service
A 420	Specification for Piping Fittings of Wrought Carbon Steel and Alloy Steel for Low Temperature Service
A 694	Specification for Forgings, carbon and Alloy Steel for Pipe Flanges, Fittings, Valves and Parts for High Pressure Transmission Service
A 707	Specification for Flanges, Forged, Carbon and Alloy Steel for Low Temperature Service

Problem Set 2

1. A project award has been made. At the kick off meeting, the PM advises that piping design will be to B31.4. The facility is steam piping in a refinery extending from the boiler to the tank farm. What do you do or say and why?

2. A liquid pipeline is to be built to Z184. You raise an issue. Why?

3. What flange specification would you expect to reference for a gas pipeline facility?

   Show the development of your answers.

Section 1 – Attachments

Please refer to specific documents cited:

Fig 100.1.2(B) of ASME B31.1
Fig 300.1.1 of ASME B31.3 1996
Fig 300.1.1 of ASME B31.3 1999
Fig 400.1.1 of ASME B31.4
Fig 400.1.2 of ASME B31.4
Fig 1.1 of CSA Z 662
Fig 1.2 of CSA Z 662
Table of Contents CSA Z 662

3.0 Supplemental Documents

3.1 Owner's Specifications & Documents

Many of the Owners in the industries we service are technically sophisticated and will often have supplementary specifications, standards or practices. It is the intent of these documents to clarify and provide interpretation of the legislated Codes and industry accepted standards specific to the Owner's facilities.

These specifications typically go beyond the requirements of Codes and without exception do not contravene a Code requirement.

Owner	Specification .
Exxon / Imperial Oil	Global Practices (GP's)
Shell	
Petro-Canada	Petro Canada Engineering Standards
Husky Oil	Engineering Design Specification (EDS) Project Design Specification (PDS)
Syncrude Canada	Syncrude Engineering Standards
Suncor Inc	Suncor OSG Technical Standards
Dow Chemical	Engineering Practices
Celanese	Celanese Edmonton Standards Methanol / Braun Engineering Site Standards Corporate Engineering Standards PIP (Process Industry Practices)
Enbridge	Enbridge Engineering Standards

3.2 Contractor's Specifications & Documents

The engineering contractor and may be called upon to provide the engineering specifications for a project if an Owner does not have his own standards or if required by terms of the contract.

Problem Set 3

1 What is the typical precedence of documents for engineering standards?

2 Can the Owner's engineering standard override a Code provision?

3 Under what conditions can the Owner's standard override a Code provision?

4 How would you deviate from an Owner's engineering specification?

4.0 Piping Design

Piping design deals with the:

- analytical design
- material selection
- geometric layout
- fabrication
- inspection specification
- component specification

of piping and piping components.

4.1 Failure Mechanisms

Piping and piping components may fail if inadequately designed, by a number of different mechanisms. These failures, in the majority of cases are either load controlled or displacement controlled failures.

- Pipe rupture due to overpressure
- Bending failure in pipe span
- Elbow cracking after 10 years of service, 5000 cycles of heat up to 500 F
- On heat up, a line comes into contact with adjacent header which is at ambient temperature
- During startup on a cold winter day in Grande Prairie, an outdoor gas line located above grade and constructed to Z662 is suddenly subjected to full line pressure and ruptures.
- A 12" Sch.40 header, bottom supported, 40 feet long runs vertically up a tower and connects to a nozzle. On steam out of the vessel, a 1' deflection is observed in the pipe and remains after the steam out procedure is completed and the pipe returns to ambient temperature.
- A header of a reciprocating compressor has been stressed checked; during operation vibration is observed in the line. During the unit turnaround, cracking is found at midspan in the wrought piping material.
- A stress check determines that a hot, high alloy line does not pass the flexibility requirements per B31.3. Twenty-five cycles are expected over the lifetime of the line.

4.2 Code Considerations for Design

Design of piping systems is governed by Codes. All codes have a common theme, they are intended to set forth engineering requirements deemed necessary for safe design and construction of piping installations.

The Codes are not intended to apply to the operation, examination, inspection, testing, maintenance or repair of piping that has been placed in service. The Codes do not prevent the User from applying the provisions of the Codes for those purposes.

Engineering requirements of the Codes, while considered necessary and adequate for safe design, generally use a simplified approach. A designer capable of applying a more rigorous analysis shall have the latitude to do so, but must be able to demonstrate the validity of such analysis.

Design Conditions

Design conditions refer to the operating and design temperature and pressure that the piping system will operate at over the course of its design life.

