Society of Piping Engineers and Designers
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PIPING STRESS ANALYSIS 101

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What is Piping Stress Analysis?

Piping Stress Analysis is the calculation & evaluation of a piping system's:

1. deflections,
2. rotations,
3. forces,
4. moments &
5. stresses

Why would one want to perform Piping Stress Analysis?

To calculate deflections, rotations, forces, moments and stresses, right?

Okay, but why calculate them at all and what are you going to do with them once you have them calculated?

Why would one want to perform Piping Stress Analysis? (cont'd)

The answer to this question is not simple and straight forward.

Why would one want to perform Piping Stress Analysis? (cont'd)

1. What do you wish to achieve?

   a) Calculate stresses in a piping system and compare them with piping code allowables.

   b) Evaluate the loads on rotating equipment nozzles and casing.

Why would one want to perform Piping Stress Analysis? (cont'd)

What do you wish to achieve? (cont'd)

c) Evaluate the loads on nozzles on heat exchangers, pressure vessels or tanks.

d) Evaluate the loads on structural anchors and foundations.

Why would one want to perform Piping Stress Analysis? (cont'd)

What do you wish to achieve? (cont'd)

e) Evaluate the loads on pipe supports from thermal expansion or contraction as well as from system weight.

f) Evaluate piping system movements from thermal expansion or contraction as well as from system weight & pressure.

Why would one want to perform Piping Stress Analysis? (cont'd)

What do you wish to achieve? (cont'd)

g) Evaluate the effects of occasional loads on the piping system, pipe supports, anchors & attached equipment including:

- Wind
- Earthquake

Why would one want to perform Piping Stress Analysis? (cont'd)

What do you wish to achieve? (cont'd)

- Snow
- Ice
- Wave Loading
- Transient Loads

Why would one want to perform Piping Stress Analysis? (cont'd)

What do you wish to achieve? (cont'd)

h) Evaluate the effects of support friction on piping system movements and stresses.

i) Evaluate the effects of expansion joints on piping system movements and stresses.

Why would one want to perform Piping Stress Analysis? (cont'd)

What do you wish to achieve? (cont'd)

j) Evaluate the effects of soil resistance on piping system movements and stresses.

k) Evaluate the effects of changes in temperature, pressure and weight on flanged connections to identify possible locations where leakage may occur.

Why would one want to perform Piping Stress Analysis? (cont'd)

2. Which Piping Code will govern the design of the piping system?
   a) B31.1 Power Piping
   b) B31.2 Fuel Gas Piping (withdrawn in 1988)
   c) B31.3 Process Piping

Why would one want to perform Piping Stress Analysis? (cont'd)

d) B31.4 Liquid Transportation Systems for Hydrocarbons, Liquid Petroleum Gas, Anhydrous Ammonia & Alcohols

e) B31.5 Refrigeration Piping

f) B31.6 Chemical Plant Piping
(withdrawn before publication – mid 70's)

Why would one want to perform Piping Stress Analysis? (cont'd)

g) B31.7 Nuclear Power Piping (last published as B31.7 in 1969) – later withdrawn & superseded by ASME Code, Section III

h) B31.8 Gas Transmission and Distribution Piping Systems

i) B31.9 Building Services Piping

Why would one want to perform Piping Stress Analysis? (cont'd)

j) B31.10 Cryogenic Piping (never issued as a separate document, made a part of the B31.3 Process Piping Code)

k) B31.11 – Slurry Transportation Piping

l) B31.12 – Hydrogen Piping (project was initiated in 2004 & published in 2008)

Why would one want to perform Piping Stress Analysis? (cont'd)

3. Collect all plan and elevation drawings.
4. Obtain or construct an isometric drawing – align North arrows.

Why would one want to perform Piping Stress Analysis? (cont'd)

5. Collect the necessary physical properties as follows:

   a) Nominal Pipe Diameter

   b) Pipe Schedule / Wall Thickness

   c) Corrosion Allowance

   d) Specific Gravity of contents

Why would one want to perform Piping Stress Analysis? (cont'd)

e) Insulation Material or Density & Thickness

f) Piping Material or density, modulus of elasticity & coefficient of expansion

g) Operating Temp, Design Temp, Upset Condition Temp & Base or Ambient Temp

Why would one want to perform Piping Stress Analysis? (cont'd)

h) Operating Pressure, Design Pressure & Upset Condition Pressure

i) Flange Rating & Type

j) Valve Rating & Type

k) Elbow and/or Bend Radius or Bend Radius Ratio and Fitting Thickness

Why would one want to perform Piping Stress Analysis? (cont'd)

l) Reducer Length, Inlet & Outlet Diameters, Schedule or Wall Thick, Concentric or Eccentric (flat side orientation)

m) Branch Connection Type and reinforcement

Why would one want to perform Piping Stress Analysis? (cont'd)

n) Expansion Joint Properties – Translational & Rotational Spring Constants, Length of Bellows, Length of Tie Rods, Center of Bellow to Center of Bellows for Tandem Expansion Joints & Pressure Thrust Area

o) Structural Member Specifications – AISC designation for standard shapes & dimensional info for non-standard shapes

