ASME B31.3 Process Piping

Charles Becht IV, PhD, PE
Don Frikken, PE
Instructors

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

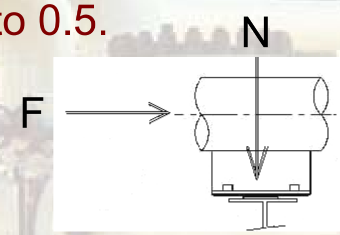
General Considerations

- 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

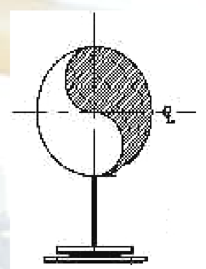
- Displacement causes piping to move over sliding supports
- Friction forces are in one direction when the pipe is heating and in the opposite direction when cooling
- The coefficient of friction used for steel on steel ranges from 0.3 to 0.5.

$$F = \mu N$$

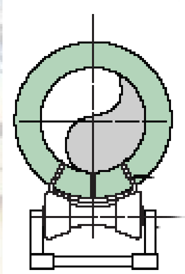


Friction

- The coefficient of friction can be reduced to 0.1 by using PTFE or graphite impregnated plates



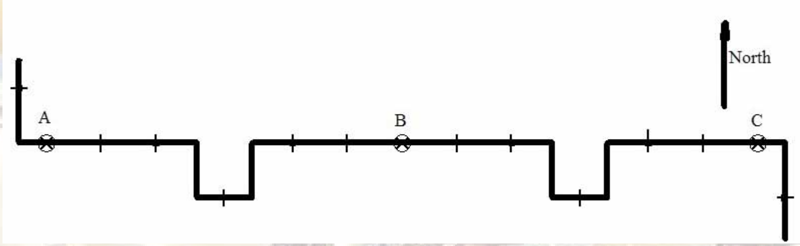
- Using roller supports can further reduce the coefficient of friction to 0.02