Code Design Temperature & Design Pressure

Code	Design Temperature	Design Pressure
B31.1	The piping shall be designed for a metal temperature representing the maximum sustained condition expected. The design temperature shall be assumed to be the same as the fluid temperature unless calculations or tests support the use of other data, in which case the design temperature shall not be less than the average of the fluid temperature and the outside wall temperature.	The internal design pressure shall be not less than the maximum sustained operating pressure (MSOP) within the piping system including the effects of static head.
B31.3	The design temperature of each component in a piping system is the temperature at which, under the coincident pressure, the greatest thickness or highest component rating is required in accordance with par. 301.2	The design pressure of each component in a piping system shall be not less than the pressure at the most severe condition of coincident internal or external pressure and temperature expected during service, except as provided in par. 302.2.4.
B31.4	The design temperature is the metal temperature expected in normal operation. It is not necessary to vary the design stress for metal temperatures between –20 °F and 250 °F.	The piping component at any point in the piping system shall be designed for an internal design pressure which shall not be less than the maximum steady state operating pressure at that point, or less than the static head pressure at that point with the line in a static condition. The maximum steady state operating pressure shall be the sum of the static head pressure, pressure required to overcome friction losses and any required back pressure.
B31.8	No design temperature. The Code mentions only ambient temperature and ground temperature. (1975)	Design pressure is the maximum operating pressure permitted by the Code, as determined by the design procedures applicable to the materials and locations involved.

Code Design Temperature & Design Pressure (cont'd)

Z662	For restrained piping, the temperature differential shall be the difference between the maximum flowing fluid temperature and the metal temperature at the time of restraint. For unrestrained piping, the thermal expansion range to be used in the flexibility analysis shall be the difference between the maximum and minimum operating temperatures.	The design pressure at any specific location shall be specified by the designer, shall not be less than the intended maximum operating pressure at any location, and shall include static head, pressure required to overcome friction loss and any required back pressure.

Design of Piping – B31.1

B31.1 essentially limits the pressure design consideration to three items:

Minimum thickness for pressure

$$t_{min} = \frac{(P * Do)}{2(SE + PY)} + A$$

$$\text{or } t = \frac{P * d + 2SE + 2yPA}{2(SE + Py - P)}$$

The limit is based on the limit stress being less than the basic allowable stress at temperature. This limit is based on the static yield strength of the material.

Maximum longitudinal stress due to sustained loadings (S_L)

$S_L \leq S_h$; stress due to sustained loadings shall be less than the basic allowable stress at temperature. Sustained loadings are those due to pressure, self weight of contents & piping and other sustained loadings particular to the situation. The limit is based on the static yield strength of the material.

$$S_{LP} = \frac{P * Do}{4 * tn}$$

The computed displacement stress range S_E

$S_E \leq S_A = f \bullet (1.25\ S_c + 0.25\ S_h)$. S_E stresses arise from the constraint of the thermal strain displacements associated with the expansion of pipe due to temperature. The limit is based on fatigue considerations.

Where the sum of the longitudinal stresses is less than S_h, the difference may be used as an additional thermal expansion allowance.

$$S_E = \sqrt{S_b{}^2 + 4 * S_t{}^2}$$

$$S_b = \frac{\sqrt{i_i M_i{}^2 + i_o M_o{}^2}}{Z}$$

B31.1 (cont'd)

The computed displacement stress range S_E

The factor " f " is a stress range reduction factor:

Cycles, N	Factor, f
7,000 and less	1.0
> 7,000 to 14,000	0.9
>14,000 to 22,000	0.8
> 22,000 to 45,000	0.7
> 45,000 to 100,000	0.6
> 100,000 to 200,000	0.5
> 200,000 to 700,000	0.4
> 700,000 to 2,000,000	0.3

Design of Piping – B31.3

B31.3 essentially limits the pressure design consideration to three items:

Minimum thickness for pressure

t = $\frac{P * D}{2(SE + PY)}$ or t = $\frac{P * D}{2SE}$ or t = $\frac{D}{2} * \left((1 - \sqrt{\frac{SE - P}{SE + P}} \right)$ (Lamé Equation)

The limit is based on the limit stress being less than the basic allowable stress at temperature. This limit is based on the static yield strength of the material.

Maximum longitudinal stress due to sustained loadings (S_L)

$S_L \leq S_h$; stress due to sustained loadings shall be less than the basic allowable stress at temperature. Sustained loadings are those due to pressure, self weight of contents & piping and other sustained loadings particular to the situation. The limit is based on the static yield strength of the material.

The computed displacement stress range S_E

$S_E \leq S_A = f \bullet (1.25\ S_c + 0.25\ S_h)$. S_E stresses arise from the constraint of the thermal strain displacements associated with the expansion of pipe due to temperature. The limit is based on fatigue considerations.

Where the sum of the longitudinal stresses is less than S_h, the difference may be used as an additional thermal expansion allowance. This is known as the “liberal” application of the stress criteria.