Why would one want to perform Piping Stress Analysis? (cont'd)

6. For all Anchors, collect the following data:
   a) Location
   b) Stiffness or Flexibility
   c) Movements - thermal growth & settlement
   d) Origin of thermal growth in Anchored Equipment

Why would one want to perform Piping Stress Analysis? (cont'd)

7. For all Restraints, collect the following data:
   a) Location of each restraint.
   b) Translational Restraints - the axis of action & 1 directional or double acting.
   c) Limit Stops – the axis of action, the plus & minus gaps & stiffness when limit is encountered.

Why would one want to perform Piping Stress Analysis? (cont'd)

d) Imposed Movements - the axis of action & the amount of the movement (+/-).

e) Imposed Forces - the axis of action, the amount of the force (+/-) & spring constant, if applicable.

f) Dampers (Snubbers) – the axis of action.

g) Sway Braces – preset load, spring rate & axis of action.

Why would one want to perform Piping Stress Analysis? (cont'd)

h) Frictional Resistance to Movement - the plane on which the friction occurs, the static and dynamic coefficient of friction.

i) Existing Spring Hangers - the location, the installed load, the operating load, the spring constant & the minimum and maximum load and travel from the installed position.

Why would one want to perform Piping Stress Analysis? (cont'd)

i) Existing Spring Hangers – (cont'd) It is also helpful to know if the spring hanger supports from above or below the pipe.

j) New Spring Hangers - the location, the number of spring hangers in that location, the percentage load variation allowed and whether a hanger or support is desired.

Why would one want to perform Piping Stress Analysis? (cont'd)

k) Sway Struts – axis of action and location of pinned points.

l) Rotational Restraints – the location & the axis about which rotation is to be resisted.

m) Imposed Rotations - the location, the number of degrees of rotation & the direction of rotation.

Why would one want to perform Piping Stress Analysis? (cont'd)

n) Imposed Moments – the location, the amount of moment & the direction of action.

8. Special Effects such as Cold Spring:

a) Cut Short - the location, the axes of application, the amount of cold spring & whether Cut Short or Cut Long.

Why would one want to perform Piping Stress Analysis? (cont'd)

9. Special Loading Conditions

   a) Wind Loading – the piping segments where wind is to be applied, the orientation of the wind vector, wind speed or pressure per unit length and shape factor.

Why would one want to perform Piping Stress Analysis? (cont'd)

b) Wave Loading – the piping segments where wave loading is to be applied, the orientation of the loading vector, the wave loading pressure per unit length and shape factor.

Why would one want to perform Piping Stress Analysis? (cont'd)

c) Uniform Loads such as Snow and Ice – the piping segments on which the loads are to be applied, the amount of the loading per unit length and the load orientation with regards to X, Y & Z.

Why would one want to perform Piping Stress Analysis? (cont'd)

d) Seismic Loads – the method to be used to simulate the seismic event (RSA or percentage of gravity) and the magnitude of the seismic event.

e) Soil Interaction – the piping segments on which soil restraints are to be applied, the soil spring constants or the soil properties.

Why would one want to perform Piping Stress Analysis? (cont'd)

10. Orient the Global (X, Y & Z) Axis System on the Isometric Drawing – Y is always Up.
11. Now, assign Node Numbers to the piping isometric drawing in accordance with the guidelines set forth for the software you are using.

ASME®

- ASME - THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
- ASME is the registered trademark of The American Society of Mechanical Engineers Responding to evident need & at the request of The American Society of Mechanical Engineers, the American Standards Association initiated Project B31 in March 1926, with ASME as sole administrative sponsor.

ASME®

- Initial publication in 1935 was as the American Tentative Standard Code for Pressure Piping.
- Revisions from 1942 through 1955 were published as American Standard Code for Pressure Piping, ASA B31.1.

ASME®

- The Standards Committee was reorganized in 1978 as a Committee operating under ASME procedures with ANSI (American National Standards Institute) accreditation. It is now the ASME Code for Pressure Piping, B31 Committee.
- The Section Committee structure remains essentially unchanged.

ASME®

- ASME accepts responsibility for only those interpretations of the CODES issued in accordance with the established ASME procedures and policies, which precludes the issuance of interpretations by individuals.

ASME® PIPING CODES

- 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 & cooling plants.

ASME® PIPING CODES

- B31.3 - Process Piping

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

ASME® PIPING CODES

- B31.4 - Pipeline Transportation Systems for Liquid Hydrocarbons & Other Liquids – Piping systems transporting products which are predominately liquid between plants and terminals and within terminals, pumping, regulating and metering stations.