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

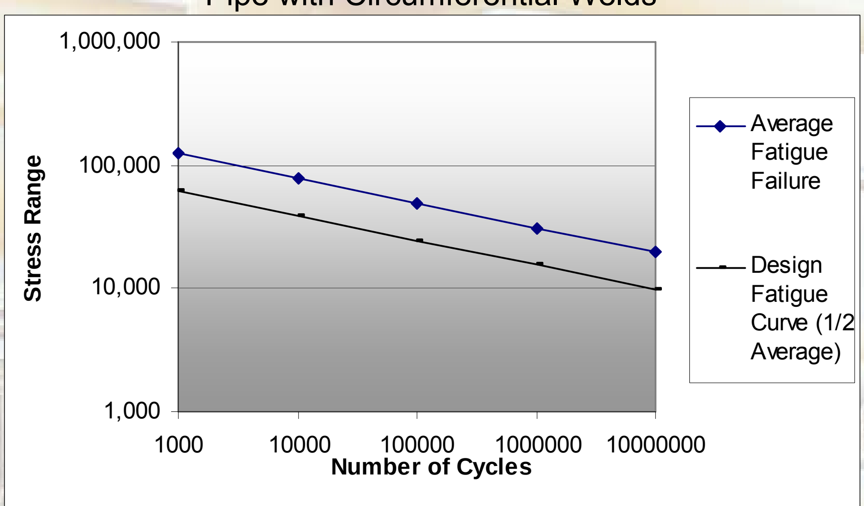
Stress Intensification

- 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

BECHT *ENGINEERING COMPANY, INC.* Flexibility - 11

Stress Intensification

Pipe with Circumferential Welds



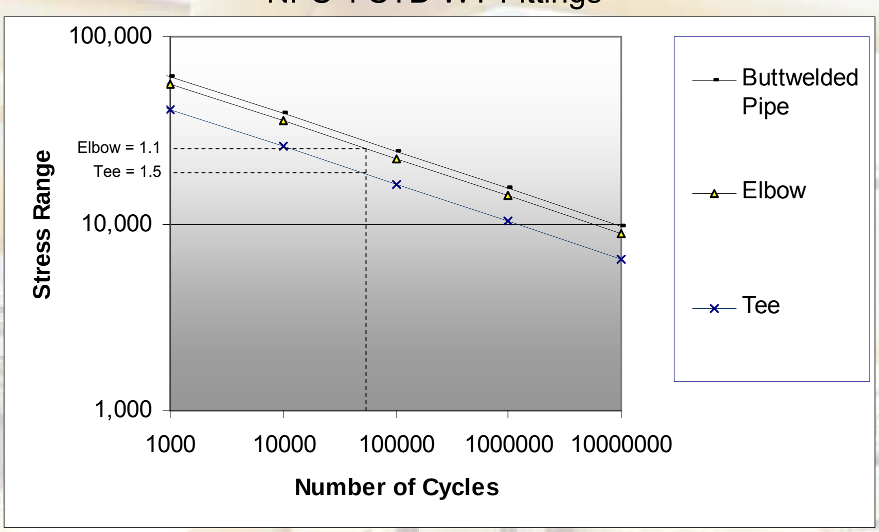
BECHT *ENGINEERING COMPANY, INC.* Flexibility - 12

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



Thermal Expansion

Thermal Expansion of metals can be calculated by

$$\Delta L = \alpha \, \Delta T \, L$$

Where:

- α = Coefficient of thermal expansion
- L = Length of piping
- ΔL = Change in length of piping
- ΔT = Change in temperature, usually temperature range

BECHT *ENGINEERING COMPANY, INC.* Flexibility - 15

Thermal Expansion

Thermal Expansion of metals can also be calculated by

$$\Delta L = Exp \, L$$

Where:

- Exp = Total thermal expansion, in/100 ft (mm/m)
- L = Length of piping, 100 ft (m)
- ΔL = Change in length of piping, in (mm)

BECHT *ENGINEERING COMPANY, INC.* Flexibility - 16

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 -29ºF (-34ºC), and
- Has a maximum expected temperature of 300ºF (150ºC)

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

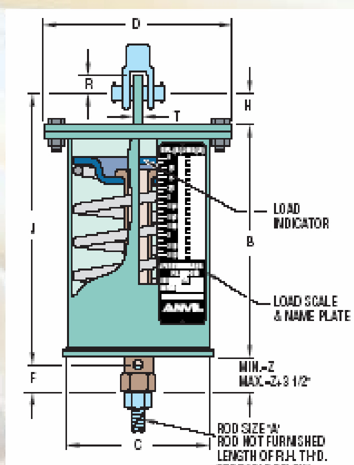
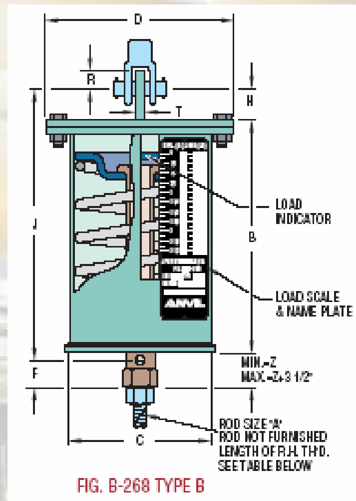
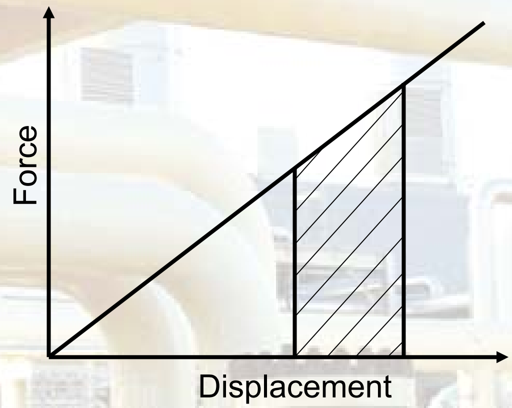


