Piping Development Process

1. Establish applicable system standard(s)
2. Establish design conditions
3. Make overall piping material decisions
   - Pressure Class
   - Reliability
   - Materials of construction
4. Fine tune piping material decisions
   - Materials
   - Determine wall thicknesses
   - Valves
5. Establish preliminary piping system layout & support configuration
6. Perform flexibility analysis
7. Finalize layout and bill of materials
8. Fabricate and install
9. Examine and test
8. Flexibility

- General Considerations
- Friction
- Stress Intensification
- Thermal Expansion
- Spring Hangers
- The Displacement Load Analysis

The Material in This Section is Addressed by B31.3 in:

Chapter II - Design
Appendix D - Flexibility & Stress Intensification Factors
General Considerations

- Main purpose is to provide sufficient flexibility to safely accommodate changes in length resulting from temperature variations, avoiding failure caused by:
  - Fatigue
  - Creep-fatigue
  - Ratchet
- Another purpose is to keep movement of piping within a manageable range:
  - Avoiding interference with other stuff
  - Supports designed to handle displacements

General Considerations

- Loads are actions that cause one end of a pipe segment to move relative to the other end and actions that have an equivalent effect:
  - Thermal expansion of attached equipment
  - Temperature changes in the piping
- Peak stresses are accounted for using stress intensification factors
- Acceptance criterion is based on the stress range
Friction

- Displacement causes piping to move over sliding supports
- Friction forces are in one direction when the pipe is heating and in the opposite direction when cooling
- The coefficient of friction used for steel on steel ranges from 0.3 to 0.5.

\[ F = \mu N \]

- The coefficient of friction can be reduced to 0.1 by using PTFE or graphite impregnated plates
- Using roller supports can further reduce the coefficient of friction to 0.02
Friction Workshop

Calculate the east-west reactions at the anchors caused by friction.

- Assume steel on steel
- Line is NPS 6, std WT steel, uninsulated and full of water

Stress Intensification

- Stress intensification factors (SIF's) are used to account for higher stresses that may exist at discontinuities in the piping at fittings and joints
- The calculated stresses at a fitting or joint are taken as the stress calculated for a perfect circular cylinder times the SIF
- SIF's are given in Appendix D of B31.3
Stress Intensification

- SIF's are based on Markl testing of piping components
  - Primarily A106 Gr B pipe, with some types 316 and 347 stainless steel
  - NPS 4 Sch 40
  - Fully reversed bending
  - Displacement controlled tests
- Markl started with a fatigue curve generated by fatigue tests on pipe with circumferential welds

Pipe with Circumferential Welds

<table>
<thead>
<tr>
<th>Number of Cycles</th>
<th>Stress Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>1,000</td>
</tr>
<tr>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>100,000</td>
<td>100,000</td>
</tr>
<tr>
<td>1,000,000</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

- Average Fatigue Failure
- Design Fatigue Curve (1/2 Average)
Stress Intensification

- Components such as tees and elbows were similarly fatigue tested
- The SIF for a component is the ratio of the nominal stress in the circumferentially welded pipe divided by the nominal stress in the component at failure for the same number of cycles
- Even though the component may have thicker walls, the evaluation is based on the dimensions of the pipe

Stress Intensification
NPS 4 STD WT Fittings

<table>
<thead>
<tr>
<th>Stress Range</th>
<th>Number of Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>100,000</td>
<td>100,000</td>
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<tr>
<td>10,000</td>
<td>100,000</td>
</tr>
<tr>
<td>1,000</td>
<td>100,000</td>
</tr>
</tbody>
</table>

- Butt welded Pipe
- Elbow
- Tee

Elbow = 1.1
Tee = 1.5
Thermal Expansion

Thermal Expansion of metals can be calculated by

\[ \Delta L = \alpha \Delta T L \]

Where:

\( \alpha \) = Coefficient of thermal expansion

\( L \) = Length of piping

\( \Delta L \) = Change in length of piping

\( \Delta T \) = Change in temperature, usually temperature range

Thermal Expansion

Thermal Expansion of metals can also be calculated by

\[ \Delta L = \text{Exp} L \]

Where:

\( \text{Exp} \) = Total thermal expansion, in/100 ft (mm/m)

\( L \) = Length of piping, 100 ft (m)

\( \Delta L \) = Change in length of piping, in (mm)
Thermal Expansion

What is the change in length of a carbon steel line that has

- An original length of 60 ft (18.3 m)
- Has a minimum expected temperature of -29°F (-34°C), and
- Has a maximum expected temperature of 300°F (150°C)

See pages 41-44 of the supplement.

Spring Hangers

Spring hangers are used to provide support for piping while allowing vertical movement of the piping caused by displacement loads.

Variable Type
Spring Hangers

Selection Process

- Calculate weight to be supported
- Calculate movement of the line at the support location
- Select hanger size based on the load
- Decide allowable load variation
  - Usually less than 25%
  - Less if needed to meet stress or reaction requirements
- Select hanger from manufacturer’s table
Spring Hanger Workshop

Select a spring hanger that will minimize the weight reaction on the pump.

Spring Hangers

Variable Spring Hanger Installation (Anvil International)
[Note that springs are always in compression.]
Spring Hangers

Constant type spring hangers are used when the load variation on a variable type spring hanger would be too high.