ASME® PIPING CODES

- B31.5 - Refrigeration Piping
  - Piping for refrigerants and secondary coolants.

ASME® PIPING CODES

- B31.8 - Gas Transmission and Distribution Piping –

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

ASME® PIPING CODES

- B31.9 - Building Services Piping

  Piping typically found in industrial, institutional, commercial and public buildings and in multi-unit residences which do not require the range of sizes, pressures and temperatures covered in B31.1

ASME® PIPING CODES

- B31.11 - Slurry Transportation Piping Systems - Piping transporting aqueous slurries between plants and terminals within terminals, pumping and regulating stations.

ASME® PIPING CODES

- B31.12 Hydrogen Piping and Pipelines - Applies to design, construction, operation, and maintenance requirements for piping, pipelines, and distribution systems in hydrogen service.

Supplements for ASME® B31 PIPING CODES

- B31G - Manual for Determining Remaining Strength of Corroded Pipelines
- B31E - Standard for the Seismic Design and Retrofit of Above-Ground Piping Systems
- B31J - Standard Test Method for Determining Stress Intensification Factors (i- Factors) for Metallic Piping Components

Supplements for ASME® B31 PIPING CODES

- B31Q - Pipeline Personnel Qualification
- B31T - Standard Toughness Requirements for Piping

B31.3 - Process Piping

- The Process Piping Code is a Section of the American Society of Mechanical Engineers Code for Pressure Piping, ASME B31. It is an American National Standard. Each section is published as a separate document for convenience of Code users.

B31.3 - Process Piping

- The Code includes the following:
  - a) *references to acceptable material specifications and component standards, including dimensional requirements as well as pressure – temperature ratings*
  - b) *requirements for design of components and assemblies, including pipe supports*
  - c) *requirements and data for evaluation and limitation of stresses, reactions and movements associated with pressure, temperature changes and other forces*

B31.3 - Process Piping

d) *guidance and limitations on the selection and application of materials, components and joining methods*

e) *requirements for the fabrication, assembly and erection of piping*

f) *requirements for examination, inspection and testing of piping*

B31.3 - Process Piping

- **300.1.1 Content and Coverage**

  The Code applies to piping for all fluids, including:

  (1) raw, intermediate & finished chemicals
  (2) petroleum products
  (3) gas, steam, air and water
  (4) fluidized solids
  (5) refrigerants
  (6) cryogenic fluids

B31.3 - Process Piping

- **301.2 Design Pressure**
- **301.2.1 General**

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 (minimum or maximum) expected during service, except as provided in paragraph 302.2.4.

B31.3 - Process Piping

- **301.3 Design Temperature**

  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 paragraph 301.2.

  (To satisfy the requirements of paragraph 301.2, different components in the same piping system may have different design temperatures.)

B31.3 - Process Piping

- **301.3 Design Temperature (cont'd)**

  In establishing design temperatures, consider at least the fluid temperatures, ambient temperatures, solar radiation, heating or cooling medium temperatures, and the applicable provisions of paragraphs 301.3.2, 301.3.3, and 301.3.4.

  - *For un-insulated, safe assumption – fluid temp.*
  - *For insulated lines - design temp is fluid temp.*
  - *For internally insulated lines - heat transfer calcs.*

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- **302 DESIGN CRITERIA**

  302.1 General

  Paragraph 302 states that pressure–temperature ratings, stress criteria, design allowances and minimum design values together with permissible variations of these factors are to be applied for the design of piping.

B31.3 - Process Piping

- **302.2.1 Listed Components Having Established Ratings**

  Except as limited elsewhere in the Code, pressure–temperature ratings contained in standards for piping components listed in Table 326.1 are acceptable for design pressures and temperatures in accordance with the Code.

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- **302.3 Allowable Stresses and Other Stress Limits**

302.3.1 General. The allowable stresses defined in paragraphs 302.3.1(a), (b), and (c) shall be used in design calculations unless modified by other provisions of the Code.

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- **302.3 Allowable Stresses and Other Stress Limits (cont'd)**

  302.3.5 Limits of Calculated Stresses Due to Sustained Loads & Displacement Strains

  a) *Internal Pressure Stresses.*

  Stresses due to internal pressure shall be considered safe when the wall thickness of the piping component, including any reinforcement, meets the requirements of paragraph 304 of the Code – "Pressure Design of Components".

B31.3 - Process Piping

- **302.3 Allowable Stresses and Other Stress Limits (cont'd)**

  302.3.5 Limits of Calculated Stresses Due to Sustained Loads & Displacement Strains

  b) *External Pressure Stresses.*

  Stresses due to external pressure shall be considered safe when the wall thickness of the piping component, including any stiffening, meets the requirements of paragraph 304 of the Code – "Pressure Design of Components".

