Designing Systems to Compensate for Thermal Expansion and Contraction
Things We Have Learned From Being Sued
6" Model MC - 6 Corrugations
Anchor Load @ 150psi - 11,600#
This is why you should use guides
Use Any Natural Flexibility In The piping layout
2008 ASHRAE Handbook

Heating, Ventilating, and Air Conditioning
Systems and Equipment

Chapter 45
For a Basic Expansion Elbow

Hard Pipe

\[ L = \sqrt[3]{3 \Delta DE} \sqrt{(144\text{in}^2/\text{ft}^2)S_A} \]

Where

- \( \Delta \) = Thermal expansion of leg AB
- \( D \) = Pipe Outside Diameter
- \( E \) = Modulus of Elasticity
- \( S_A \) = Allowable Stress

Or this can be simplified to

\[ L = 6.225 \sqrt{\Delta D} \]
For a Basic Expansion “Z” Bend

\[ L = 4 \sqrt{\Delta D} \]

Where
- \( \Delta \) = Thermal expansion of leg AB
- \( D \) = Pipe Outside Diameter
- \( E \) = Modulus of Elasticity
- \( S_A \) = Allowable Stress

Anchor to Anchor Expansion

Anchor

Guide

A

L

Guide

B

L

L

L

Anchor
ZIG-ZAG

Approximately 420 miles of the 800-mile pipeline are built above ground. In sections where the pipeline is elevated, a zig-zag design is apparent. This configuration contributes to the flexibility of the line, converting the changes in line length to sideways movement.

Anchor structures, 700 to 1800 feet apart, hold the pipe in position. Between anchors—which can be identified by their four supporting “legs”—the pipe can move sideways on its cross-beams a total of 12 feet in case of thermal expansion and contraction, and another 2 feet in case of seismic activity.
So what kind of expansion joint to use?
For a Basic Expansion Loop

Hard Pipe

$L = 6.225 \sqrt{\Delta D}$

$W = L/5$

$H = 2*W$

Where

$\Delta$ = Thermal expansion of run
$D$ = Pipe Outside Diameter
$E$ = Modulus of Elasticity
$S_A$ = Allowable Stress
Hard Loops Pro/Con

Pro
- Same material as the rest of piping
- Constructed on site
- Medium anchor loads
- Grandfather used ‘em

Con
- Constructed on site, costly to fabricate, hang and insulate
- Needs lots of room
- High lateral loads on moment guides.
Flexible Expansion Loop
“V” Loops
The flexible pipe loop is also smaller and has less anchor load than a hard pipe loop.

Design Conditions:
- Pipe: 6 inch Schedule 40
- Movement: 4" Axial Compression
- Pressure: 150 PSI
- Temperature: 300°F
- Length of Run: 177 feet

- 98% less anchor load than Bellows Expansion Joint
- 74% less anchor load than Hard Pipe Loop
- 69% less space required than Hard Pipe Loop
Corrugated stainless steel hose by itself has great hoop strength, but poor tensile strength.
# Stainless Steel Hose and Braid Maximum Design Conditions

Seam Welded Annular Corrugated Hose

**Braid Type**
- U - Unbraided
- S - Single Braided
- D - Double Braided

(see page 5 for column heading explanations)

<table>
<thead>
<tr>
<th>Nominal Hose I.D. in Inches</th>
<th><em>Braid Type</em></th>
<th>Nominal Hose O.D. in Inches</th>
<th>Minimum Centerline Bend Radius in Inches</th>
<th>Max. Working Pressure @ 70° PSIG</th>
<th>Max. Test Pressure @ 70° PSIG</th>
<th>Burst Pressure @ 70° PSIG</th>
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<td>33</td>
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OFFSET MOTION
Offset motion occurs when one end of the hose assembly is deflected in a plane perpendicular to the longitudinal axis with the ends remaining parallel.

FORMULA: 
\[ L = \sqrt{6RT + T^2} \]
\[ Lp = \sqrt{L^2 - T^2} \]

- \( L \) = Live Hose Length (inches)
- \( Lp \) = Projected Live Hose Length (inches)
- \( R \) = Minimum Centerline Bend Radius for constant flexing (inches)
- \( T \) = Offset Motion to one side of Centerline (inches)

Note 1: When the offset motion occurs to both sides of the hose centerline, use total travel in the formula; i.e. 2 times “\( T \).”