Design of Piping – B31.4

B31.4 essentially limits the pressure design consideration to three items:

Minimum thickness for pressure

$$t = \frac{Pi * D}{2S}$$

The limit is based on the limit stress being less than the basic allowable stress at temperature. This limit is based on the static yield strength of the material.

$S = 0.72 * E * SMYS$,

where SMYS is the specified minimum yield strength of the material

Maximum longitudinal stress due to sustained loadings (S_L)

$S_L \leq 0.75 \bullet S_A$

where $S_A = 0.72 * SMYS$

S_L, the stress due to sustained loadings shall be less than 0.75 x the allowable stress range, S_A at temperature. Sustained loadings are those due to pressure, self weight of contents & piping and other sustained loadings particular to the situation.

The computed displacement stress range S_E

For restrained lines:

$S_L = E * a * \Delta T - v \cdot * S_h \leq 0.9 SMYS$

For unrestrained lines:

$S_E \leq S_A$

Design of Piping – B31.8

B31.8 (1975) essentially limits the pressure design consideration to three items:

Design pressure

$$P = \frac{2 * S * t}{D} \; F \bullet E \bullet T$$

F = design factor for construction type (includes a location factor)
E = longitudinal joint factor
T = temperature derating factor

$S = SMYS$,

where SMYS is the specified minimum yield strength of the material

Total combined stress

The total of the following shall not exceed S:

a) Combined stress due to expansion
b) Longitudinal pressure stress
c) Longitudinal bending stress due to internal + external loads

Further,

The sum of (b) + (c) $\leq 0.75 \bullet S \bullet F \bullet T$

The computed displacement stress range S_E

B31.8 applies itself to the above ground piping in discussing expansion and flexibility to a temperature of 450 °F.

For these "unrestrained" lines:

$S_E \leq 0.72 \bullet S$

Design of Piping – CSA Z662

Z662 essentially limits the pressure design consideration to three items:

Pressure Design

P = $\frac{2S * t \times 10^{3} \times F \times L \times J \times T}{D}$; units are metric

F = design factor = 0.8
L = location factor per Table 4.1 (appear to be safety factors)
J = longitudinal joint factor
T = temperature derating factor
S = Specified Minimum Yield Strength (SMYS)

Maximum longitudinal stress due to sustained loadings (S_L)
For restrained lines (below ground):

$S_h - S_L + S_B \leq 0.90 \bullet S \bullet T$; where, $S_L = v \cdot * S_h - E * a * \Delta T$ (below ground)

* note conservatism with respect to definition of ΔT, Code requires use of temperature at time of restraint

$S_h - S_L + S_B \leq S \bullet T$; (above ground, freely spanning segments)

The computed displacement stress range S_E

For unrestrained lines (above ground):

$S_E \leq 0.72 \bullet S \bullet T$

The Design Effort Continuum

Code **Code +**

Calculation Method

Simple ↔ Complex

Answer Quality

Conservative ↔ Accurate

Effort

Least ↔ Most

Design Loads

The Codes prescribe minimum rules for stress conditions and alert the designer explicitly to some of the loadings likely to act on a system. In addition to the previous listing, most of the Codes specify design rules for:

- Occasional loads such as wind & earthquake
- External pressure

The Codes caution the designer to consider the effect of other loadings and their impact on the stress state of the system:

- impact events (hydraulic shock, liquid & solid slugging, flashing, transients)
- auto- refrigeration, seasonal temperature variations
- vibration
- discharge reactions
- temperature gradients
- bi-metallic connections

- effects of support & restraint movements
- cyclic effects

The Codes do not explicitly alert the designer to other loadings which may cause failure in the piping system, including:

- buckling (shell & column)
- nozzle loadings on attached equipment, such as
  - pumps, compressors, engines
  - pressure vessels
  - steam generating equipment
  - fired heaters
  - heat exchangers
  - loadings on in-line equipment such as flanges, valves, filters, strainers

4.3 Material Selection

Key Considerations

- Material specification
- Chemical Composition
- Mechanical Properties
    - Brittle fracture toughness
    - Carbon equivalent
- Inspection
- Repair Welding Procedure