B31.3 - Process Piping

- **302.3 Allowable Stresses & Other Stress Limits (cont'd)**

302.3.5 Limits of Calculated Stresses Due to Sustained Loads & Displacement Strains

c) Longitudinal Stresses, SL.

The sum of the longitudinal stresses due to sustained loads, SL, such as pressure and weight in any component in a piping system, shall not exceed *Sh*, *where Sh is taken* from Table A-1 at the metal temperature of the operating condition being considered.

B31.3 - Process Piping

- **302.3 Allowable Stresses & Other Stress Limits (cont'd)**

302.3.5 Limits of Calculated Stresses Due to Sustained Loads & Displacement Strains

d) Allowable Displacement Stress Range, SA.

The computed displacement stress range, SE, in a piping system (see paragraph 319.4.4) shall not exceed the allowable displacement stress range, SA (see paragraphs 319.2.3 and 319.3.4), calculated by applying equation (1a) as shown on the next 2 slides:

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- **319.2.3 Displacement Stress Range**

  a) **Displacement stresses are permitted to attain sufficient magnitude to cause localized yielding**
     i. **Growth and strain**
     ii. **Reversal & redistribution (self-springing)**

  b) **Calculation of stress range for systems that operate in the creep range – same for all systems**

  c) **Average Axial Stresses – Normally not considered. When high axial loads are imposed or in buried pipelines, axial stresses must be considered**

B31.3 - Process Piping

$$S_A = f\left(1.25S_c + 0.25S_h\right) \qquad (1a)$$

When *Sh is greater than SL, the difference between* them may be added to the term $0.25S_h$ *in equation (1a).* In that case, the allowable stress range is calculated by applying equation (1b):

$$S_A = f\left[1.25(S_c + S_h) - S_L\right] \qquad (1b)$$

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Stress Range Reduction Factor – f

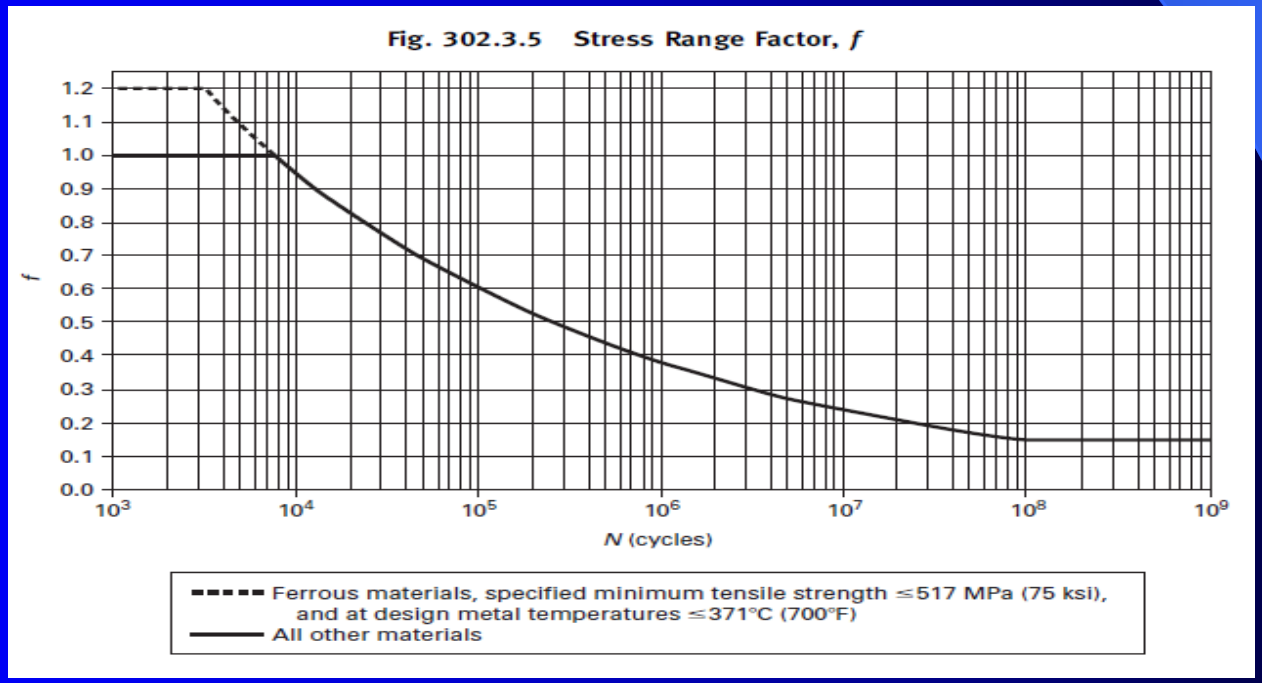
Full Temperature Cycles	f
7000	1.0
7,001 - 14,000	0.9
14,001 - 22,000	0.8
22,001 - 45,000	0.7
45,001 - 100,000	0.6
>100,000	0.5

B31.3 - Process Piping

For equations (1a) and (1b):

f = stress range factor, calculate by equation (1c).