Constant Type

Spring Hangers

Constant Support Hanger Installation (Anvil International)
The Displacement Load Analysis

- Temperature Range
- Displacement Stress Calculation
- Calculation Methods

Temperature Range

- B31.3 requires that we consider “…the algebraic difference between strains in the extreme displacement condition and the original (as-installed) condition (or any anticipated condition with a greater differential effect)…” (319.2.3(b))
- The minimum and maximum temperatures used don’t necessarily correspond to the design temperature and the design minimum temperature
Temperature Range

**design temperature:** the temperature at which, under the coincident pressure, the greatest thickness or highest component rating is required (301.3).

**design minimum temperature:** the lowest component temperature expected in service (301.3.1)

Minimum temperature may be due to:
- Normal operation
- Excursion operation
- Expected winter temperature

Maximum temperature may be due to:
- Normal operation
- Excursion operation
- Piping exposed to hot summer sun [120°F, 50°C]
- Empty piping exposed to heat tracing
- Steam cleaning
Temperature Range Examples

- Outdoor cooling tower water line:
  - Minimum water temperature is 45°F (7°C)
  - Maximum water temperature is 90°F (32°C)
  - The piping is installed during February, which has an average daily temperature of 53°F (12°C)
  - Minimum average daily temperature is 30°F (-1°C)
  - Temperature range is _______ to _______

- Outdoor compressed air piping
  - Minimum compressed air temperature is ambient
  - Maximum compressed air temperature is 150°F (65°C)
  - The piping is installed during July, which has an average daily temperature of 64°F (18°C)
  - Minimum average daily temperature is -30°F (-35°C)
  - Temperature range is _______ to _______
Temperature Range Examples

➢ Outdoor steam traced water line:
  - Minimum water temperature is 40°F (4°C)
  - Maximum water temperature is 60°F (16°C)
  - The piping is installed during September, which has an average daily temperature of 76°F (24°C)
  - Minimum average daily temperature is 30°F (-1°C)
  - Calculated maximum temperature for no flow condition with steam tracing on is 280°F (140°C)
  - Temperature range is _______ to _______

Displacement Stress Calculation

\[ \sigma = \frac{E \cdot \Delta L}{L} \]
\[ \Delta L = \alpha \cdot \Delta T \cdot L \]
\[ \sigma = E \cdot \alpha \cdot \Delta T \]

1. What is \( \sigma \) for carbon steel and \( \Delta T = 330°F \) (185°C)?
   E for carbon steel = 29E6 psi (200 GPa)
2. What is \( \sigma \) for stainless steel under the same condition?
   E for stainless steel = 28.3E6 psi (195 GPa)
Calculation Methods

The Code describes four acceptable methods to demonstrate adequate flexibility:

1. Formal analysis
2. Duplicate of a successful system
3. System that can be judged adequate by comparison
4. Empirical equation for piping that meets certain requirements

Calculation Methods

The empirical equation is:

\[
\frac{Dy}{(L - U)^2} \leq 30\frac{S_A}{E_a} \text{ (in/ft)}^2
\]

\[
\frac{Dy}{(L - U)^2} \leq 208,000\frac{S_A}{E_a} \text{ (mm/m)}^2
\]

Where:

- \(D\) = Pipe outside diameter (in) (mm)
- \(L\) = Developed length of piping between anchors (ft) (m)
- \(U\) = Distance between anchors (ft) (m)
- \(Y\) = Total displacement strain to be absorbed by the piping (in) (mm)
- \(S_A\) = Allowable stress range
- \(E_a\) = Elastic modulus at room temperature
Calculation Methods

\[ L = L_1 + L_2 \]
\[ y = \alpha U \Delta T \]

The empirical equation can be used if the piping system:
- Is of uniform size
- Has no more than two points of fixation
- Has no intermediate restraints

The equation is not applicable to systems subject to severe cyclic conditions.

The equation may not be accurate for certain geometries.
Calculation Methods

The Code describes four acceptable methods to demonstrate adequate flexibility

1. Formal analysis
2. Duplicate of a successful system
3. System that can be judged adequate by comparison
4. Empirical equation for piping that meets certain requirements

Calculation Methods

Formal analyses can be simple or complex. The complex analyses are done using computer programs such as

- Caesar, Coade, Inc., http://www.caesarii.com/
- TRIFLEX, Nor-Par a.s, http://www.norpar.com/triflex.htm
Calculation Methods

The simple analyses are done using equations, charts and graphs such as described in

- Piping Design and Engineering, Grinnell Corporation, First Edition 1963

One of the simplest methods is the guided cantilever method described in the Kellogg book.

\[ \delta = \frac{48L^2S_A}{E_aD} \]

Where \( \delta \) = maximum permissible displacement
Guided Cantilever Method

See page 49 of the Supplement.

Calculation Methods

The Code describes four acceptable methods to demonstrate adequate flexibility

1. Formal analysis
2. Duplicate of a successful system
3. System that can be judged adequate by comparison
4. Empirical equation for piping that meets certain requirements
Calculation Methods

Judging by comparison

If this line is OK, what can we say about this line, which is in the same fluid service?

If this line is OK, what can we say about this line, which has the same pipe material at a lower temperature range?
Calculation Methods

Judging by comparison

If this line is OK, what can we say about this line, which is in the same fluid service?

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Flexibility - 45

NPS 6

Calculation Methods

Judging by comparison

If this line is OK, what can we say about this line, which is in the same fluid service?

BECHT ENGINEERING COMPANY, INC.

Flexibility - 46

NPS 6, carbon steel

NPS 6, stainless steel