Brittle Fracture

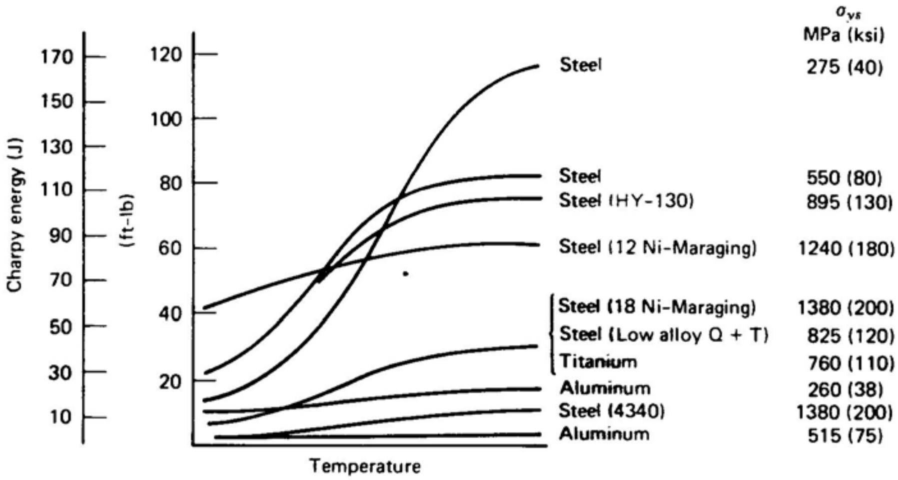


FIGURE 9.4 Charpy impact energy versus temperature behavior for several engineering alloys.[3] (Reprinted by permission of the American Society for Testing and Materials from copyright material.)

Brittle fracture refers to the often catastrophic failure of materials when subjected to stresses at a lower temperature which the materially would normally be able to withstand at higher temperatures.

A “transition temperature” can be defined at the 13.5, 20, 27 J (10, 15, 20 ft-lb) energy level.

Charpy test resutls for steel plate obtained from failures of Liberty ships revealed that plate failure never occurred at temperatures greater than the 20-J (15 ft-lb) transition temperatue.

This transition temperature varies with the material and is not used as a criterion.

Transition Temperatures

TABLE 9.1a Transition Temperature Data for Selected Steels[6]

Material	σ_{ys} MPa / σ_{ts}, MPa	Transition Temperature, °C		
		20 J	0.38 mm	50% fibrous
Hot-rolled C–Mn steel	210 / 442	27	17	46
Hot-rolled, low-alloy steel	385 / 570	−24	−22	12
Quenched and tempered steel	618 / 688	−71	−67	−54

TABLE 9.1b Transition Temperature Data for Selected Steels[6]

Material	σ_{ys}, ksi / σ_{ts}, ksi	Transition Temperature, °F		
		15 ft-lb	15 mil	50% fibrous
Hot-rolled C–Mn steel	30.5 / 64.1	80	62	115
Hot-rolled, low-alloy steel	55.9 / 82.6	−12	−7	53
Quenched and tempered steel	89.7 / 99.8	−95	−88	−66

Charpy Testing

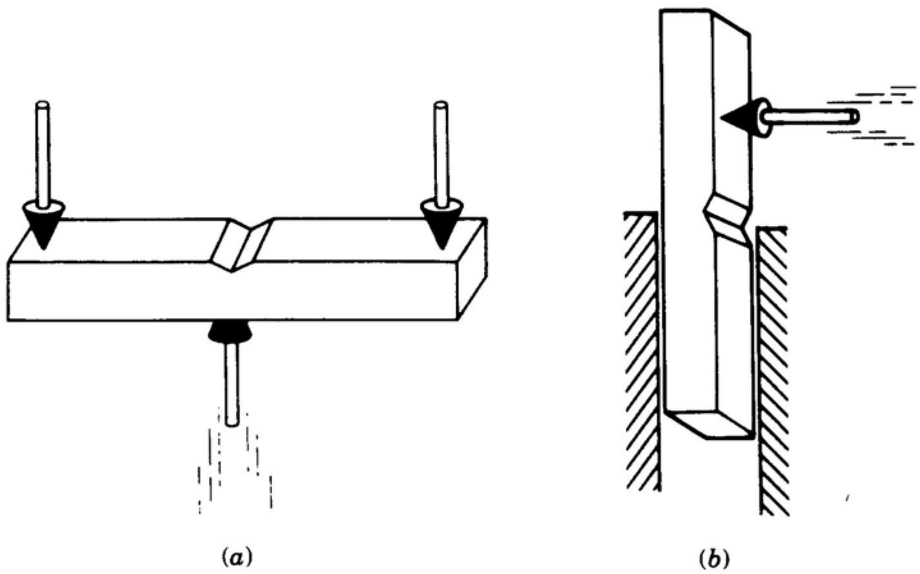


FIGURE 9.2 Flexed-beam impact samples. (*a*) Charpy type[1] (three-point loaded) used extensively with metal alloys. (*b*) Izod type[2] (cantilever-beam loaded) used extensively with polymers. Both samples contain 0.25-mm notch radius.