Note 2: The offset distance “\( T \)” for constant flexing should never exceed 25% of the centerline bend radius “\( R \).”

Note 3: If the difference between “\( L \)” and “\( Lp \)” is significant, exercise care at installation to avoid stress on hose and braid at the maximum offset distance.
Virtually any amount of movement
Cap weld, welding the hose, braid and collar together.
Weld the End Fitting to the Hose
On a flex loop the braid is the anchor
4” Sch 40 Carbon Steel
With Hard Pipe Expansion 90

Anchor with 582 pounds force

Guides

165 Feet
2.85” Exp.

19 Feet
Guides

Hose & Braid

50 Feet
.59” Exp.

165 Feet
2.85” Exp.

3 Feet
Guides

50 Feet
.59” Exp.

4” Sch 40 Carbon Steel
With H&B Dog Leg

Anchor with 180 pounds force
Flexible Loop Pro/Con

**Pro**
- Very compact
- Large movement
- Standard or custom fit
- Least expensive option
- Seismic capable
- Lowest anchor loads, almost no structural considerations.
- Minimal guiding requirements
- No maintenance

**Con**
- Some pressure limitations
There’s a lot of choices of Bellows

- Axial movement
- Lateral movement
- Angular movement

Axial Bellows
Externally Pressurized Axial Bellows
Untied Double Bellows
Gimbal Bellows
Dual Tied Bellows
Single Hinge Bellows
Double Hinged Bellows
Internally Pressurized  

Externally Pressurized

Capable of Axial, Lateral and Angular movements.  

Axial movement only
Expansion Compensators

externally pressurized

Atmosphere

Built in Liner
Squirm- Strut Instability - Limits the movement of internally pressurized bellows

The balance between the number of convolutions needed for the movement exceeds the stability of the bellows
Internally Pressurized Bellows

Are Primarily Designed to Handle Axial Movement
On the other hand, a dual-tied bellows moves:

Axially

And laterally
Dual-tied bellows joint
Anchors
Calculating forces on anchors

• **Pressure Thrust**
  
  Pressure × effective area (Use test pressure if greater)

• **Deflection Load** —
  
  Published Spring Rate × movement of the joint

• **Frictional Resistance**
  
  Total weight of pipe, media, insulation & equip. × coefficient
Calculating forces on anchors

- **Pressure Thrust**
  
  Pressure X effective area (Use test pressure if greater)

- **Example:**
  
  4” = 35.96 sq. in effective area x 125 PSI = 4495 #.
To calculate the thrust load: Effective Areas

<table>
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<tr>
<th>PIPE SIZE</th>
<th>EFFECTIVE AREAS IN INCH²</th>
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<td>PIPE</td>
<td>MSR*</td>
<td>711*</td>
<td>LOW CORR</td>
<td>MC</td>
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*This is an average number due to the flexibility of the joint. The diameter can vary under differing pressures and face to face dimensions.
Pressure Thrust for the Model MC Ring Controlled Self-Equalizing Expansion Joint

The average car weighs only 3000#.

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<th>PIPE SIZE</th>
<th>MODEL MC BELLOWS EFFECTIVE AREA (IN SQUARE INCHES)</th>
<th>PRESSURE THRUST IN POUNDS AT</th>
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<td>12</td>
<td>175</td>
<td>17,500</td>
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Deflection Load (spring rate)

Totally independent of pressure or temperature
Deflection Load on Anchors

- Published Spring Rate $\times$ Actual movement of the joint

**Example:**
4” with 6” Axial = Spring rate of 143 lbs/in

$\times$

4.3 (total amount of expansion)

= 614.9 lbs
Calculating forces on anchors

• Frictional Resistance

  Total weight of pipe, media, insulation & equip. X coeff.

• Example

  4” sch. 40 pipe at 10.8 #/ft x 75 ft = 1890 #

  4” pipe internal area 12.73 sq.in. / 144 in. per sq.ft. =
  0.088 cu.ft. x 175 linear ft. = 15.4 cu.ft. total volume

  125

  PSI steam = 3.23 cu.ft. per pound = 4.76# weight
  add guides & joint & insulation at 500#

  Total 2395# x 0.3 Coeff. = 719# frictional resistance
Total Anchor Force

4495 | Pressure Thrust
614  | Deflection Load
719  | Friction Resistance

5,828.9 lbs force

The engineer may add other loads such as snow, ice, wind, based on project conditions
Intermediate Anchors
Intermediate anchors between expansion devices do not see the full load.

