METAL EXPANSION JOINT TRAINING

FLEX-HOSE CO. INC.

AN INDUSTRY LEADER 40 FOR FORTY YEARS

Thermal Expansion In Piping Systems-Course Outline

- Principles and calculations of thermal expansion in piping systems.
- Piping system loads and impact on building systems and structural systems
- Metal Expansion Joint Anatomy and options
- Guidelines and methodology for applying and selecting metal expansion devices for compensation of thermal expansion and equipment connections and isolation

Metal Bellows Expansion Joints

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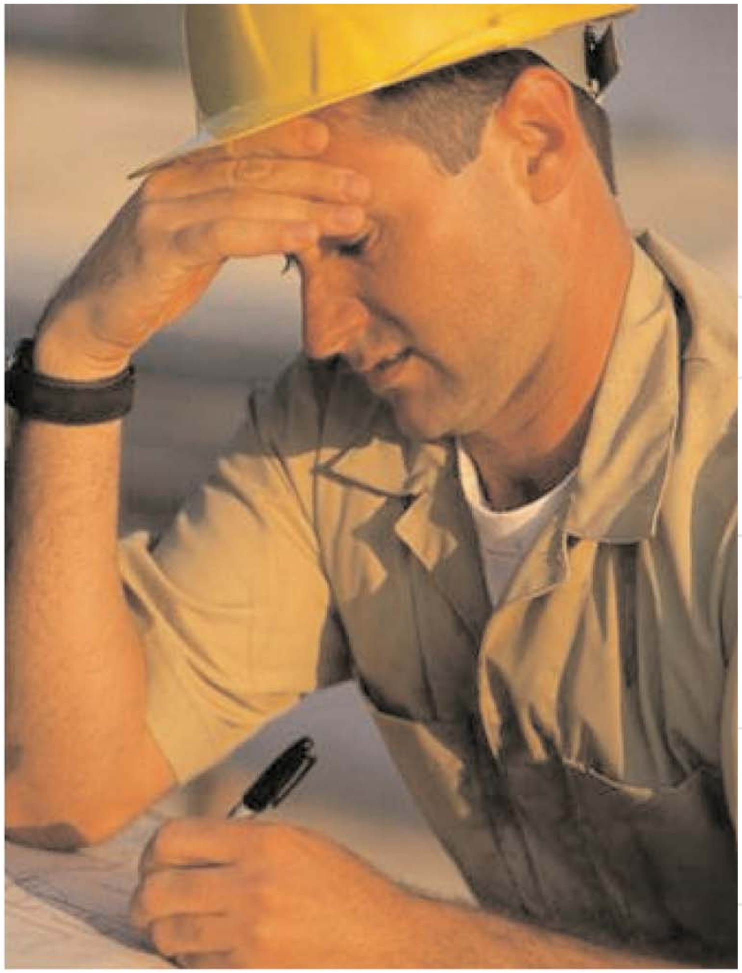
Application Guide for Piping Systems

Basic Principles: Thermal Expansion

THERMAL EXPANSION is a major problem confronting engineers designing, installing and maintaining piping systems.

To help you save time and money we have developed this metal expansion joint application guide to assist you in applying metal expansion joint technology to your piping system.

We also invite you to call us toll free for technical support at **1.877.Metal XJ.**



Basic Principles: Thermal Expansion

THERMAL EXPANSION is a major problem confronting engineers designing, installing and maintaining piping systems.

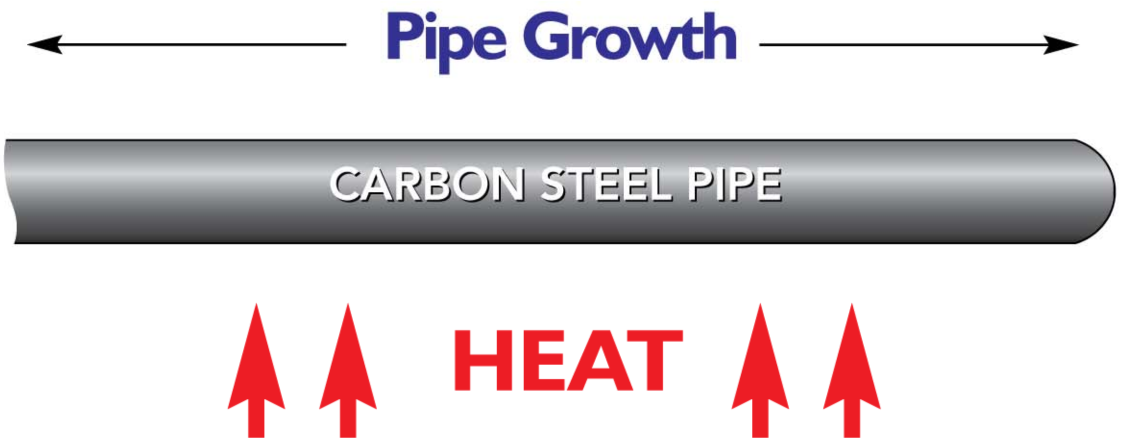
As

Temperature Increases

Pipe

Grows in

Length



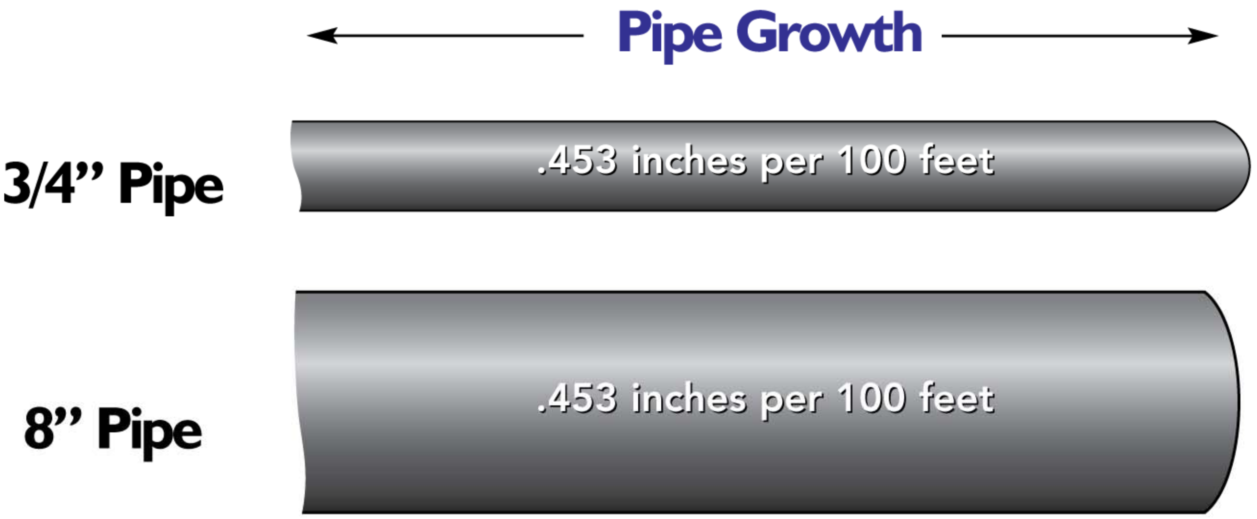
APPLICATION	TEMPERATURE RANGE	Thermal Expansion
Chilled Water	40°F → 100°F	**.453** inches per 100 ft
Condensor Water	40°F → 100°F	**.453** inches per 100 ft
Domestic Hot Water*	40°F → 140°F	**1.139** inches per 100 ft
Hot Water	40°F → 200°F	**1.220** inches per 100 ft
Steam 100 psig	40°F → 338°F	**2.400** inches per 100 ft

* Copper Pipe

Thermal Expansion for carbon steel pipe is the same for all pipe sizes.

Example: Chilled Water

40°F ⟶ 100°F



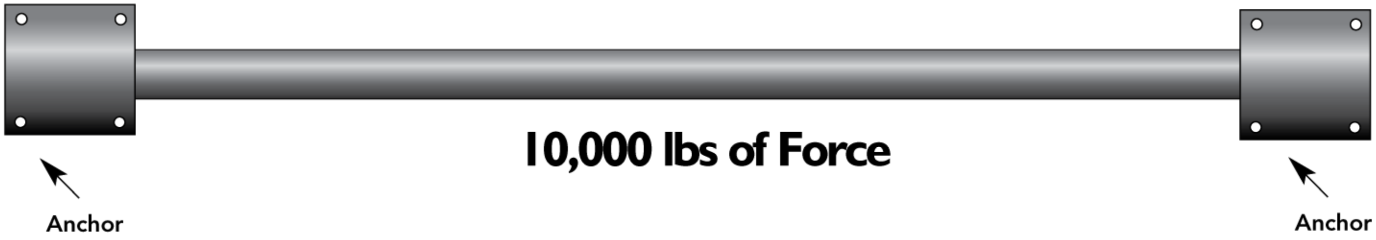
Pipe Growth

3/4" Pipe .453 inches per 100 feet

8" Pipe .453 inches per 100 feet

Note: Anchor Thrust loads will vary

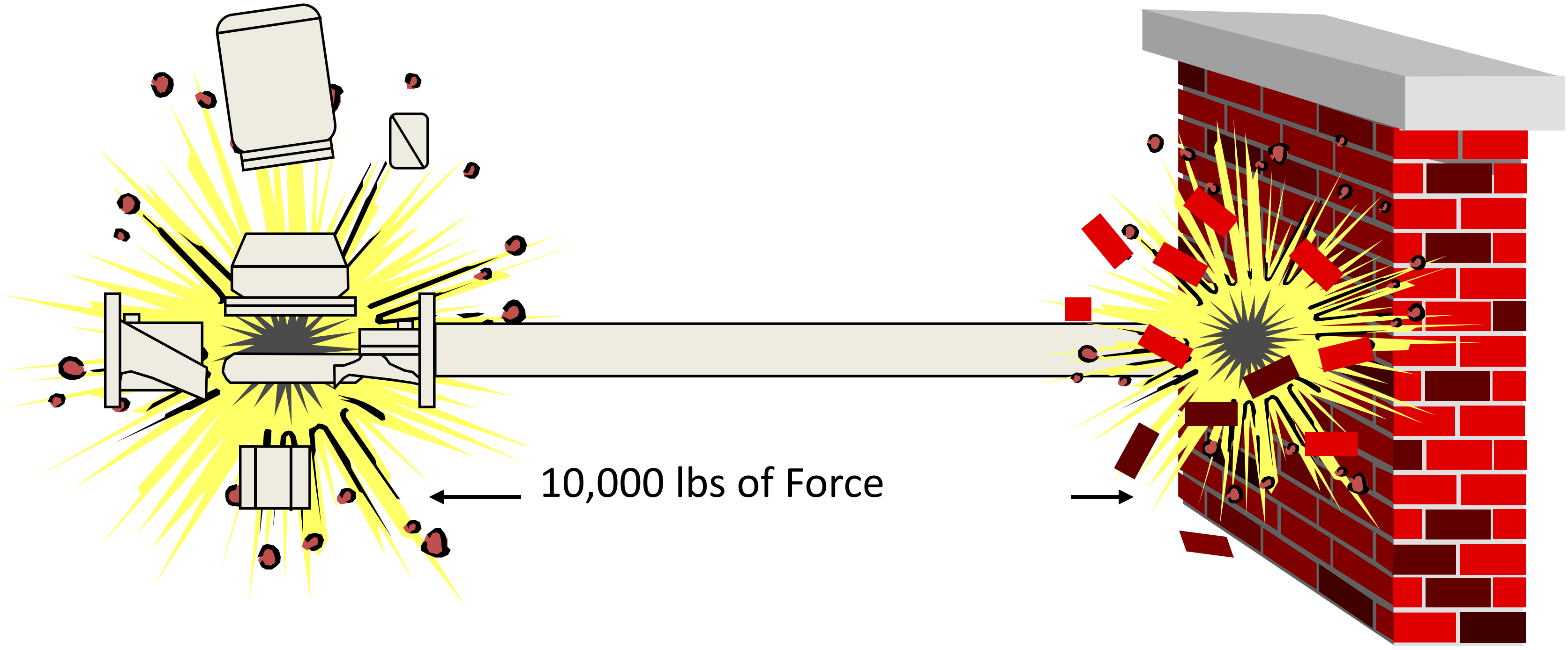
The Consequence of Thermal Expansion: Serious Problem



Stress Loads can be above 10,000 lbs of Force

Unless compesnation is provided for these dimensional changes, high stressed will be transmitted throughout the system to pumps, chillers, anchors and the connected equipment.