FIG. B-268 TYPE B

Spring Hangers





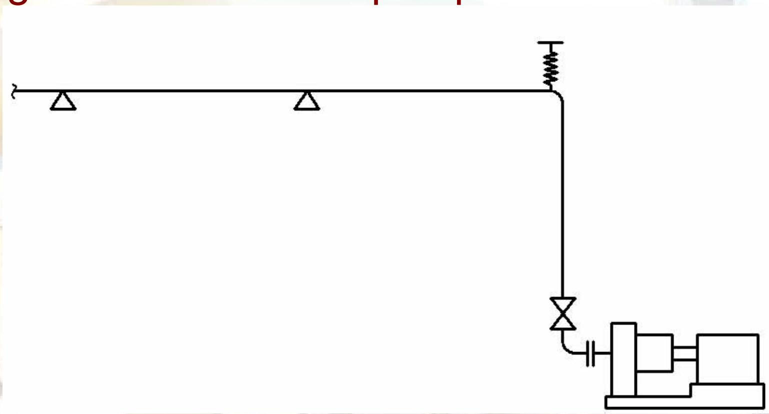
Spring Hangers

Selection Process

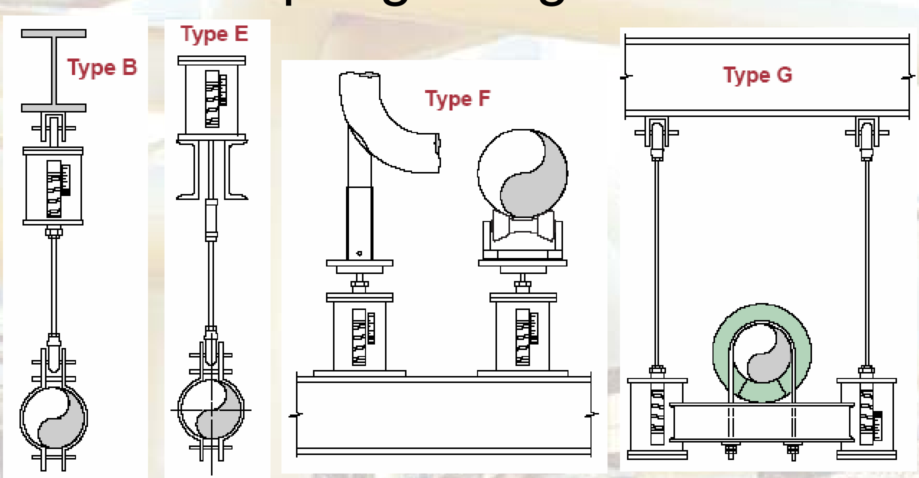
- Calculate weight to be supported
- Calculate movement of the line at the support location
- Select hanger size based on the load
- Decide allowable load variation
  - Usually less than 25%
  - Less if needed to meet stress or reaction requirements
- Select hanger from manufacturer’s table

Spring Hanger Workshop

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



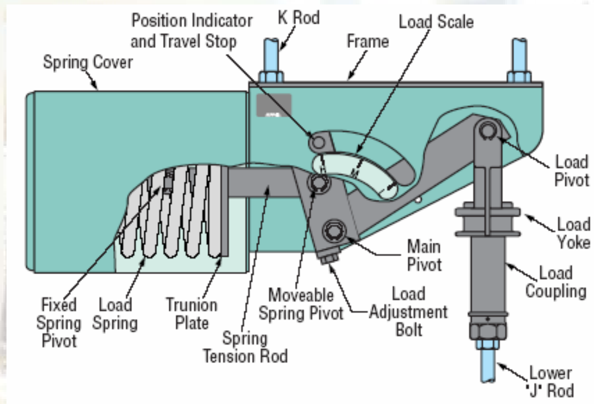
Spring Hangers



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

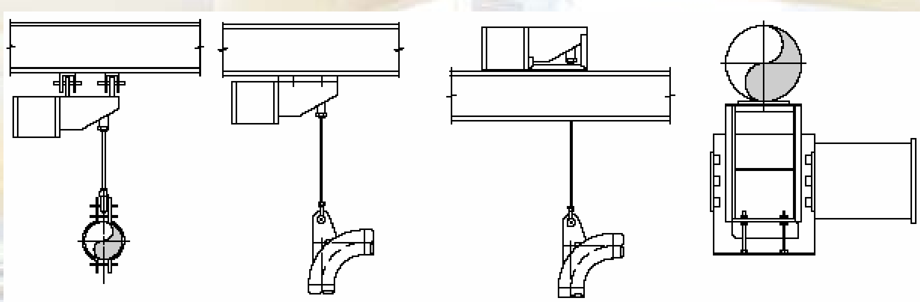
Spring Hangers

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



Constant Type

Spring Hangers



Type B and Type C | Type D | Type E | Type F

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)