In equations (1a) and (1b), Sc and Sh shall be limited to a maximum of 20,000 psi (138 MPa) when using a value of f > 1.0.



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- N = equivalent number of full displacement cycles during the expected service life of the piping system
- S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
- S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

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- When the computed stress range varies, whether from thermal expansion or other conditions, *SE is defined as* the greatest computed displacement stress range. The value of N in such cases can be calculated by equation (1d):

$$N = N_E + \sum(r_i^5 N_i) \text{ for } i = 1, 2, \ldots, n \qquad (1d)$$

where

N_E = number of cycles of maximum computed displacement stress range, S_E

N_i = number of cycles associated with displacement stress range, S_i

$r_i = S_i/S_E$

S_i = any computed displacement stress range smaller than S_E

B31.3 - Process Piping

- **302.3.6 Limits of Calculated Stresses Due to Occasional Loads**

  a) *Operation.* The sum of the longitudinal stresses, SL, due to sustained loads, such as pressure and weight, and of the stresses produced by occasional loads, such as wind or earthquake, may be as much as 1.33 times the basic allowable stress given in Appendix A.

  Wind and earthquake forces need not be considered as acting concurrently.

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- **304 PRESSURE DESIGN OF COMPONENTS**

  304.1 Straight Pipe

  304.1.1 General

  a) *(a)* The required thickness of straight sections of pipe shall be determined in accordance with equation (2):

$$t_m = t + c \qquad (2)$$

The minimum thickness, *T,* for the pipe selected, considering manufacturer's minus tolerance, shall be not less than tm.

B31.3 - Process Piping

- **304.1.2 Straight Pipe Under Internal Pressure**

  a) For t < D/6, the internal pressure design thickness for straight pipe shall be not less than that calculated in accordance with either equations (3a) or (3b):

$$t = \frac{PD}{2(SEW + PY)} \qquad (3a)$$

$$t = \frac{P(d + 2c)}{2[SEW - P(1 - Y)]} \qquad (3b)$$

c = sum of the mechanical allowances ; E = quality factor
D = outside diameter of the pipe ; P= internal design gage pressure
d = inside diameter of the pipe ; Y = 0.4 – coefficient from Table 304.1.1

B31.3 - Process Piping

- **319 PIPING FLEXIBILITY**

  319.1 Requirements

  319.1.1 Basic Requirements.

  Piping systems shall have sufficient flexibility to prevent thermal expansion or contraction or movements of piping supports and terminals from causing:

  a) failure of piping or supports from overstress or fatigue

  b) leakage at joints

  c) detrimental stresses or distortion in piping and valves or in connected equipment (pumps and turbines, vessels, etc.), resulting from excessive forces and moments in the piping

B31.3 - Process Piping

- **319.4 Flexibility Analysis**

  319.4.1 Formal Analysis Not Required.

  No formal analysis of adequate flexibility is required for a piping system which:

  a) duplicates, or replaces without significant change, a system operating with a successful service record

  b) can readily be judged adequate by comparison with previously analyzed systems

  c) is of uniform size, has no more than two points of fixation, no intermediate restraints, and falls within the limitations of empirical equation (16)

B31.3 - Process Piping

$$\frac{Dy}{(L-U)^2} \le K_1 \qquad (16)$$

where

D = outside diameter of pipe, mm (in.)

E_a = reference modulus of elasticity at 21°C (70°F), MPa (ksi)

K_1 = 208 000 S_A/E_a, $(\text{mm/m})^2$
= 30 S_A/E_a, $(\text{in./ft})^2$

L = developed length of piping between anchors, m (ft)

S_A = allowable displacement stress range in accordance with eq. (1a), MPa (ksi)

U = anchor distance, straight line between anchors, m (ft)

B31.3 - Process Piping

- **319.4.3 Basic Assumptions & Requirements.**

  Standard assumptions specified in paragraph 319.3 shall be followed in all cases. In calculating the flexibility of a piping system between anchor points, the system shall be treated as a whole. The significance of all parts of the line and of all restraints introduced for the purpose of reducing moments and forces on equipment or small branch lines and also the restraint introduced by support friction, shall be recognized.

B31.3 - Process Piping

- **319.3 Properties for Flexibility Analysis**

  The following paragraphs deal with properties of piping materials and their application in piping flexibility stress analysis.

- **319.3.1 Thermal Expansion Data**

  a) *Values for Stress Range.* Values of thermal displacements to be used in determining total displacement strains for computing the stress range shall be determined from Appendix C as the algebraic difference between the value at maximum metal temperature and that at the minimum metal temperature for the thermal cycle under analysis.