Uncontrolled
Thermal Expansion



Thermal Expansion of Metal Pipe

Linear Thermal Expansion, in/100 ft.

	Saturated Steam Pressure, psig	Temperature °F	Carbon Steel	Copper	Type 304 Stainless Steel
		-30	-0.19	-0.32	-0.30
		-20	-0.12	-0.21	-0.20
		-10	-0.06	-0.11	-0.10
		0	0	0	0
		10	0.08	0.12	0.11
		20	0.15	0.24	0.22
Vacuum	-14.6	32	0.24	0.37	0.36
	-14.6	40	0.30	0.45	0.45
	-14.5	50	0.38	0.57	0.56
	-14.4	60	0.46	0.68	0.67
	-14.3	70	0.53	0.79	0.78
	-14.2	80	0.61	0.90	0.90
	-14.0	90	0.68	1.02	1.01
	-13.7	100	0.76	1.13	1.12
	-13.0	120	0.91	1.37	1.35
	-11.8	140	1.06	1.59	1.57
	-10.0	160	1.22	1.80	1.79
	-7.2	180	1.37	2.05	2.02
	-3.2	200	1.52	2.30	2.24
	0	212	1.62	2.38	2.43
	2.5	220	1.69	2.52	2.48
	10.3	240	1.85	2.76	2.71
	20.7	260	2.02	2.99	2.94
	34.6	280	2.18	3.22	3.17
	52.3	300	2.35	3.46	3.40
	75.0	320	2.53	3.70	3.64
	103.3	340	2.70	3.94	3.88
	138.3	360	2.88	4.18	4.11
	181.1	380	3.05	4.42	4.35
	232.6	400	3.23	4.87	4.59
	666.1	500	4.15	5.91	5.80
	1528	600	5.13	7.18	7.03
	3079	700	6.16	8.47	8.29
		800	7.23	9.79	9.59
		900	8.34	11.16	10.91
		1000	9.42	12.54	12.27

Calculating Pipe Growth

Application:
Heating Hot Water

Example:
A 2” copper pipe line is 134 feet long. Maximum temperature the line will encounter is 200°F. Lowest temperature is 40°F.

Calculation:
From chart – the expansion of copper pipe at:

200°F	2.30”per 100 ft. pipe
40°F	.45” per 100 ft. pipe
Difference	1.85”per 100 ft. pipe

134/100 x 1.85 = 2.48” total length change

……

Application:
110# Steam

Example:
A 6” steel pipe line is 152 feet long. Maximum temperature the line will encounter is 340°F.
Lowest ambient temperature is -20°F.

Calculation:
From chart – the expansion of steel pipe at:

340°F	2.70”per 100 ft. pipe
-20°F	.12” per 100 ft. pipe
Total	2.82”per 100 ft. pipe

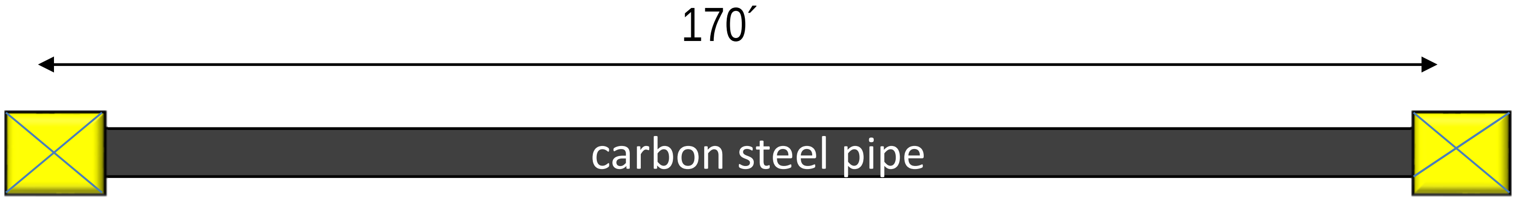
152/100 x 2.82 = 4.29” total length change

Thermal Expansion and Contraction

Application	Temperature Range (°F)	Thermal Expansion (per 100 ft.)
Chilled Water	40° - 100°	.46”
Condenser Water	40° - 100°	.46”
Domestic Hot Water *(Copper Pipe)*	40° - 140°	1.14”
Hot Water	40° - 200°	1.22”
Steam 100 psig	40° - 338°	2.40”

Thermal Expansion of Metal Pipe

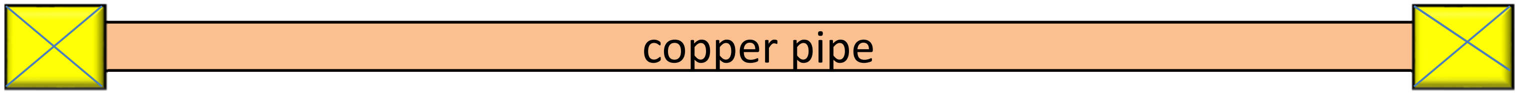
- Heating Water 40-200 Deg. F.
- 170 Foot Run Between Anchor Points



Carbon Steel Pipe=1.22” growth, per/100ft. TPG= 2.07”

Stainless Steel Pipe= 1.79” growth, per/100 ft. TPG=3.04”

+30% vs. CS



Copper Pipe=1.85” growth, per/100 ft. TPG=3.15”

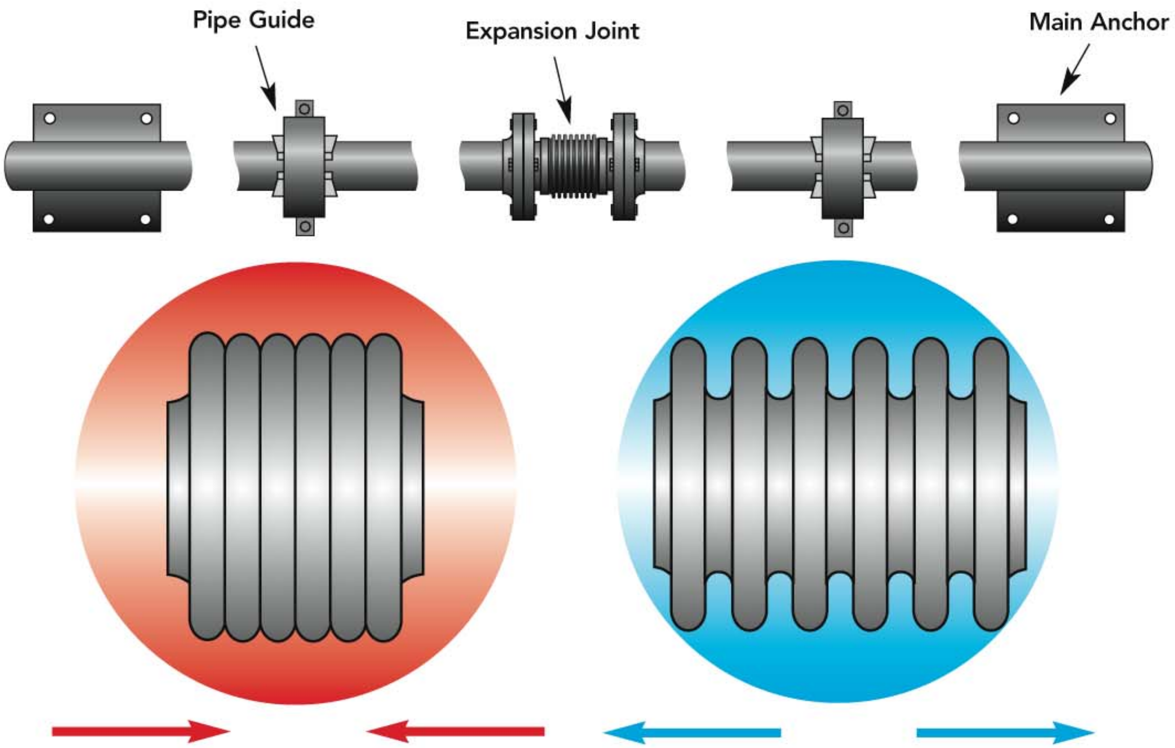
+35% vs. CS
+5%   vs. SS

Thermal Movement

All materials **expand** and **contract** due to temperature changes. In a piping or ducting system, these thermal changes can produce stress on the system at fixed points such as vessels and rotating equipment as well as the piping or duct work system itself.

Thermal changes are produced by the following:

- The temperature of the system when installed is different from operating temperature.
  For example: chilled water,
  100°F when installed,
  operates at 40°F
- The temperature cycle during operation
- The system is exposed to ambient temperature changes



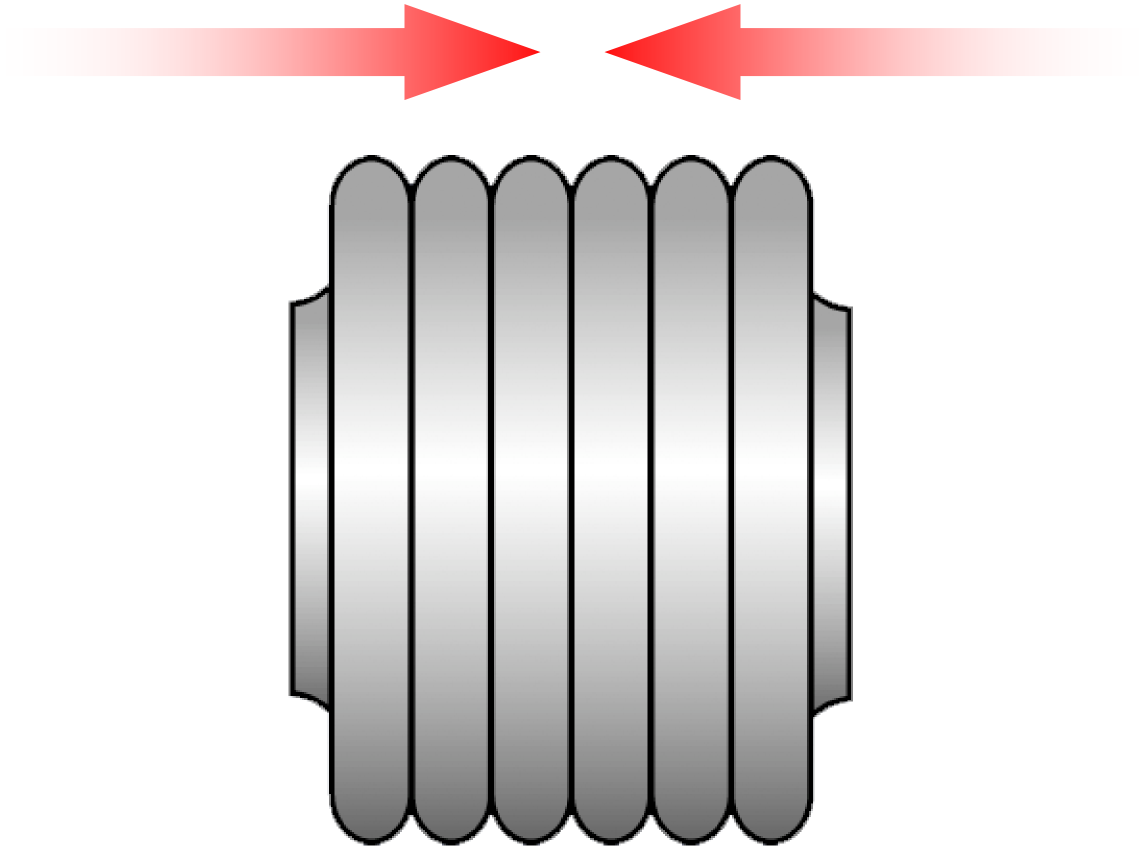
Axial compression: *Heat in a piping system causes the expansion joint to compress axially when piping system is properly anchored.*