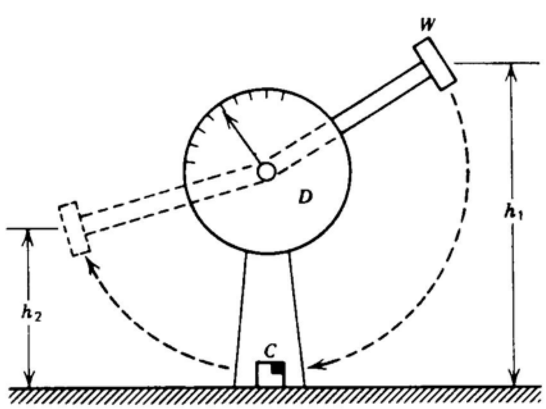


FIGURE 9.3 Diagram showing impact hammer *W* dropping from height h_1, impacting sample at *C* and rising to maximum final height h_2. Energy absorbed by sample, related to height differential $h_2 - h_1$, is recorded on dial *D*.

Charpy Testing (cont'd)

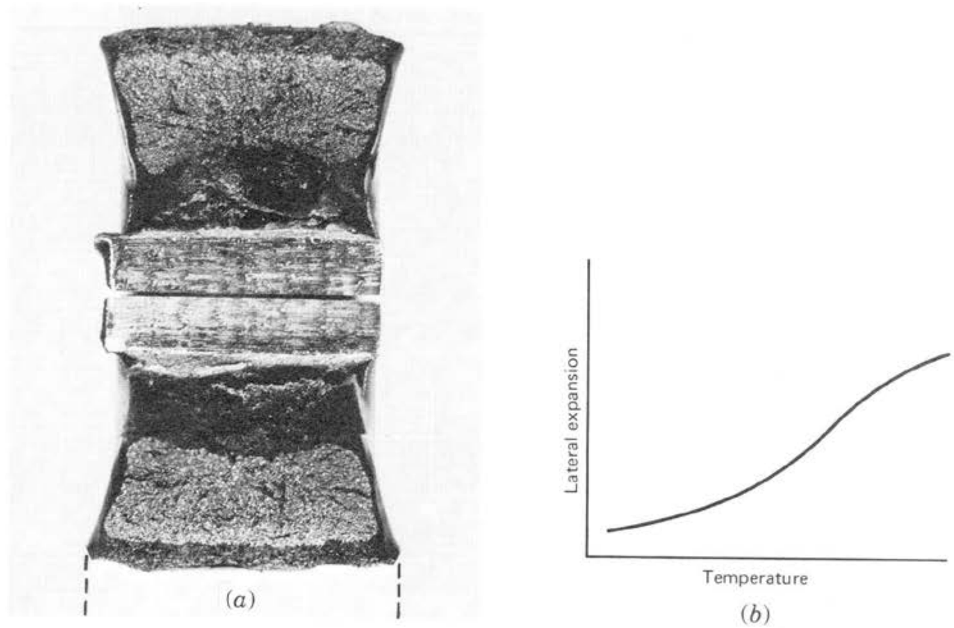


FIGURE 9.5 (*a*) Measurement of lateral expansion at compression side of Charpy bar; (*b*) schema of temperature dependence of lateral expansion revealing transition behavior.