Temperature Range

- 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 [120ºF, 50ºC]
  - Empty piping exposed to heat tracing
  - Steam cleaning

Temperature Range Examples

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

BECHT ENGINEERING COMPANY, INC. Flexibility - 29

Temperature Range Examples

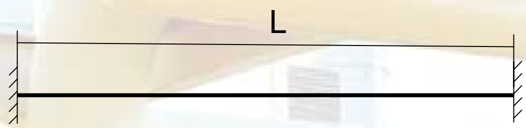
- Outdoor compressed air piping
  - Minimum compressed air temperature is ambient
  - Maximum compressed air temperature is 150ºF (65ºC)
  - The piping is installed during July, which has an average daily temperature of 64ºF (18ºC)
  - Minimum average daily temperature is -30ºF (-35ºC)
  - Temperature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

BECHT ENGINEERING COMPANY, INC. Flexibility - 30

Temperature Range Examples

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

Displacement Stress Calculation



$$\sigma = E \cdot \Delta L / L$$
$$\Delta L = \alpha \cdot \Delta T \cdot L$$
$$\sigma = E \cdot \alpha \cdot \Delta T$$

1. What is σ for carbon steel and ΔT = 330ºF (185ºC)?
   E for carbon steel = 29E6 psi (200 GPa)
2. What is σ 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:

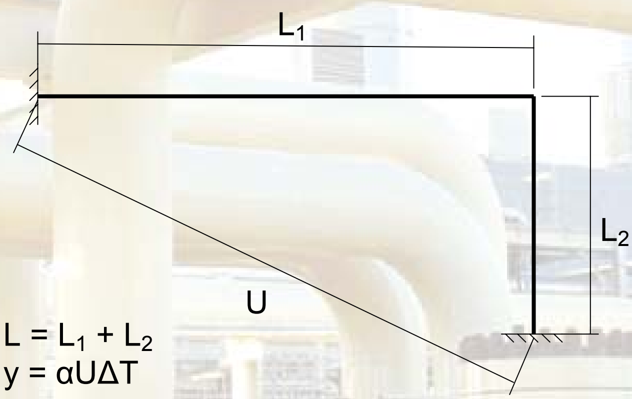
$$Dy/(L - U)^2 \le 30S_A/E_a \ (in/ft)^2$$

$$Dy/(L - U)^2 \le 208{,}000S_A/E_a \ (mm/m)^2$$

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



$L = L_1 + L_2$

$y = \alpha U \Delta T$

Calculation Methods

- 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

- Autopipe, Siber Technology, http://www.siber.co.uk/rebis/autopipe.shtml
- CAEPIPE, SST Systems, Inc., http://www.sstusa.com/
- Caesar, Coade, Inc., http://www.caesarii.com/
- PipePak, Algor, http://www.pipepak.com/products/Profes1504/default.asp
- SIMFLEX, Peng Engineering, http://www.pipestress.com/
- TRIFLEX, Nor-Par a.s, http://www.norpar.com/triflex.htm

Calculation Methods

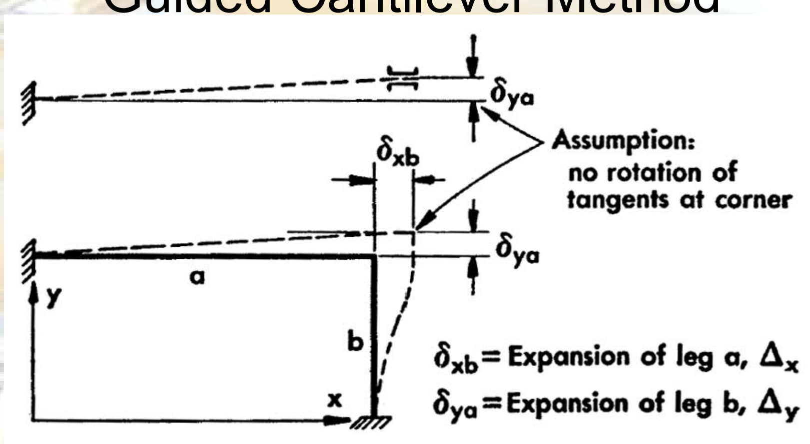
The simple analyses are done using equations, charts and graphs such as described in