Axial extension: *Cold in a piping system causes the expansion joint to extend axially when piping system is properly anchored.*

Note: 80/20 Rule: 80% motion compression/20% extension.
Example: Expansion joints rated for 3" total axial travel = 2.40 axial compression/.60 axial extension

Thermal Movement

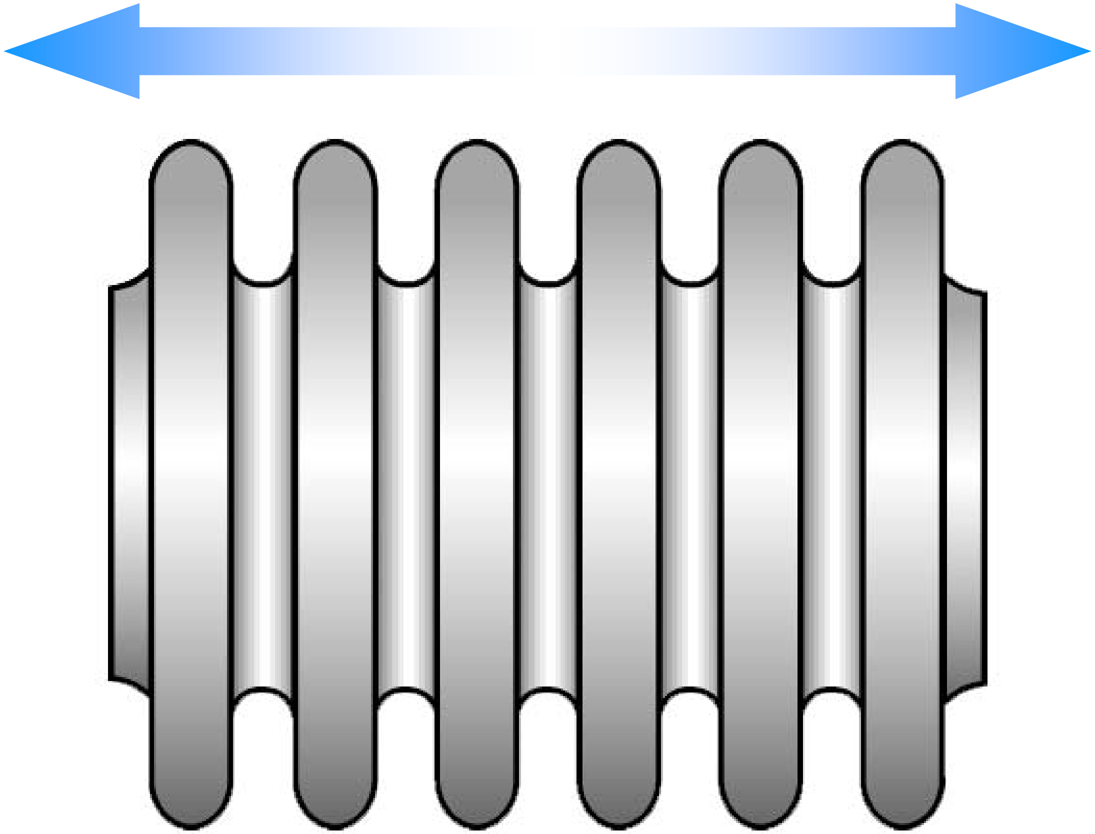
Axial compression



Heat in a piping system causes the expansion joint to compress axially when piping system is properly anchored.

Thermal Movement

Axial extension

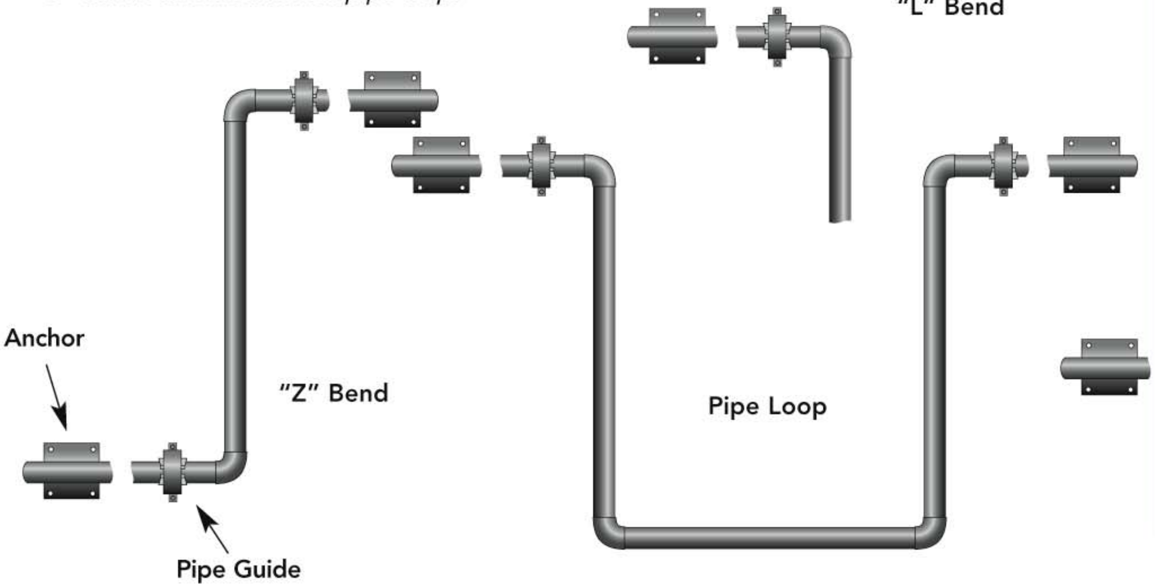


Cold in a piping system causes the expansion joint to extend axially when piping system is properly anchored.

Compensating for Thermal Movement

The basic methods of compensating for thermal movement in a piping system are:

- Design a flexible piping system which utilizes changes of direction to absorb movement *For example: "Z" bends, "L" bends and mechanical pipe loops*
- Design expansion devices, expansion joints or flexible loop technology



Why Expansion Joints?

- Flex-Hose can assist with product selection, layout & design
- Inline, compact design saves valuable space reducing welding & other labor costs
- Ability to handle large amounts of axial expansion with one device vs. multiple devices

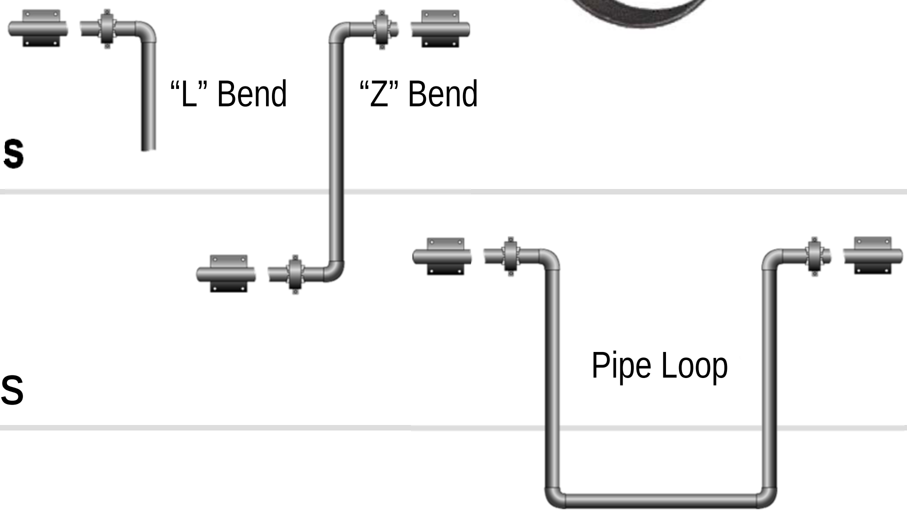
Pipe bends and loops:

- Proper design requires accurate calculations for contraction, expansion & anchor loads
- Requires minimum lengths of offsets
- Pipe guides are essential
- May require more piping & labor costs
- May add to heat/friction lost & operating cost
- Require large space to install & may need multiple locations.