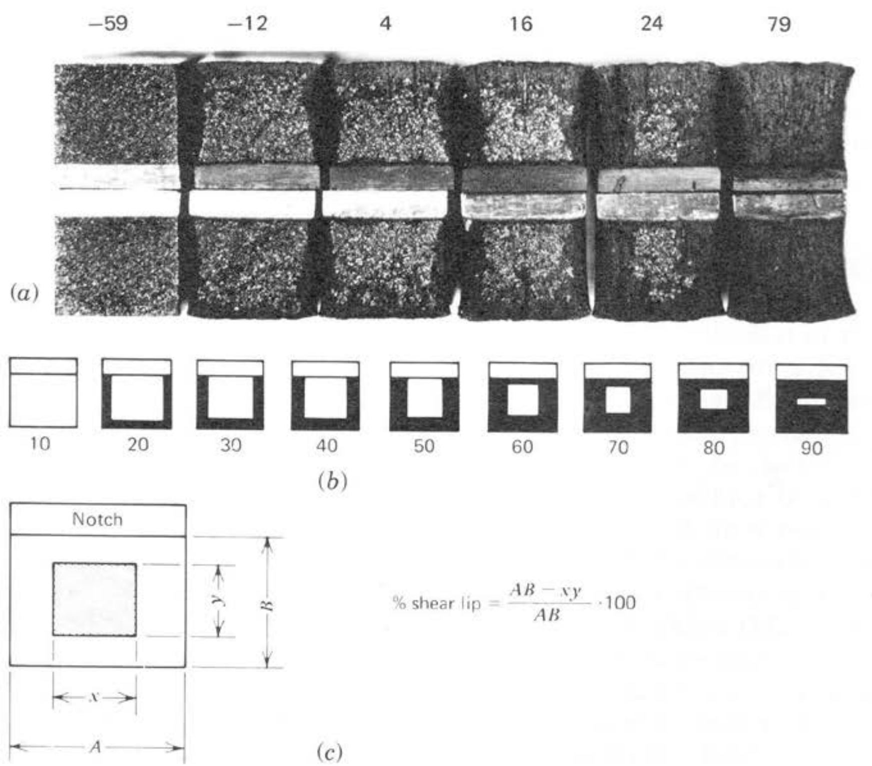


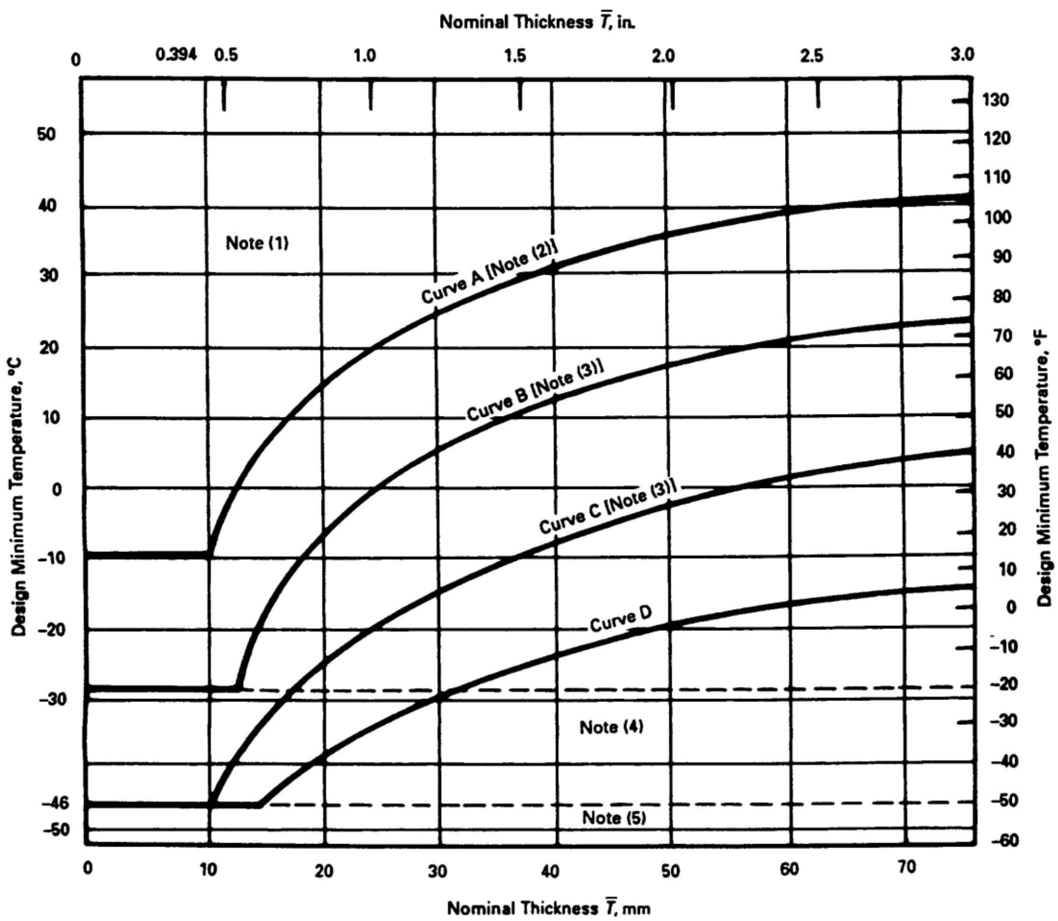
FIGURE 9.6 Transition in fracture surface appearance as function of test temperature. (*a*) Actual fracture series for A36 steel tested in the transverse direction; (*b*) standard comparison chart showing percentage shear lip; (*c*) computation for percentage shear lip.

Minimum Required Charpy V Notch Impact Values (B31.3-1999)

Specified Minimum Tensile Strength	Number of Specimens	Energy			
		Fully Deoxidized Steels		Other than Fully Deoxidized Steels	
		Joules	Ft-lbf	Joules	Ft-lbf
(a) Carbon & Low Alloy Steels					
SMTS ≤ 65 ksi	Average for 3 specimens Minimum for 1 specimen	18 16	13 10	14 10	10 7
65 ksi < SMTS ≤ 75 ksi		20 16	15 12	18 14	13 10
75 ksi > SMTS < 95 ksi		27 20	20 15	… …	… …
		Lateral Expansion			
96 ksi < SMTS	Minimum for 3 specimen	0.015 in			
(b) Steels in P-Nos. 6, 7, 8	Minimum for 3 specimen	0.015 in			