- Design of Piping Systems, The M.W. Kellogg Company, John Wiley & Sons, Inc., First Edition 1941
- Piping Design and Engineering, Grinnell Corporation, First Edition 1963

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

BECHT ENGINEERING COMPANY, INC. Flexibility - 39

Guided Cantilever Method

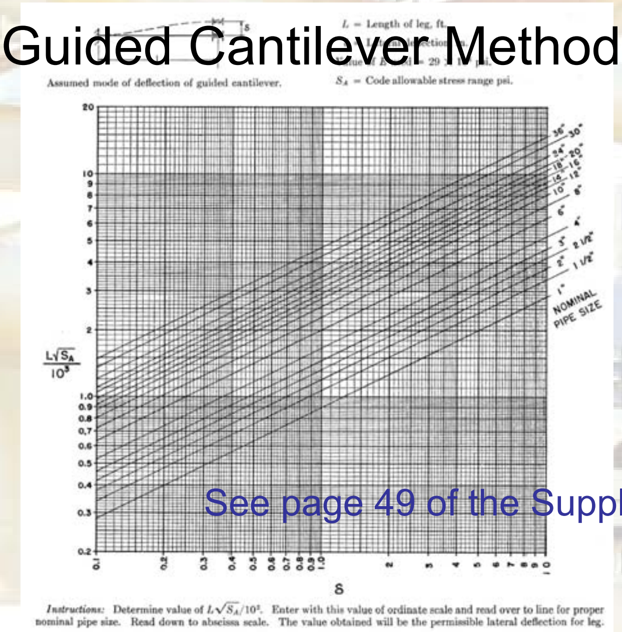


$$\delta = 48L^2S_A/E_aD$$

Where δ = maximum permissible displacement

BECHT ENGINEERING COMPANY, INC. Flexibility - 40

Guided Cantilever Method

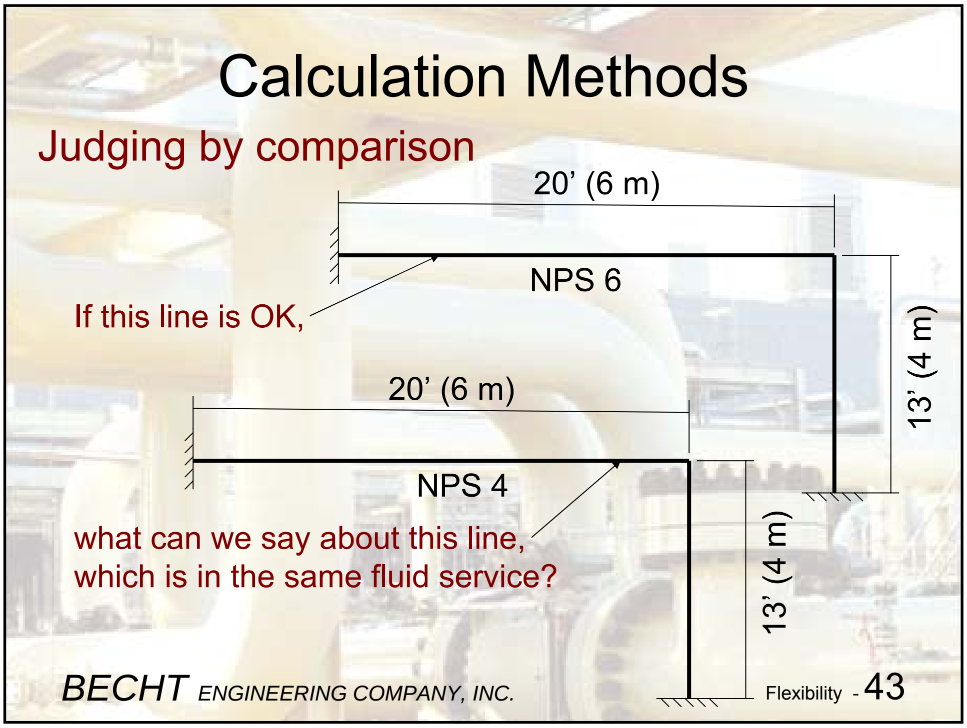


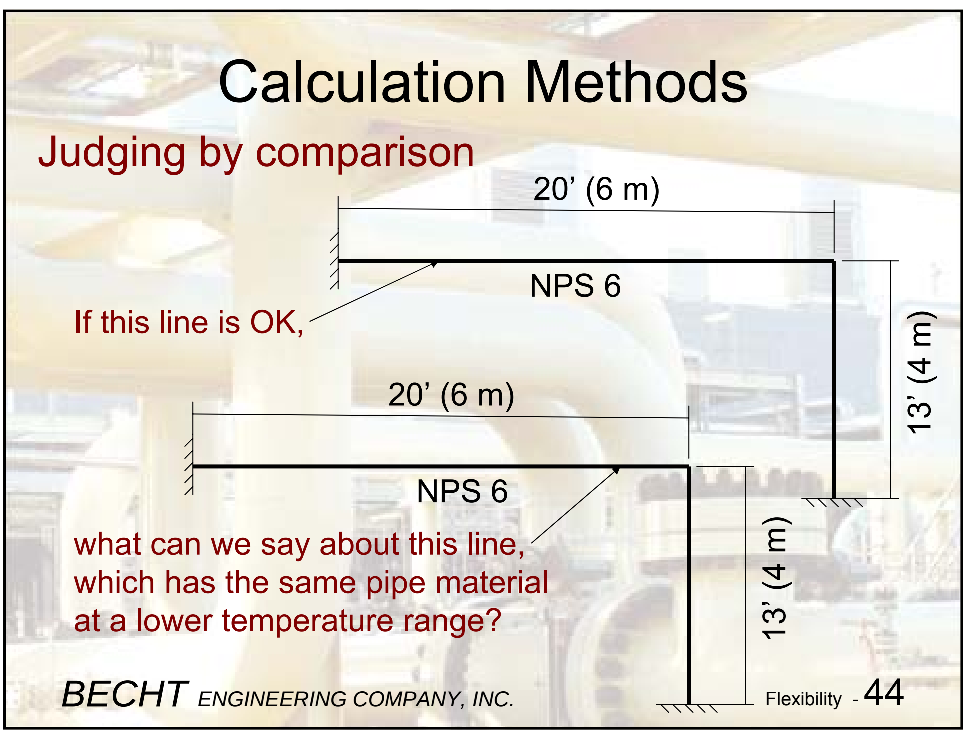
See page 49 of the Supplement.