How to Control Thermal Expansion

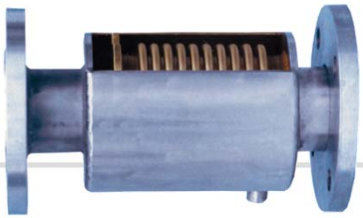
☒ Free Floating Pipe

☒ Pipe Bends



☒ Pipe Loops

☒ Externally Pressurized Expansion Joints

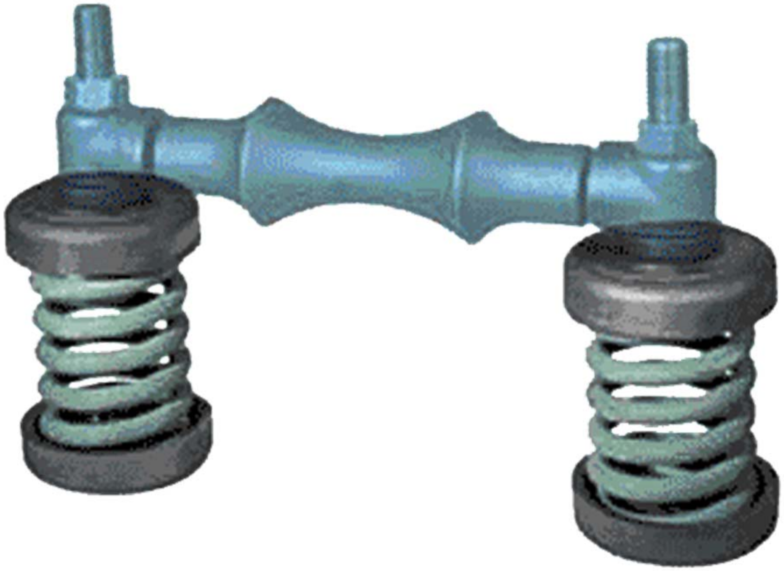


☒ Metal Bellows type Expansion Joints

How to Control Thermal Expansion

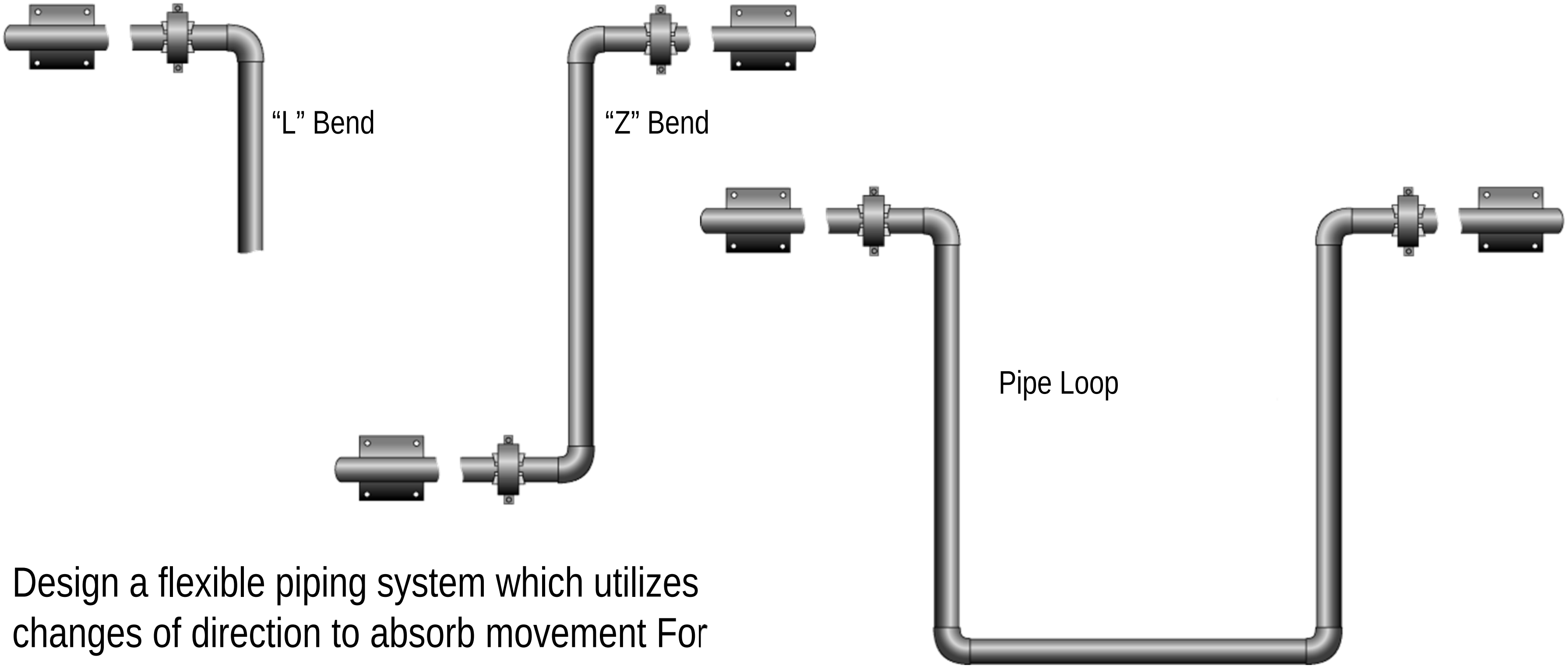
Free Floating Pipe

Clevis Hanger



Spring cushion
hanger with roller

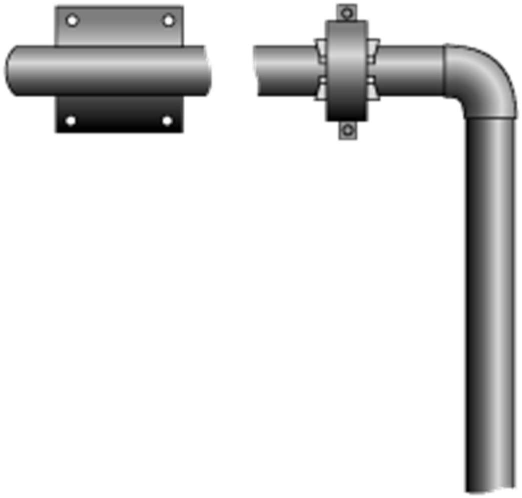
Pipe Bends and Pipe Loops



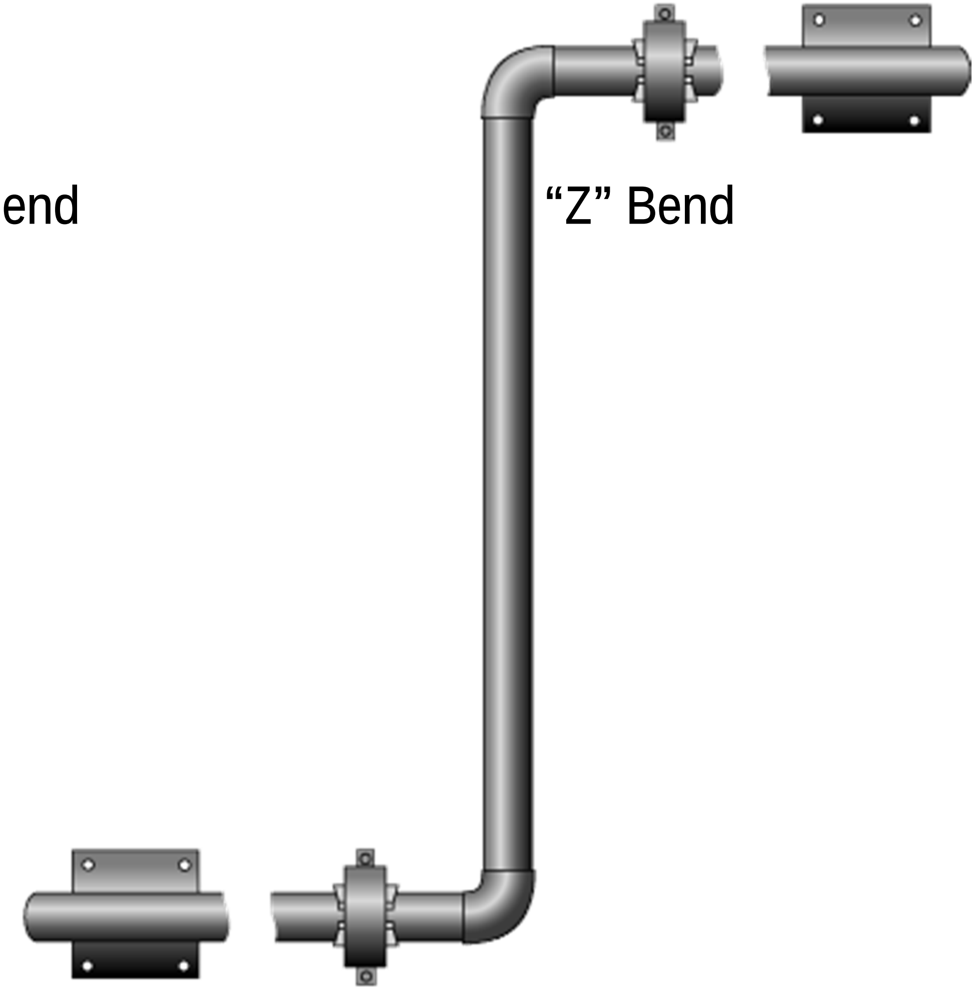
Design a flexible piping system which utilizes changes of direction to absorb movement For example: “Z” bends, “L” bends and mechanical pipe loops