B31.3 - Process Piping

a) *Values for Reactions.* Values of thermal displacements to be used in determining total displacement strains for computation of reactions on supports and connected equipment shall be determined as the algebraic difference between the value at maximum (or minimum) temperature for the thermal cycle under analysis and the value at the temperature expected during installation.

- **319.3.2 Modulus of Elasticity.** The reference modulus of elasticity at 21°C (70°F), Ea, and the modulus of elasticity at maximum or minimum temperature, Em, shall be taken as the values shown in Appendix C

B31.3 - Process Piping

- **319.3.3 Poisson's Ratio.** Poisson's ratio may be taken as 0.3 at all temperatures for all metals. More accurate and authoritative data may be used, if available.
- **319.3.4 Allowable Stresses**
  a) *The allowable displacement stress range, SA, and* permissible additive stresses shall be as specified in paragraph 302.3.5(d) for systems primarily stressed in bending and/or torsion.
  b) *The stress intensification factors in Appendix D* have been developed from fatigue tests of representative piping components and assemblies manufactured from ductile ferrous materials.

B31.3 - Process Piping

- **319.3.5 Dimensions.** Nominal thicknesses & outside diameters of pipe and fittings shall be used in flexibility calculations.
- **319.3.6 Flexibility & Stress Intensification Factors.** In the absence of more directly applicable data, the flexibility factor k and stress intensification factor i shown in Appendix D shall be used for flexibility calculations described in paragraph 319.4.
  - If two or more of the geometries shown in Appendix D are combined, their combined k and i might be significantly different from the values shown.
  - Examples include trunnions on elbows and branch connection fittings welded to anything other than straight pipe.

B31.3 - Process Piping

- **319.4.4 Flexibility Stresses**

a) The range of bending and torsional stresses shall be computed using the reference modulus of elasticity at 21°C (70°F), Ea, except as provided in paragraph 319.2.2(b)(4), and then combined in accordance with equation (17) to determine the computed displacement stress range, SE, which shall not exceed the allowable stress range, SA, in paragraph 302.3.5(d).

B31.3 - Process Piping

$$S_E = \sqrt{S_b^2 + 4S_t^2} \qquad (17)$$

where

M_t = torsional moment

S_b = resultant bending stress

S_t = torsional stress

= $M_t/2Z$

Z = section modulus of pipe

B31.3 - Process Piping

(b) The resultant bending stresses, S_b, to be used in eq. (17) for elbows, miter bends, and full size outlet branch connections (Legs 1, 2, and 3) shall be calculated in accordance with eq. (18), with moments as shown in Figs. 319.4.4A and 319.4.4B.

$$S_b = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} \qquad (18)$$

where

i_i = in-plane stress intensification factor from Appendix D

i_o = out-plane stress intensification factor from Appendix D

M_i = in-plane bending moment

M_o = out-plane bending moment

S_b = resultant bending stress

Z = section modulus of pipe

B31.3 - Process Piping

Fig. 319.4.4A Moments in Bends

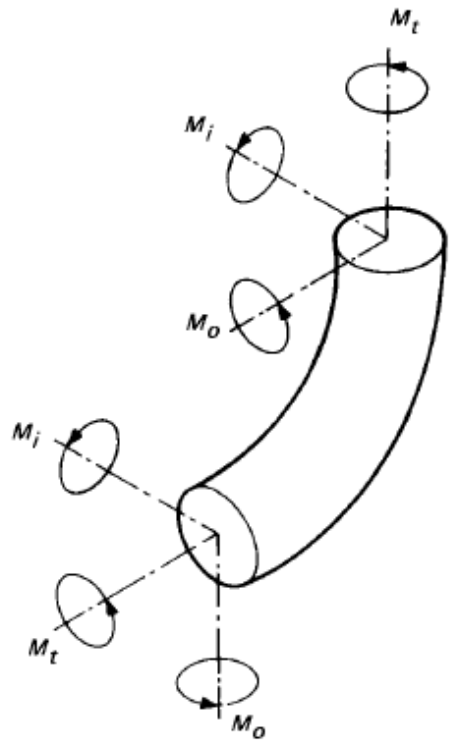
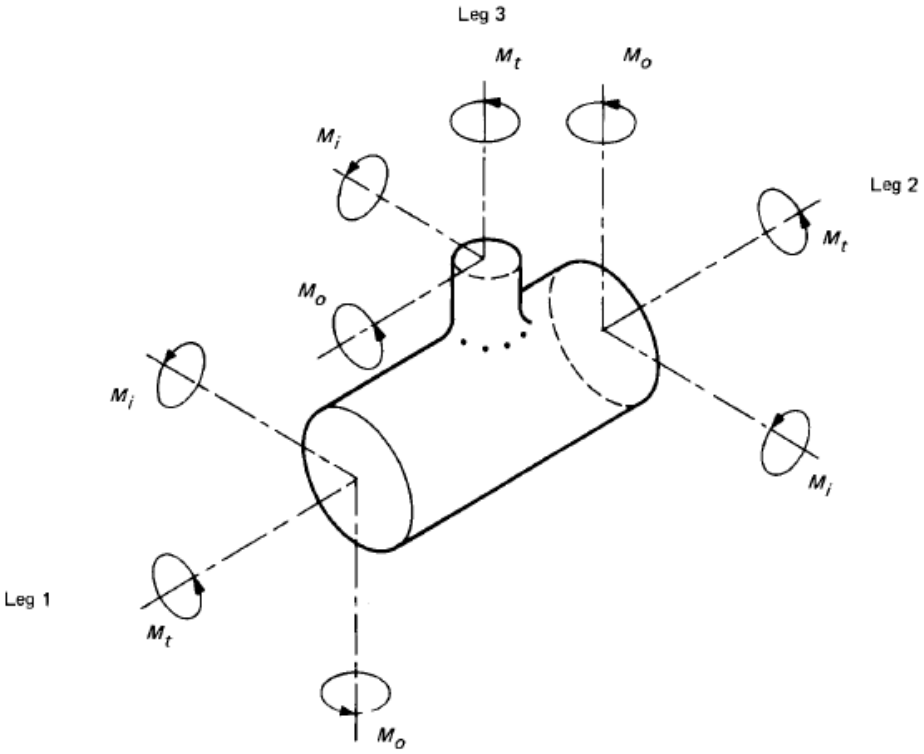