Impact Testing Exemption Temperatures – B31.3

Fig. 323.2.2 ASME B31.3-1999 Edition



NOTES:
(1) Any carbon steel material may be used to a minimum temperature of –29°C (–20°F) for Category D Fluid Service.
(2) X Grades of API 5L, and ASTM A 381 materials, may be used in accordance with Curve B if normalized or quenched and tempered.
(3) The following materials may be used in accordance with Curve D if normalized:
(a) ASTM A 516 Plate, all grades;
(b) ASTM A 671 Pipe, Grades CE55, CE60, and all grades made with A 516 plate;
(c) ASTM A 672 Pipe, Grades E55, E60, and all grades made with A 516 plate.
(4) A welding procedure for the manufacture of pipe or components shall include impact testing of welds and HAZ for any design minimum temperature below –29°C (–20°F), except as provided in Table 323.2.2, A-3(b).
(5) Impact testing in accordance with para. 323.3 is required for any design minimum temperature below –46°C (–50°F).

FIG. 323.2.2 MINIMUM TEMPERATURES WITHOUT IMPACT TESTING FOR CARBON STEEL MATERIALS
(See Table A-1 for Designated Curve for a Listed Material)

Minimum Required Charpy V Notch Impact Values (CSA Z 662-1999)

Δ

Table 5.1
Pipe Body Notch Toughness for Steel Pipe
(See Clause 5.2.2.2.)

Service fluid category	Design operating stress, MPa	Minimum design temperature, °C	Pressure test medium	CSA Z245 notch toughness category
LVP	50 or greater	All	Liquid	I
HVP	50 to 225 incl.	All	Liquid	I
HVP	> 225	All	Liquid	III
LVP or HVP	50 to $PTSV_1$ incl.	–30 or higher	Gas	I
LVP or HVP	50 to $PTSV_1$ incl.	Lower than –30	Gas	II*
LVP or HVP	> $PTSV_1$	All	Gas	II
CO_2	50 or greater	All	All	II
Gas	50 to $PTSV_1$ incl.	–30 or higher	All	I
Gas	50 to $PTSV_1$ incl.	Lower than –30	All	II*
Gas	> $PTSV_1$	All	All	II

**It shall be permissible to substitute Category I pipe in pipe runs shorter than 50 m.*

Notes:

(1) *The applicable value for $PTSV_1$ (the pipe threshold stress value for Category I pipe) shall be as given in Table 5.2.*

(2) *The absorbed energy and fracture appearance notch toughness, by category, shall be as specified in CSA Standard Z245.1.*

(3) *CSA Standard Z245.1 requires that the pipe body of Category II and III pipe exhibit a minimum absorbed energy (based on full-size Charpy V-notch impact test specimens) of 27 J for pipe smaller than 457 mm OD, and 40 J for pipe 457 mm or larger.*

(4) *It shall be permissible to substitute pipe with proven notch toughness properties for Category I pipe.*

(5) *For other than carbon dioxide pipelines, it shall be permissible to substitute Category III pipe for Category II pipe in pipe runs shorter than 100 m.*

(6) *A pipe run is a continuous portion of the pipeline system in which there are no components and all of the pipe (with or without attachments) has the same nominal wall thickness and is in the same minimum design temperature range (either –30°C or over, or under –30°C).*

(7) *For minimum design temperatures lower than –5°C, see Clause 5.2.2.5 for weld metal notch toughness requirements.*

Minimum Required Charpy V Notch Impact Values (CSA Z 662-1999) (cont'd)

Table 5.2
Pipe Threshold Stress Values
(See Table 5.1 and Clause 5.2.2.3.)

Pipe OD, mm	$PTSV_1$	Pipe threshold stress value, MPa — Pipe with proven pipe body notch toughness properties — Minimum absorbed energy of 27 J	Minimum absorbed energy of 40 J
114.3–141.2	300	365	
141.3–168.2	280	340	
168.3–219.0	265	320	
219.1–273.0	240	295	
273.1–323.8	225	275	
323.9–355.5	210	260	
355.6–406.3	205	250	
406.4–456	195	240	
457–507	190		300
508–558	180		290
559–609	175		280
610–659	170		275
660–710	165		265
711–761	165		260
762–812	160		255
813–863	155		250
864–913	155		245
914–964	150		240
965–1015	145		235
1016–1066	145		230
1067–1167	140		225
1168–1218	140		220
1219–1320	135		215
1321–1371	135		210
1372–1421	130		210
1422–1523	130		205
1524–1574	130		200
1575–1675	125		200
1676–1726	125		195
1727–1777	120		195
1778–1980	120		190
1981–2031	120		185
2032	115		185

Notes:

(1) *$PTSV_1$ is the pipe threshold stress value for Category I pipe.*

(2) *CSA Standard Z245.1 requires that the pipe body of Category II and III pipe exhibit a minimum absorbed energy (based on full-size Charpy V-notch impact test specimens) of 27 J for pipe smaller than 457 mm OD, and 40 J for pipe 457 mm or larger.*

(3) *For pipe that is required to exhibit a value of minimum absorbed energy for the pipe body different from that given in Note 2, the applicable pipe threshold stress value shall be as derived using the formula given in the note to Clause 5.2.2.3, with "S" being the pipe threshold stress value rather than the design operating stress or the maximum expected hoop stress during pressure testing with a gaseous medium.*

Material Selection – Common Specifications for Carbon Steel Systems

Commodity	B31.1	B31.3	B31.4	B31.8	CSA Z662
Pipe	ASTM A 106	ASTM A 53 API 5L	ASTM A 53 API 5L API 5LU	ASTM A 53 API 5L	CSA Z 245.1
Pipe – Low Temp	ASTM A 333 Gr.6	ASTM A 333 Gr.6	ASTM A 333 Gr.6	ASTM A 333 Gr.6	CSA Z 245.1
Pipe – High Temp	ASTM A 106	ASTM A 106	ASTM A 106	ASTM A 106	
Bolting	ASTM A 193 B7	ASTM A 193 B7 ASTM A 320	ASTM A 193 B7 ASTM A 320	ASTM A 193 B7 ASTM A 354 ASTM A 449	CSA Z 245.
Nut	ASTM A 194 2H	ASTM A 194 2H	ASTM A 194 2H	ASTM A 194 2H	
Fittings	ASTM A 234 WPB	ASTM A 234 WPB		MSS SP-75	CSA Z 245.11
Fittings – Low Temp	ASTM A 420 WPL6	ASTM A 420 WPL6	ASTM A 420 WPL6		CSA Z 245.11
Fittings – High Temp	ASTM A 234 WPB ASTM A 216 WCB	ASTM A 234 WPB ASTM A 216 WCB	ASTM A 234 WPB		
Flanges	ASTM A 105 ASTM A 181 ASME B16.5	ASTM A 105 ASTM A 181 ASME B16.5	ASTM A 105 ASTM A 181 ASME B16.5	ASTM A 105 ASTM A 372 MSS SP-44	CSA Z 245.12
Flanges – Low Temp	ASTM A 350 LF2 ASTM A 352 LCB	ASTM A 350 LF2 ASTM A 352 LCB	ASTM A 350 LF2		CSA Z 245.12
Flanges – High Temp	ASTM A 105 ASTM A 181 ASTM A 216 WCB	ASTM A 105 ASTM A 181 ASTM A 216 WCB	ASTM A 105 ASTM A 216 WCB		
Valves	ASTM A 105 ASME B16.34	ASTM A 105 API 600	API 6D API 600	ASTM A 105 API 6D ASME B16.34 ASME B16.38	CSA Z 245.15
Valves – Low Temp	ASTM A 350 LF2 ASTM A 352 LCB	ASTM A 350 LF2 ASTM A 352 LCB			CSA Z 245.15
Valves – High Temp	ASTM A 216 WCB	ASTM A 216 WCB			

4.4 Fabricated Tees & Area Reinforcement

See Codes for details.

The concept of area reinforcement is straightforward; when material in the header run is removed, it must be replaced adjacent the opening / branch run. The difficulty is in the tediousness of the calculations for determination of the replacement areas.

The Codes are very clear in describing these areas and spreadsheet type software tools conveniently address the arithmetic calculations.

4.5 Flexibility Analysis

Typical Stress Analysis Criteria

This stress analysis criteria establishes the procedure, lists critical lines and piping stress/design liaison flow sheet to be followed.

Lines to be analyzed:

- all lines attached to pumps, compressors, turbines and other rotating equipment
- all lines attached to reciprocating compressors
- all relief piping
- all lines 3” and over attached to non rotating equipment
- all category M piping
- all lines on racks
- all lines which the piping designer is uncomfortable with
- all vacuum lines
- all jacketed piping
- all tie-ins to existing piping
- all non metallic piping
- all steam out, decoking and regeneration lines
- all lines 16” and larger
- all lines 6” and larger over 250°C
- all lines over 400°C
- all lines specifically requested by the stress department.
- all lines specifically requested by the Client.

ASME B31.3 discusses the need and execution of flexibility analysis. Paragraph 319.4.1 lists the conditions under which flexibility analysis may be waived. If formal analysis is deemed necessary, follow the requirements of paragraph 319.4.2. The other Codes will have similar provisions.

5. References

[1] ASME B31 Piping Codes

[2] Hertzberg, "Deformation & Fracture Mechanics of Engineering Materials" 3rd Ed Wiley

[3] CSA Z 662 Oil & Gas Pipelines