Design expansion devices, expansion joints

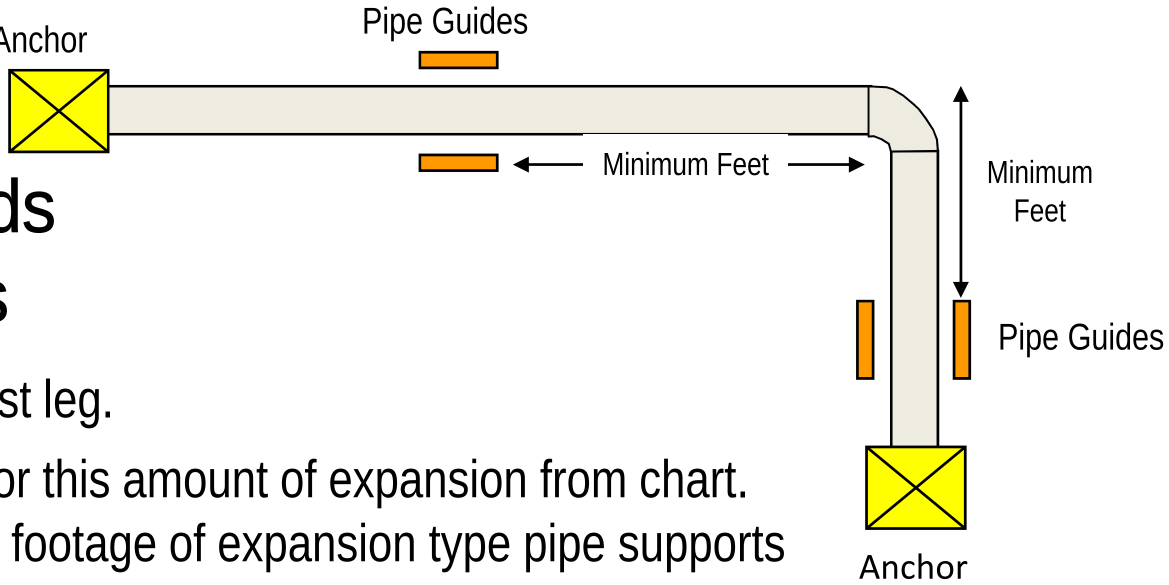
Pipe Bends



“L” Bend



“Z” Bend

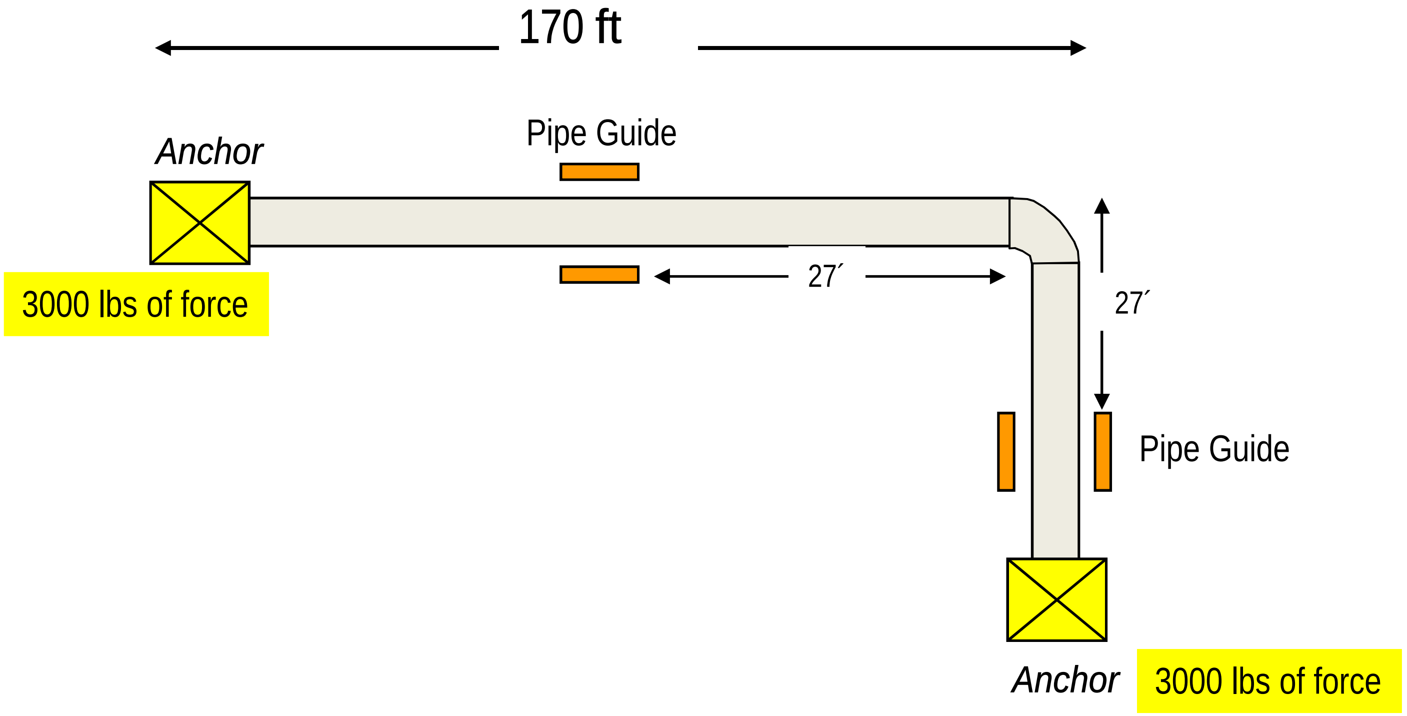


Designing “L” Bends or 90° Pipe Bends

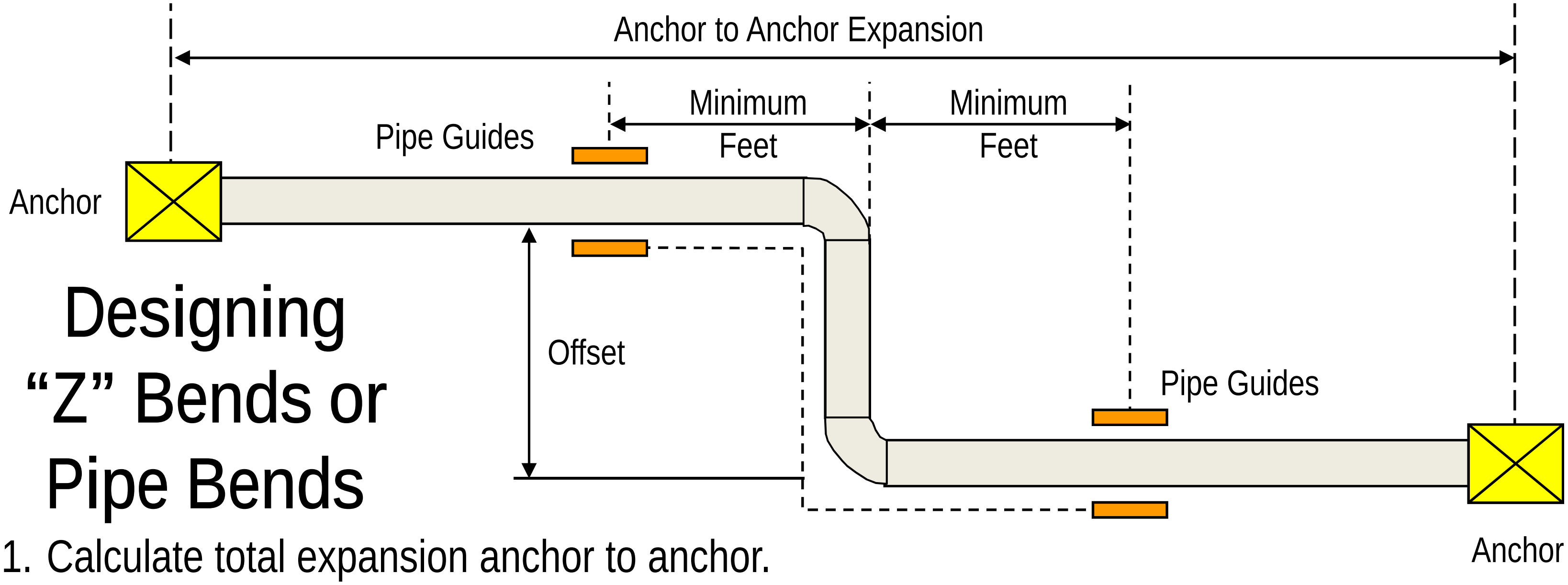
1. Calculate expansion of longest leg.
2. Find minimum feet required for this amount of expansion from chart. This represents the minimum footage of expansion type pipe supports required EACH side of elbow.

Note: Per 2000 ASHRAE Systems and Equipment Handbook page 41.11 a conservative estimate of force (Anchor Loads) is 500 lb per diameter inch.

Pipe Size	Expansion of Longest Leg								
	1″	1½″	2″	2½″	3″	3½″	4″	4½″	5″
2½″	9′	12′	14′	16′	17′	18′	19′	21′	22′
3″	10′	13′	15′	17′	18′	19′	20′	22′	23′
4″	11′	14′	16′	18′	19′	22′	22′	24′	25′
5″	12′	15′	17′	19′	21′	23′	25′	27′	28′
6″	13′	16′	19′	21′	23′	25′	27′	29′	31′
8″	18′	20′	22′	25′	27′	29′	31	33′	35′



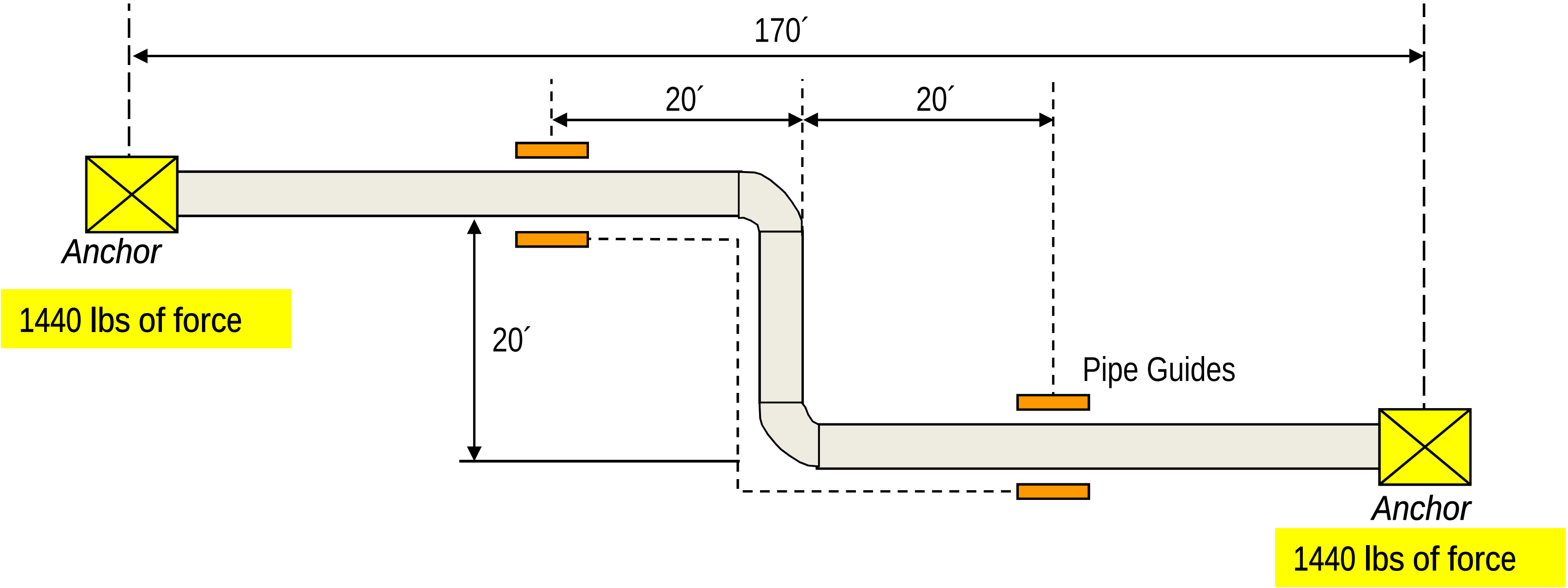
Per 2000 ASHRAE Systems and Equipment Handbook page 41.11
a conservative estimate of force (Anchor Loads)
is 500 lb per diameter inch.



Designing “Z” Bends or Pipe 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.

Pipe Size	Anchor to Anchor Expansion								
	1″	1½″	2″	2½″	3″	3½″	4″	4½″	5″
2½″	6′	8′	9′	10′	11′	12′	13′	14′	15′
3″	7′	9′	10′	12′	13′	14′	15′	16′	17′
4″	8′	10′	11′	13′	14′	16′	17′	18′	19′
5″	8′	10′	12′	14′	16′	17′	19′	20′	21′
6″	9′	11′	13′	15′	17′	19′	20′	22′	23′
8″	9′	12′	14′	17′	19′	20′	22′	24′	25′



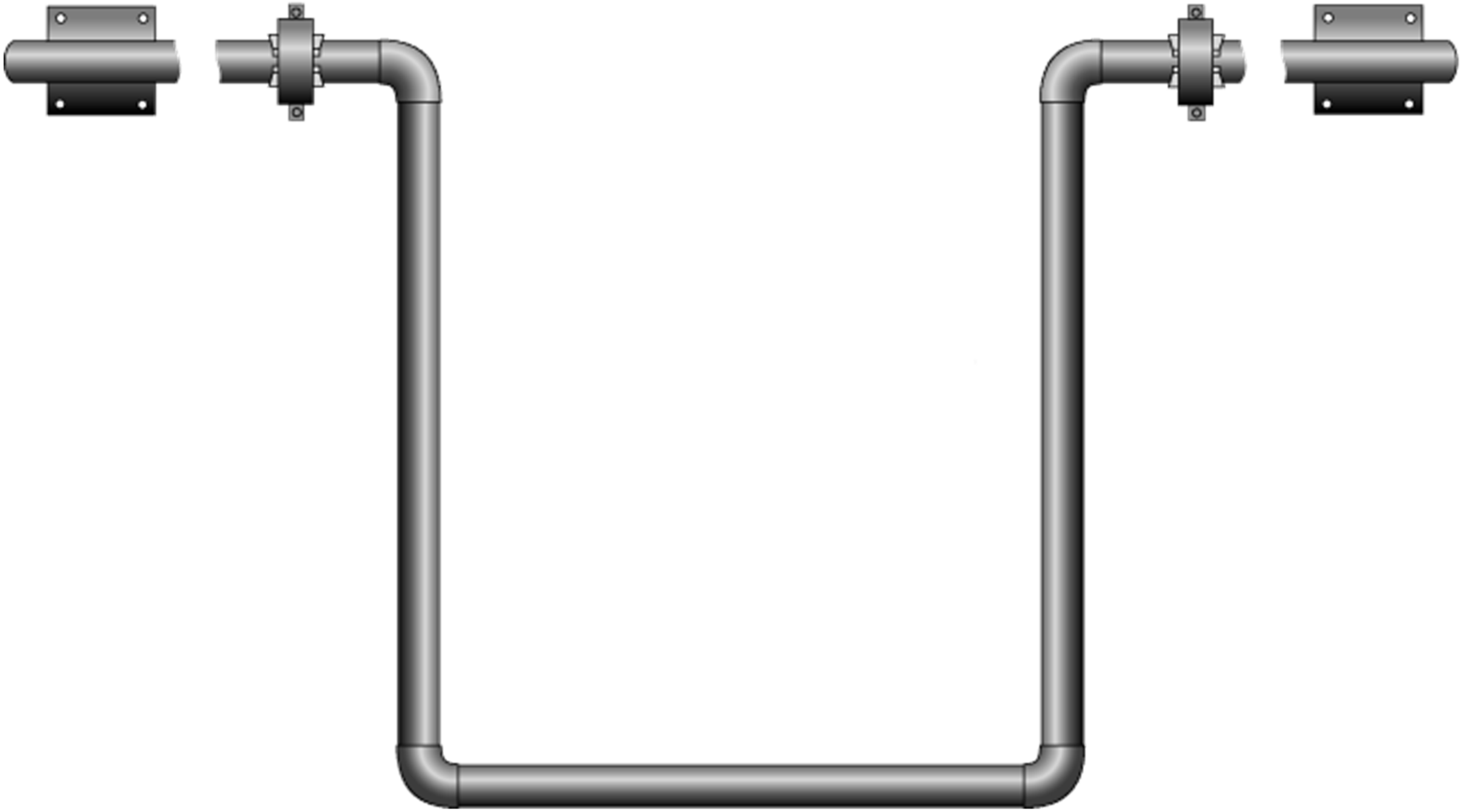
From 2000 ASHRAE Systems and Equipment Handbook, p 41.12, the force developed in a Z bend can be calculated with acceptable accuracy as follows:

$F = CE(D/L)^2$, where F is in lbs, C = 4000 lb/in, D = outside pipe diameter in inches,

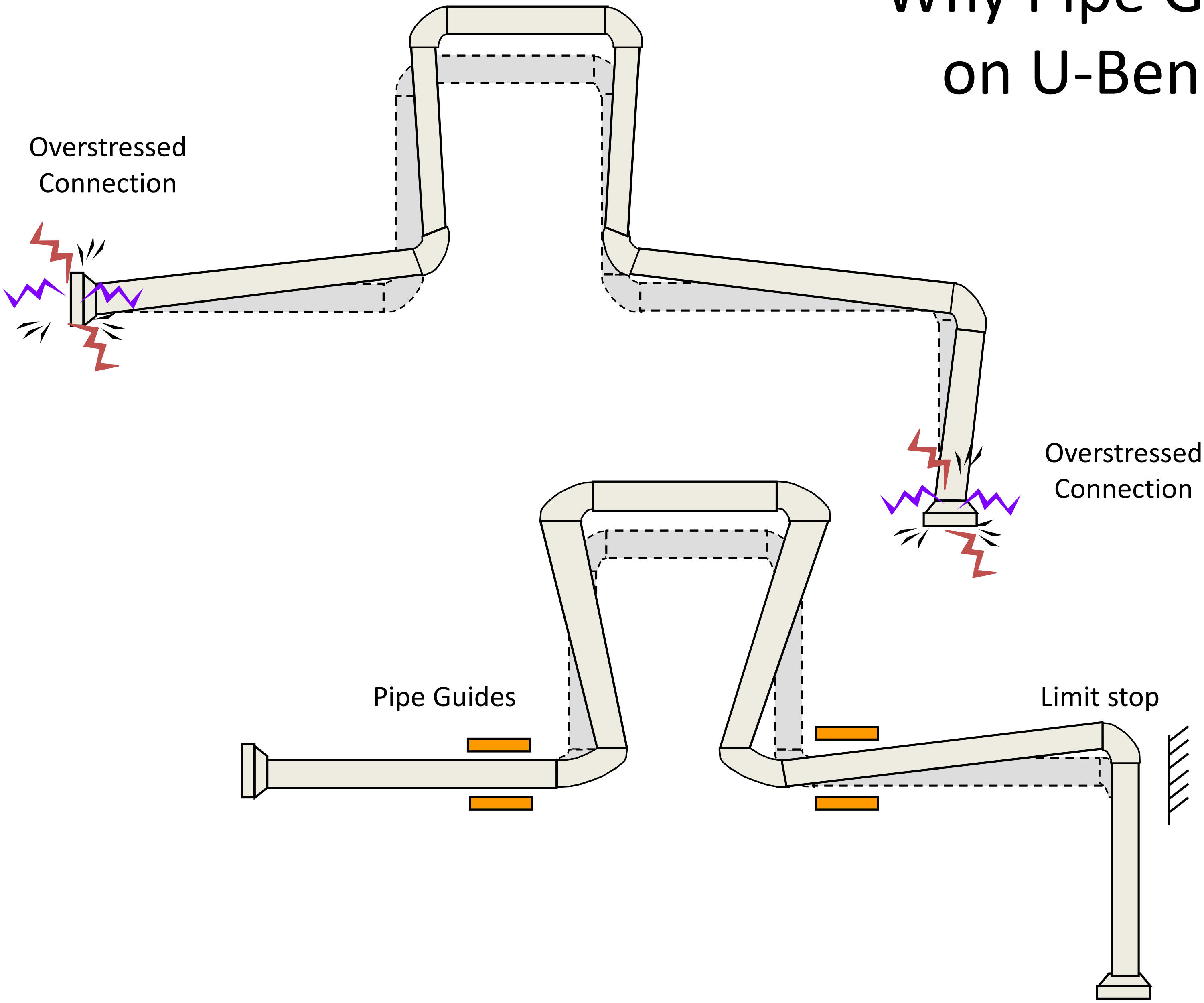
L = length of offset in ft, E = anchor to anchor expansion in inches.

$$F = CE(D/L)^2 = 4000(4)(6/20)^2 = 1440 \text{ lbs}$$

Pipe Loops



Why Pipe Guides on U-Bends?



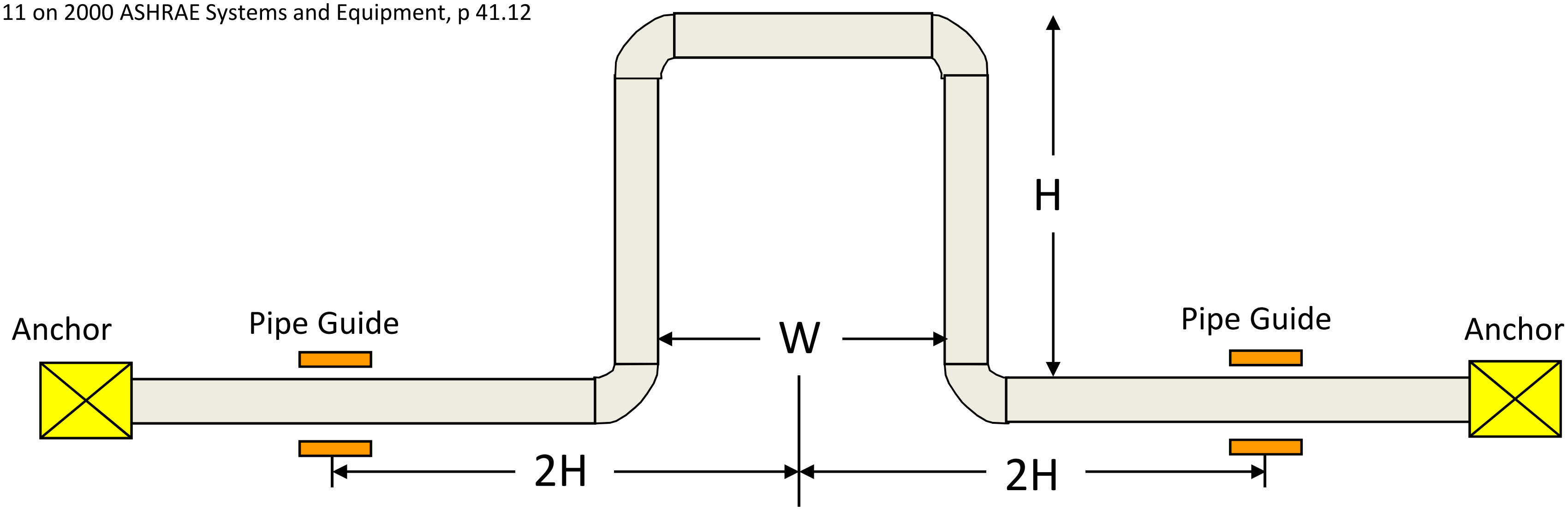
Overstressed Connection

Overstressed Connection

Pipe Guides

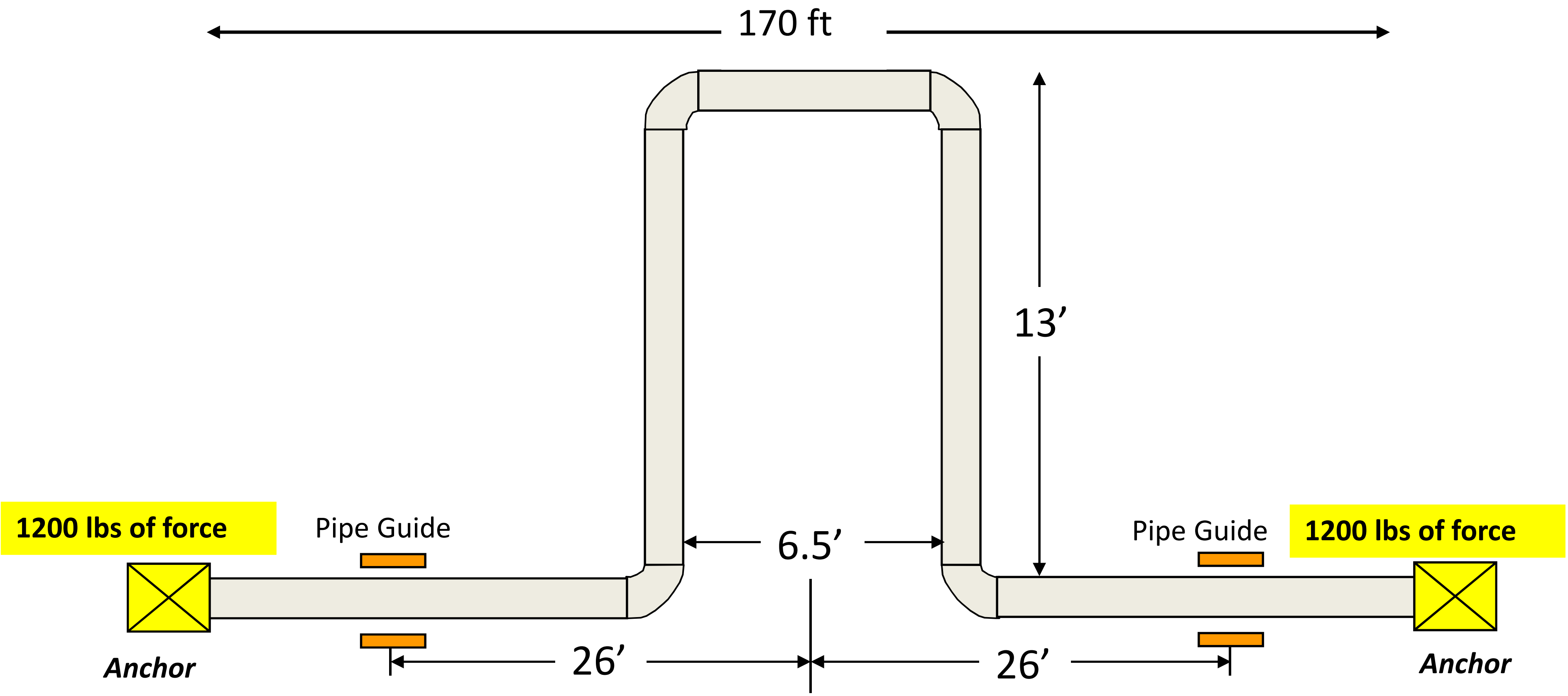
Limit stop

Table 11 on 2000 ASHRAE Systems and Equipment, p 41.12



	2 in. expansion		4 in. expansion		6 in. expansion	
Pipe Size	**W**	**H**	**W**	**H**	**W**	**H**
1	**2**	**4**	**3**	**6**	**3.5**	**7**
2	**3**	**6**	**4**	**8**	**5**	**10**
3	**3.5**	**7**	**5**	**10**	**6**	**12**
4	**4**	**8**	**5.5**	**11**	**6.5**	**13**
6	**5**	**10**	**6.5**	**13**	**8**	**16**
8	**5.5**	**11**	**7.5**	**15**	**9**	**18**