EJMA recommends to design intermediate anchors for the spring load of one of the joints.
Anchors at fittings can have multi-directional loads.
Expansion Joint Location Makes a Difference

10 STORY BUILDING
13FT/FLOOR = 130' OF PIPE

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<th>PIPE SIZE</th>
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<th>WEIGHT OF WATER</th>
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<th>LINE B</th>
<th>LINE C</th>
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ANCHOR FORCE FORMULA

LINE A
TOP = PIPE WEIGHT + THRUST
BOTTOM = WATER WEIGHT + THRUST

LINE B
TOP = \( \frac{1}{2} \) PIPE WEIGHT + THRUST
BOTTOM = WATER WEIGHT + \( \frac{1}{2} \) PIPE WEIGHT + THRUST

LINE C
TOP = THRUST
BOTTOM = WATER WEIGHT + PIPE WEIGHT + THRUST

*The Mettrified Company, 1991. All rights reserved.
Guiding
Column strength of pipe.

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Remember our Example

**Total Anchor Force**

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<td>614</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>719</td>
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</table>

---

### Maximum Loads at Lengths of

<table>
<thead>
<tr>
<th>PIPE SIZE</th>
<th>200 FT</th>
<th>100 FT</th>
<th>50 FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>359 LBS</td>
<td>1,437 LBS</td>
<td>5,748 LBS</td>
</tr>
<tr>
<td>6</td>
<td>1,396</td>
<td>5,585</td>
<td>22,341</td>
</tr>
<tr>
<td>8</td>
<td>3,602</td>
<td>14,410</td>
<td>57,641</td>
</tr>
<tr>
<td>12</td>
<td>13,864</td>
<td>55,454</td>
<td>221,820</td>
</tr>
</tbody>
</table>
LINERS

• When velocity is high and could set up vibration in bellows

• Compressed air lines

• Exhaust gases

• Abrasive flow media

• Rule of Thumb: When velocity > 10 FPS
Install 1st. Guide a max. of 4 pipe dia. From the expansion joint.


Additional guides as per EJMA recommendations
## CONCENTRIC PIPE GUIDE SPACING

* Data Per Expansion Joint Manufacturers Association

<table>
<thead>
<tr>
<th>Pipe Size</th>
<th>Maximum Distance To 1st Guide</th>
<th>Approx. Distance Between 1st to 2nd Guide</th>
<th>Approximate Distance Between Additional Pipe Guides (In feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>@ 50 PSI</td>
</tr>
<tr>
<td>1&quot;</td>
<td>4&quot;</td>
<td>1'4&quot;</td>
<td>21'</td>
</tr>
<tr>
<td>1-1/4&quot;</td>
<td>5&quot;</td>
<td>1'5&quot;</td>
<td>23</td>
</tr>
<tr>
<td>1-1/2&quot;</td>
<td>6&quot;</td>
<td>1'9&quot;</td>
<td>28</td>
</tr>
<tr>
<td>2&quot;</td>
<td>8&quot;</td>
<td>2'4&quot;</td>
<td>32</td>
</tr>
<tr>
<td>2-1/2&quot;</td>
<td>10&quot;</td>
<td>2'11&quot;</td>
<td>35</td>
</tr>
<tr>
<td>3&quot;</td>
<td>1&quot;</td>
<td>3'6&quot;</td>
<td>38</td>
</tr>
<tr>
<td>3-1/2&quot;</td>
<td>1'2&quot;</td>
<td>4'1&quot;</td>
<td>45</td>
</tr>
<tr>
<td>4&quot;</td>
<td>1'4&quot;</td>
<td>4'8&quot;</td>
<td>52</td>
</tr>
<tr>
<td>5&quot;</td>
<td>1'8&quot;</td>
<td>5'8&quot;</td>
<td>63</td>
</tr>
<tr>
<td>6&quot;</td>
<td>2&quot;</td>
<td>7&quot;</td>
<td>68</td>
</tr>
<tr>
<td>8&quot;</td>
<td>2'8&quot;</td>
<td>9'4&quot;</td>
<td>87</td>
</tr>
<tr>
<td>10&quot;</td>
<td>3'4&quot;</td>
<td>11'8&quot;</td>
<td>107</td>
</tr>
<tr>
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<td>118</td>
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<tr>
<td>14&quot;</td>
<td>4'8&quot;</td>
<td>16'4&quot;</td>
<td>122</td>
</tr>
<tr>
<td>16&quot;</td>
<td>5'4&quot;</td>
<td>18'8&quot;</td>
<td>137</td>
</tr>
<tr>
<td>18&quot;</td>
<td>6&quot;</td>
<td>21&quot;</td>
<td>145</td>
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<tr>
<td>20&quot;</td>
<td>6'8&quot;</td>
<td>23'4&quot;</td>
<td>160</td>
</tr>
<tr>
<td>24&quot;</td>
<td>8&quot;</td>
<td>28&quot;</td>
<td>181</td>
</tr>
</tbody>
</table>
Bellows Pro/Con