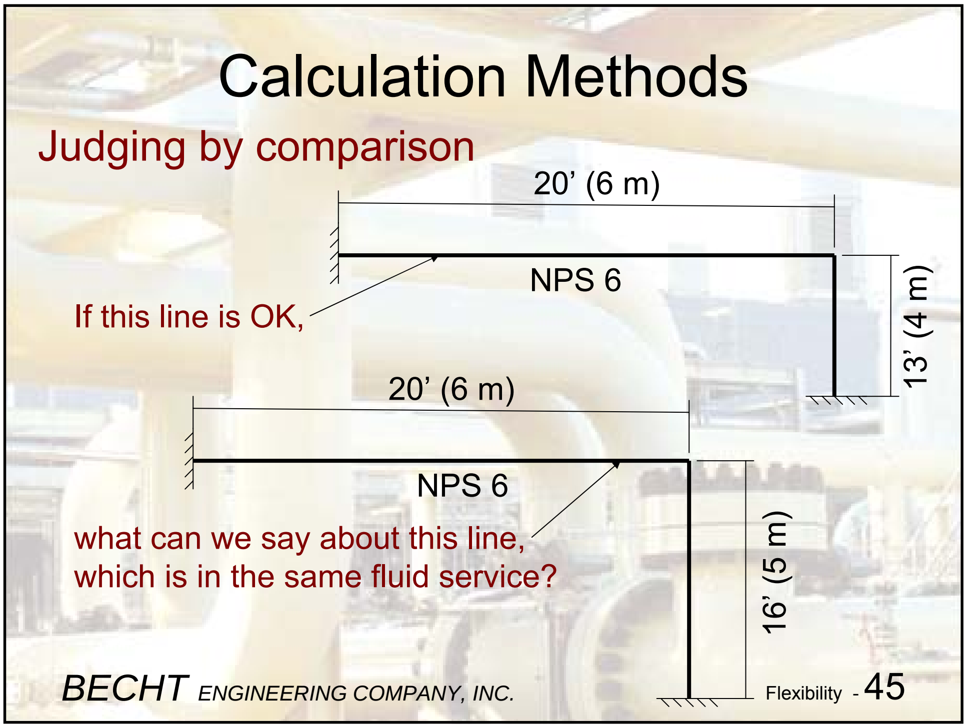
Calculation Methods

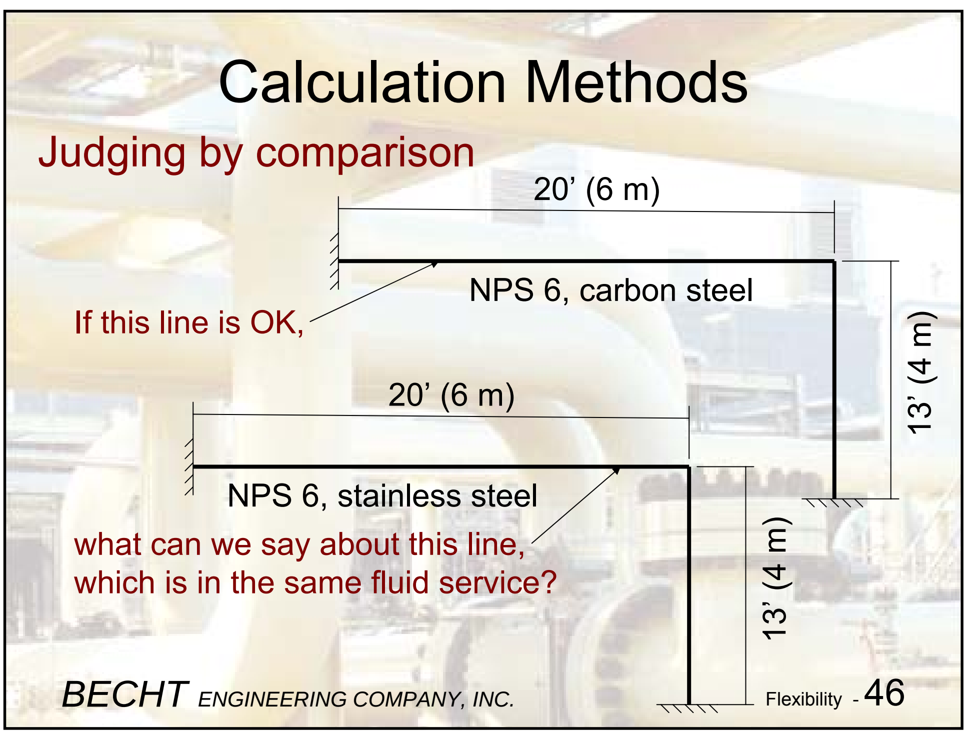
The Code describes four acceptable methods to demonstrate adequate flexibility

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
20' (6 m)
NPS 6
If this line is OK,
13' (4 m)
20' (6 m)
NPS 4
what can we say about this line,
which is in the same fluid service?
13' (4 m)
BECHT ENGINEERING COMPANY, INC.
Flexibility - 43


Calculation Methods
Judging by comparison
20' (6 m)
NPS 6
If this line is OK,
13' (4 m)
20' (6 m)
NPS 6
what can we say about this line,
which has the same pipe material
at a lower temperature range?
13' (4 m)
BECHT ENGINEERING COMPANY, INC.
Flexibility - 44


Calculation Methods
Judging by comparison
20’ (6 m)
NPS 6
13’ (4 m)
If this line is OK,
20’ (6 m)
NPS 6
what can we say about this line,
which is in the same fluid service?
16’ (5 m)
BECHT ENGINEERING COMPANY, INC.
Flexibility - 45


Calculation Methods
Judging by comparison
20’ (6 m)
NPS 6, carbon steel
13’ (4 m)
If this line is OK,
20’ (6 m)
NPS 6, stainless steel
what can we say about this line,
which is in the same fluid service?
13’ (4 m)
BECHT ENGINEERING COMPANY, INC.
Flexibility - 46