Pipe Expansion Example

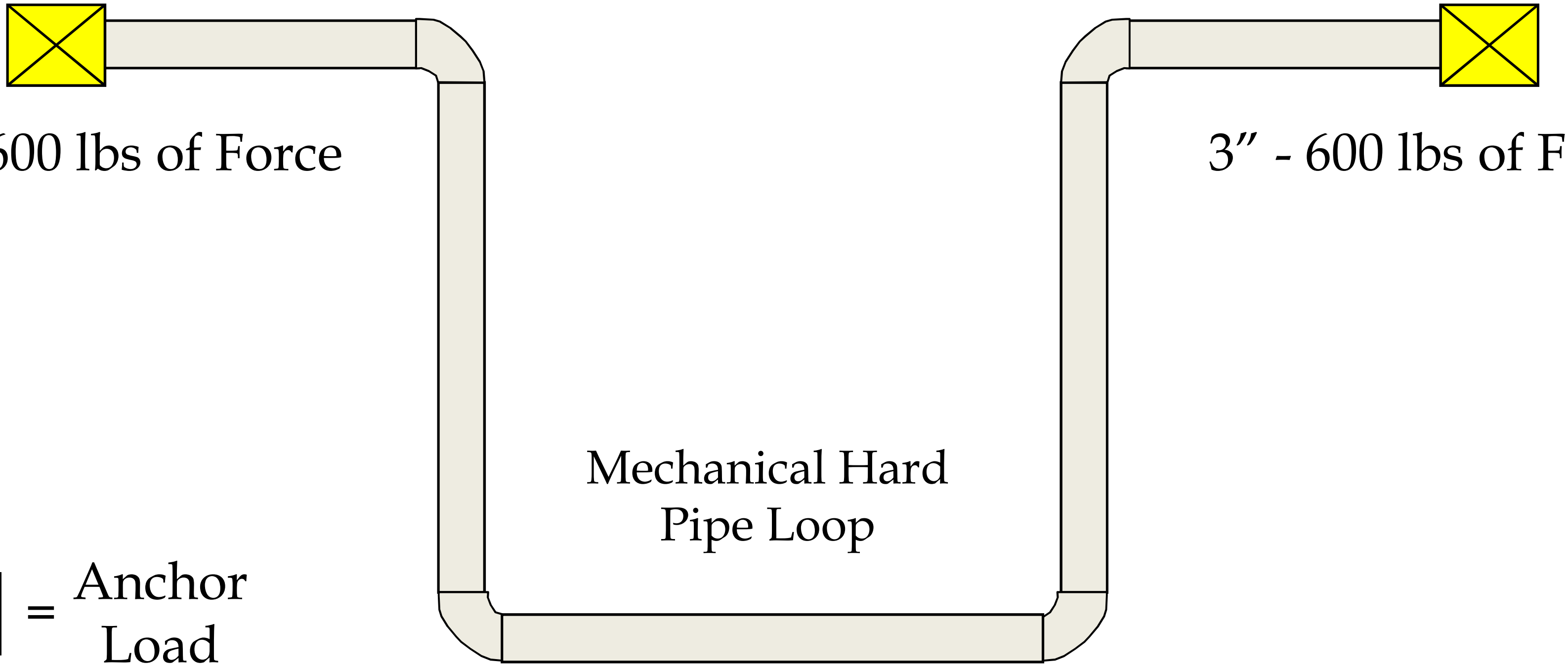


“A conservative estimate of pipe loop force is 200 lb per diameter inch.”

-- 2000 ASHRAE Systems and Equipment Handbook page 41.12

Typical Thrust Loads

3″ Pipe Loop	4″ Axial Compression	600 lbs of Force
6″ Pipe Loop	4″ Axial Compression	1200 lbs of Force



6″ - 1200 lbs of Force

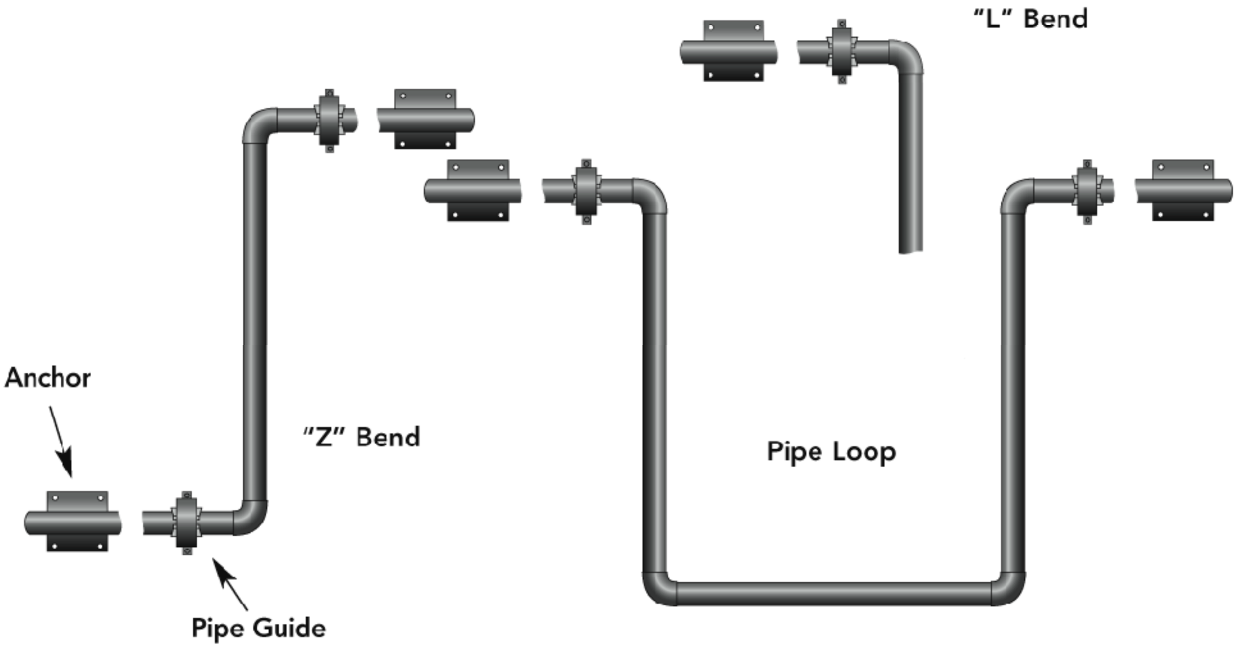
3″ - 600 lbs of Force

6″ - 1200 lbs of Force

3″ - 600 lbs of Force

Mechanical Hard Pipe Loop

☒ = Anchor Load



Pipe bends and loops:

- Proper design requires accurate calculations for contraction, expansion & anchor loads
- Requires minimum lengths of offsets
- Pipe guides are essential
- May require more piping & labor costs
- May add to heat/friction lost & operating cost
- Require large space to install & may need multiple locations.

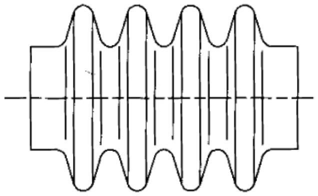
Why Expansion Joints?

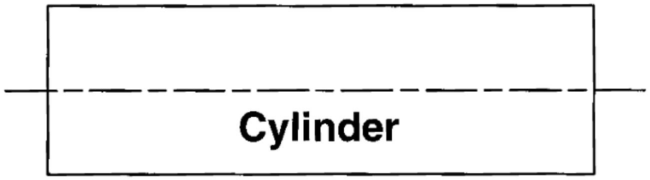
- Flex-Hose can assist with product selection, layout & design
- Inline, compact design saves valuable space reducing welding & other labor costs
- Ability to handle large amounts of axial expansion with one device vs. multiple devices

Basic Principles: Bellows Anatomy

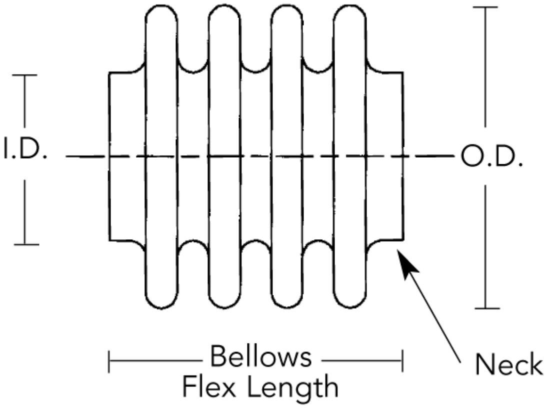
- Bellows formed from a metal cylinder in two steps
- Bellows length approximately one-third the length of original cylinder

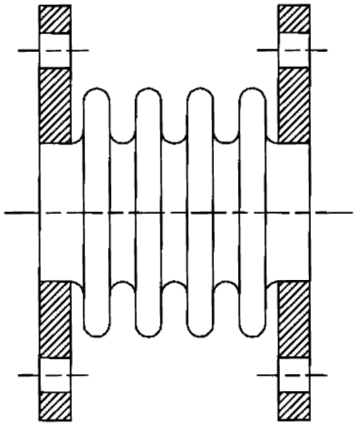
Step 1





Step 2





- Adding flanges completes assembly of the single bellows expansion joint

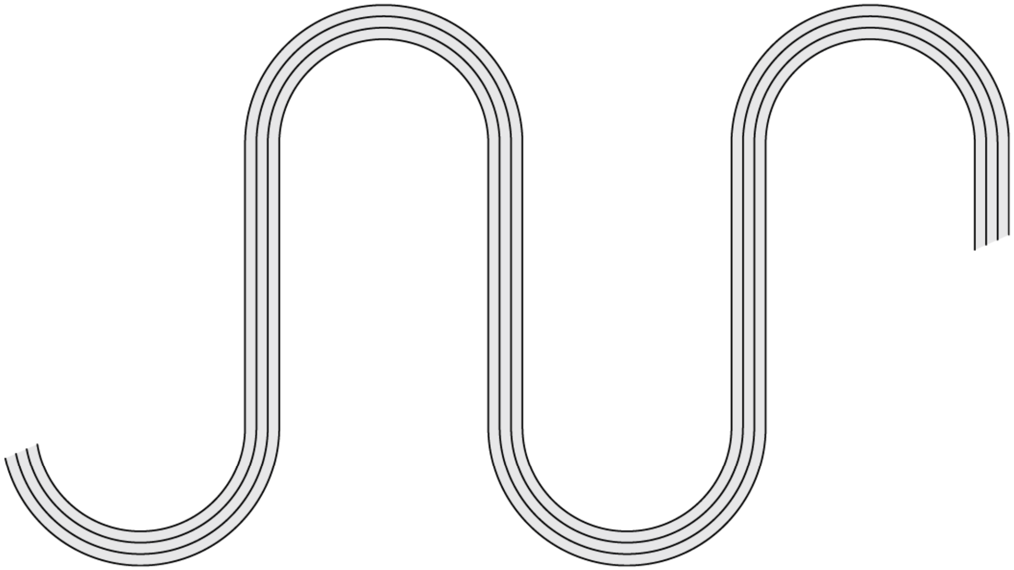
Single Ply vs. Laminated Bellows

Single Ply

Pipe Size = 6.0″
Corrugation Depth = 0.6″
Corrugation Pitch = 0.63″
Material Thickness = .036″

Laminated

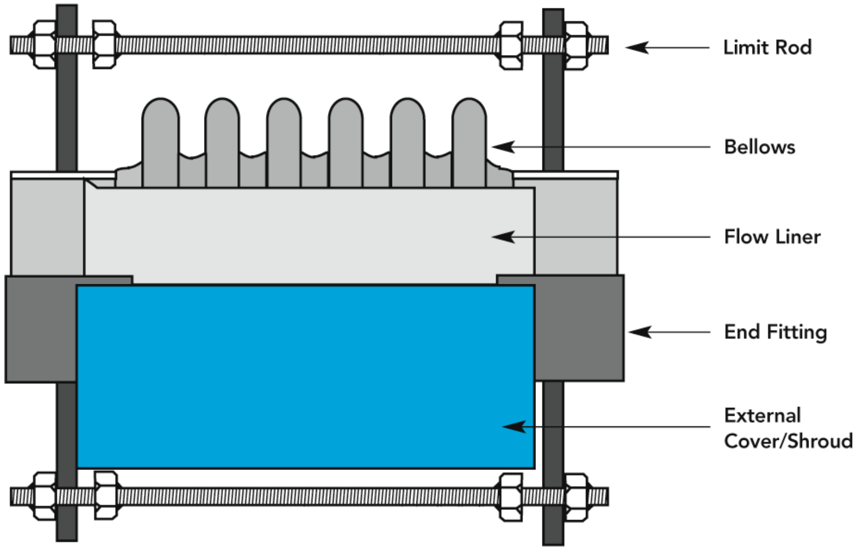
Pipe Size = 6.0″
Corrugation Depth = 0.6″
Corrugation Pitch = 0.63″
Material Thickness
is 3 plys of .11″ = .036″



Laminated of multi-ply bellows for maximum flexibility and endurance

The reduced thickness of the laminations results in lower bending stresses due to axial motion increasing the life of the bellows

Bellows Design Basics



Flex-Hose Co. metal expansion joints are designed for a wide range of service conditions. They consist of a flexible bellows element, appropriate endfittings to match adjoining pipe fittings and schedule. The bellows is a flexible seal design to contain the media, absorb thermal movement, and pressures of the system.