Pro
- Low/ no pressure drop
- Very compact
- No maintenance
- Custom fit
- Easy to insulate
- Externally pressurized-large movement

Con
- High anchor loads
- Engineered anchors
- Considerable guiding requirements
- Torque can be a problem
Slip type Joints
Slip Type Joint
Slip Joint construction detail
Ball Joints

Always in, at least pairs

Similar construction with Slip joints

Same maintenance issues
Slip Type Pro/Con

Pro
Low/ no pressure drop
Very compact
Large movement
Custom fit

Con
High anchor loads
Engineered anchors
Crucial and Considerable guiding requirements
Very High maintenance – packing frequently needed
Low or no cycling is a detriment.
Very expensive
Let's Start With Determining The Pipe Size and Pipe Dimensions
To Calculate Expansion

1. Determine design temperature – for example 200° F.

2. Establish installation temperature - For example 50° F

3. Find the expansion rate per 100 feet –
   1.179” / 100 feet for steel – 1.728” / 100 feet for copper

4. Determine the length of pipe run – for example 165 feet

5. Multiply the expansion rate by the length.
   \[(165 / 100) \times 1.179 = 1.94” \text{ Expansion}\]

6. **If the joint is for both thermal and seismic, the values must be added together!**
For An Example

Let's use

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Carbon Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service</td>
<td>Hot Water</td>
</tr>
<tr>
<td>Design Temperature</td>
<td>200°F</td>
</tr>
<tr>
<td>Installation Temperature</td>
<td>50°F</td>
</tr>
<tr>
<td>Temperature Difference $\Delta T$</td>
<td>150°F</td>
</tr>
<tr>
<td>Expansion Rate $\Delta L$</td>
<td>1.179 inches / 100 Feet</td>
</tr>
</tbody>
</table>
Let's calculate how much the pipe will expand.
Let's Establish The Anchor Points
Pipe Flexibility

Natural pipe flexibility should be examined prior to the use of other expansion devices. The following charts on "L" bends, "Z" bends, and loops can be used to determine the flexibility of the piping system.

"L" Bends

1. Calculate expansion of longest leg.
2. Find minimum feet required for this amount of expansion from chart. This represents the minimum footage of expansion type pipe supports required for EACH side of elbow.

"Z" Bends

1. Calculate total expansion anchor to anchor.
2. Find minimum feet required for this amount of expansion from chart. This represents the minimum footage for offset and minimum footage of expansion type pipe supports required for EACH side of "Z" bend.
Keep in Mind

90° changes in direction are the most efficient piping configuration to use to take up thermal expansion or contraction.

Smaller angles will compound the movements!
Next, Use Any Natural Flexibility Of The System

Anchor (typ)

Anchor (typ)

Anchor (typ)
Next, Complete The System With Flexible Pipe Loops
Or, Complete
The System With
Expansion Joints

Don't forget about the guides. Note the placement of the Metragators
What if the 75 foot run was only 18 feet?
Option 1
Use a Hose & Braid
Dog Leg

[Diagram with dimensions and annotations]
Option 2
Add an Anchor, and another expansion device

Anchor (typ)

Anchor (typ)
Next, Complete The System With Flexible Pipe Loops
Or with Expansion Joints

Anchor (typ)

12"

250'

2.95"

150'

150' 75'

3.69" 1.0" 1.77" 0.88" 0.21"

Expansion Joints

Anchor (typ)