Fig. 319.4.4B Moments in Branch Connections



B31.3 - Process Piping

- **320 ANALYSIS OF SUSTAINED LOADS**

  320.1 Basic Assumptions and Requirements

  Sustained conditions may be evaluated by detailed analysis, approximate methods, or simplified means such as span tables. When detailed analysis is performed, the stress due to sustained loads, *SL,* shall be computed and combined as described in this paragraph and shall not exceed the allowable described in paragraph 302.3.5(c).

  The loads due to weight should be based on the nominal thickness of all system components unless otherwise justified in a more rigorous analysis.

B31.3 - Process Piping

- **320.2 Stress Due to Sustained Loads**

  The equation for the stress due to sustained loads, such as pressure and weight, *SL, is provided in equation (23a).* The equation for the stress due to sustained bending moments, Sb, is provided in equation (23b).

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \qquad (23a)$$

$$S_b = \frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z} \qquad (23b)$$

B31.3 - Process Piping

where

I_i = sustained in-plane moment index. In the absence of more applicable data, I_i is taken as the greater of $0.75i_i$ or 1.00.

I_o = sustained out-plane moment index. In the absence of more applicable data, I_o is taken as the greater of $0.75i_o$ or 1.00.

M_i = in-plane moment due to sustained loads, e.g., pressure and weight

M_o = out-plane moment due to sustained loads, e.g., pressure and weight

Z = sustained section modulus. Z in eqs. (23b) and (23c) is described in para. 319.4.4 but is computed in this paragraph using nominal pipe dimensions less allowances; see para. 320.1.

B31.3 - Process Piping

The equation for the stress due to sustained torsional moment, S_t, is

$$S_t = \frac{I_t M_t}{2Z} \tag{23c}$$

where

I_t = sustained torsional moment index. In the absence of more applicable data, I_t is taken as 1.00.

M_t = torsional moment due to sustained loads, e.g., pressure and weight

The equation for the stress due to sustained longitudinal force, S_a, is

$$S_a = \frac{I_a F_a}{A_p} \tag{23d}$$

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where

A_p = cross-sectional area of the pipe, considering nominal pipe dimensions less allowances; see para. 320.1

F_a = longitudinal force due to sustained loads, e.g., pressure and weight

I_a = sustained longitudinal force index. In the absence of more applicable data, I_a is taken as 1.00.

For piping systems that contain expansion joints, it is the responsibility of the designer to determine the sustained longitudinal force due to pressure in the piping system.

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APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Table D300[1] Flexibility Factor, k, and Stress Intensification Factor, i

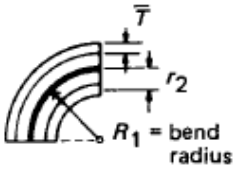
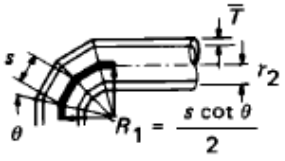
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (2), (3)]		Flexibility Characteristic, h	Sketch
		Out-of-Plane, i_o	In-Plane, i_i		
Welding elbow or pipe bend [Notes (2), (4)-(7)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\overline{T}R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2(1 + \tan\theta)$ [Notes (2), (4), (5), (7)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\left(\frac{s\overline{T}}{r_2^2}\right)$	

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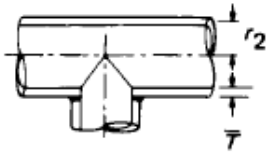
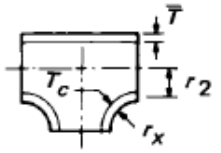
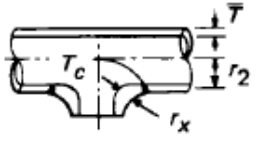
Table D300[1] Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (2), (3)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (2), (3)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (2), (4), (9), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{\overline{T}}{r_2}$	
Extruded welding tee with $r_x \geq 0.05\ D_b$ $T_c < 1.5\ \overline{T}$ [Notes (2), (4), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1 + \frac{r_x}{r_2}\right)\frac{\overline{T}}{r_2}$	
Welded-in contour insert [Notes (2), (4), (8), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\frac{\overline{T}}{r_2}$	

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APPENDIX P

ALTERNATIVE RULES FOR EVALUATING STRESS RANGE

- Appendix P provides alternative rules for evaluating the stress range in piping systems. This Appendix considers stresses at operating conditions, including both displacement and sustained loads, rather than displacement stress range only. The method is more comprehensive than that provided in Chapter II and is more suitable for computer analysis of piping systems, including nonlinear effects such as pipes lifting off supports.

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- **P302.3.5 Limits of Calculated Stresses Due to Sustained**

  Loads and Displacement Strains.

  (d) Allowable Operating Stress and Operating Stress Range. For each evaluated operating condition, the operating stress, So, for each component in a piping system [see paragraph P319.4.4(a)] shall not exceed its allowable operating stress, SoA, calculated by applying equation (P1a).

$$S_{oA} = 1.5(S_c + S_h) \qquad \text{(P1a)}$$

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- For each evaluated range of conditions, the operating stress range for each component in a piping system [see paragraphs 319.4.4 and P319.4.4(a)] shall not exceed its allowable operating stress range, *SEA (see paragraphs 319.2.3* and 319.3.4), calculated by equation (P1b). The operating stress range is the range of stress between any two operating conditions, including the ranges between operating conditions and a sustained case with the piping at ambient temperature.

$$S_{EA} = 1.25\, f(S_c + S_h) \qquad \text{(P1b)}$$

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- **P319.4.4 Flexibility Stresses**

  (a) The operating stress (and operating stress range) due to bending, torsion and axial loads (and load ranges) shall be computed using the reference modulus of elasticity at 21°C (70°F)

$$S_o = \sqrt{(|S_a| + S_b)^2 + 4S_t^2} \qquad \text{(P17a)}$$

$$S_E = \sqrt{(|S_a| + S_b)^2 + 4S_t^2} \qquad \text{(P17b)}$$

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The definitions in para. 319.4.4 apply, with the following additional definitions:

A_p = cross-sectional area of the pipe

F_a = axial force, including that due to internal pressure

i_a = axial force stress intensification factor. In the absence of more applicable data, $i_a = 1.0$ for elbows, pipe bends, and miter bends (single, closely spaced, and widely spaced), and $i_a = i_o$ (or i when listed) in Appendix D for other components; also see para. 319.3.6.

S_a = stress due to axial force = $i_a F_a / A_p$

B31.3 - Process Piping - Appendices

A	Allowable Stresses and Quality Factors for Metallic Piping and Bolting Materials
B	Stress Tables and Allowable Pressure Tables for Nonmetals
C	Physical Properties of Piping Materials
D	Flexibility and Stress Intensification Factors
E	Reference Standards
F	Precautionary Considerations
G	Safeguarding
H	Sample Calculations for Branch Reinforcement
J	Nomenclature
K	Allowable Stresses for High Pressure Piping
L	Aluminum Alloy Pipe Flanges
M	Guide to Classifying Fluid Services
P	Alternative Rules for Evaluating Stress Range
Q	Quality System Program
S	Piping System Stress Analysis Examples
V	Allowable Variations in Elevated Temperature Service
X	Metallic Bellows Expansion Joints
Z	Preparation of Technical Inquiries

Basic Assumptions

- Ambient Temp – 70 °F unless otherwise known
- Anchors - Totally rigid
- Equipment Nozzles – Totally rigid with thermal movements (growths or contractions)
- Supports – Totally rigid
- Friction – Steel / steel – coefficient of friction = .3
- Friction – Graphite/Graphite – friction coefficient = .1
- Friction – PTFE/PTFE – friction coefficient = .05

Do's & Don'ts

- Don't anchor at 2 locations along a straight run of pipe
- Don't anchor in piping near equipment nozzles
- Don't fail to consider thermal movements (growths or contractions) at equipment nozzles
- Don't fail to include friction where it can have a substantial impact on stress range calcs
- Include Pressure Thrust when using expansion joints
- When rotating equipment is connected to a piping system, stresses should rarely be a consideration. Look at loads on the equipment.

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