The bellows are manufactured from thin-walled tubing to form a corrugated cylinder. The corrugations are commonly referred to as convolutions and add the structure necessary for the bellow material to contain system pressure.

The bellows design incorporates the thickness and convolution geometry that meets the capacity of the adjoining pipe to contain system pressure at the specified design temperature.

Flexibility of the bellows is acheived through the convolution profile and pitch as multiple convolutions are required to provide the expected expansion and contraction of the piping system.

Accessories

Covers

Expansion joints require careful handling and must be protected from any impact,weld spatter, etc. Before insulating anexpansion joint, care must be taken that foreign material is not trapped in the corrugations impeding its movements. It is suitable to install a metal cover overthe flanges and then wrap the insulation around it.

Flow Liners

Flow liners are installed in the inlet bore of the expansion joint to protect the bellows from erosion damage due to abrasive media or resonant vibration caused by turbulent flow or excessive velocities.

Tie Rods

Tie Rods are devices with the primaryfunction to restrain the bellows pressure thrust. It should be pointed out that when tie rods are furnished on expansion joints subject to external axial movement, they will only restrain the pressure thrust in the event of an anchor failure. During normal operation the anchor or adjacent equipment will be subjected to the pressure thrust forces.

Limit Rods

Limit Rods are devices with the primary function of restricting the bellows movementrange. The limit rods are designed to prevent bellows over-extension or over-compression while restraining the full pressure thrust inthe event of a main anchor failure.

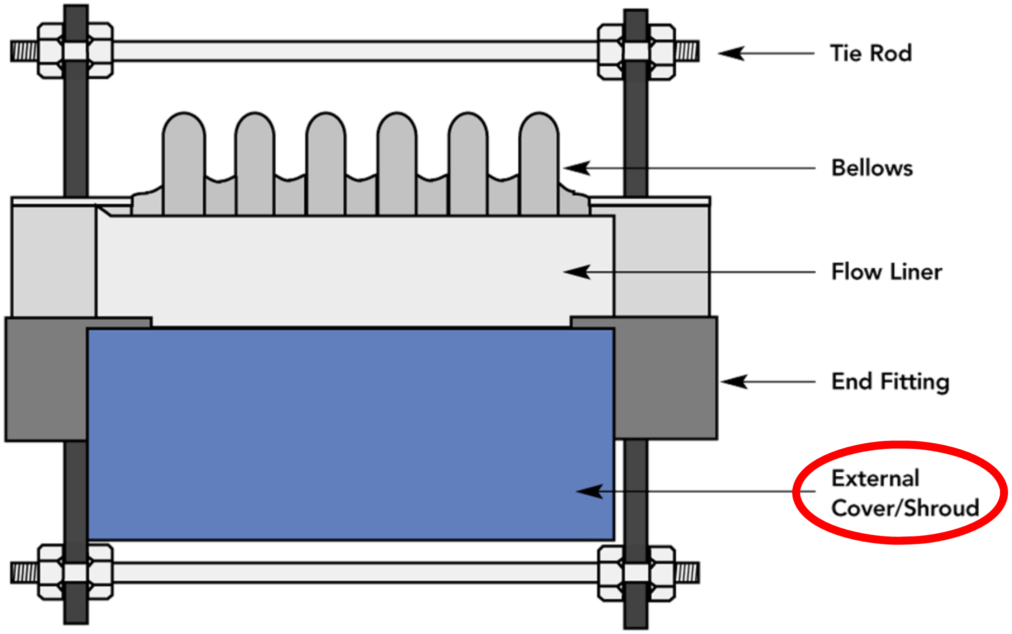
Control Rods

Control Rods are devices attached to the expansion joint with the primary function of distributing movement between the two bellows of a universal joint. Control rods are not designed to restrain bellows pressure thrust.

Accessories

Covers Flow Liners Tie Rods Limit Rods Control Rods

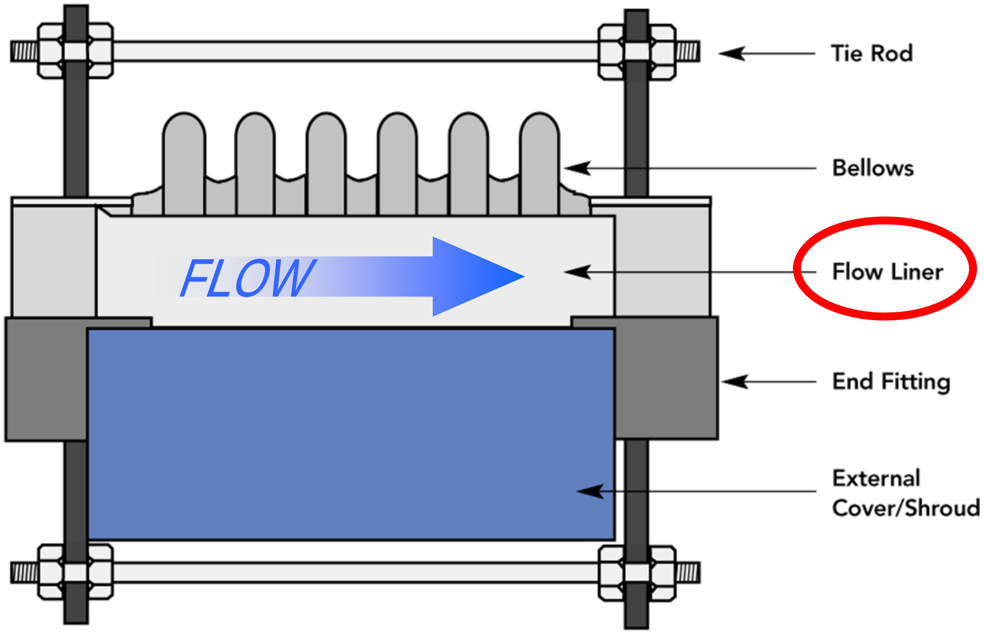
Expansion joints require careful handling and must be protected from any impact, weld spatter, etc. Before insulating an expansion joint, care must be taken that foreign material is not trapped in the corrugations impeding its movements. It is suitable to install a metal cover over the flanges and then wrap the insulation around it.



Accessories

Covers Flow Liners Tie Rods Limit Rods Control Rods

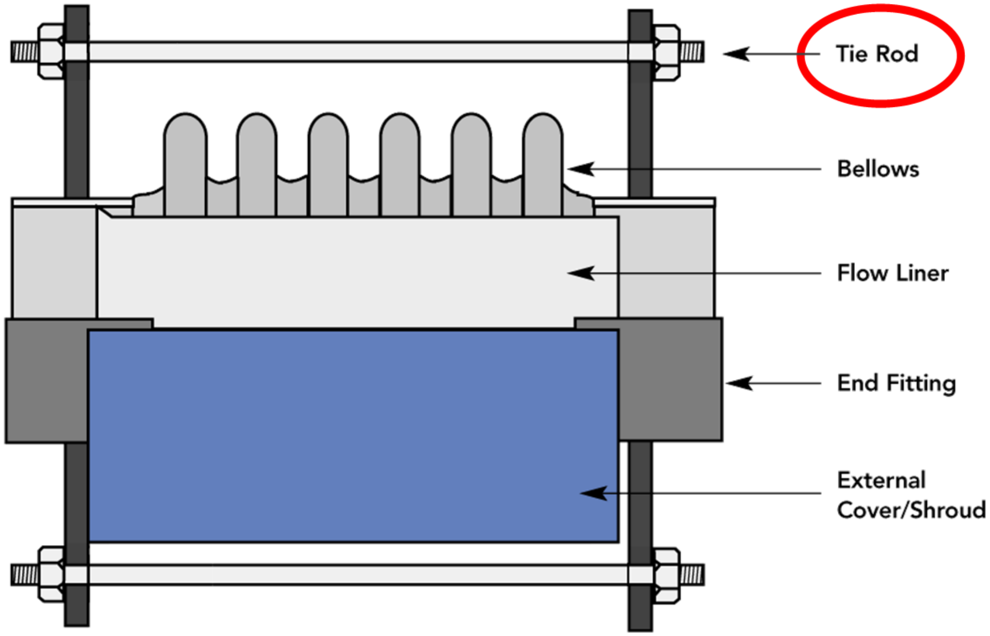
Flow liners are installed in the inlet bore of the expansion joint to protect the bellows from erosion damage due to abrasive media or resonant vibration caused by turbulent flow or excessive velocities.



Accessories

Covers Flow Liners Tie Rods Limit Rods Control Rods

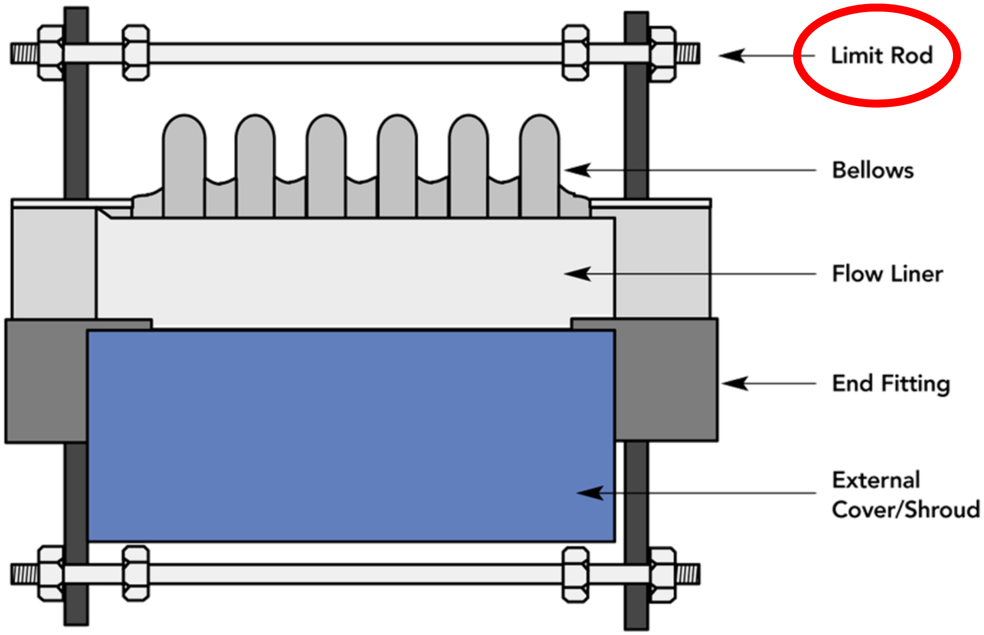
Tie Rods are devices with the primary function to restrain the bellows pressure thrust. It should be pointed out that when tie rods are furnished on expansion joints subject to external axial movement, they will only restrain the pressure thrust in the event of an anchor failure. During normal operation the anchor or adjacent equipment will be subjected to the pressure thrust forces.



Accessories

Covers Flow Liners Tie Rods Limit Rods Control Rods

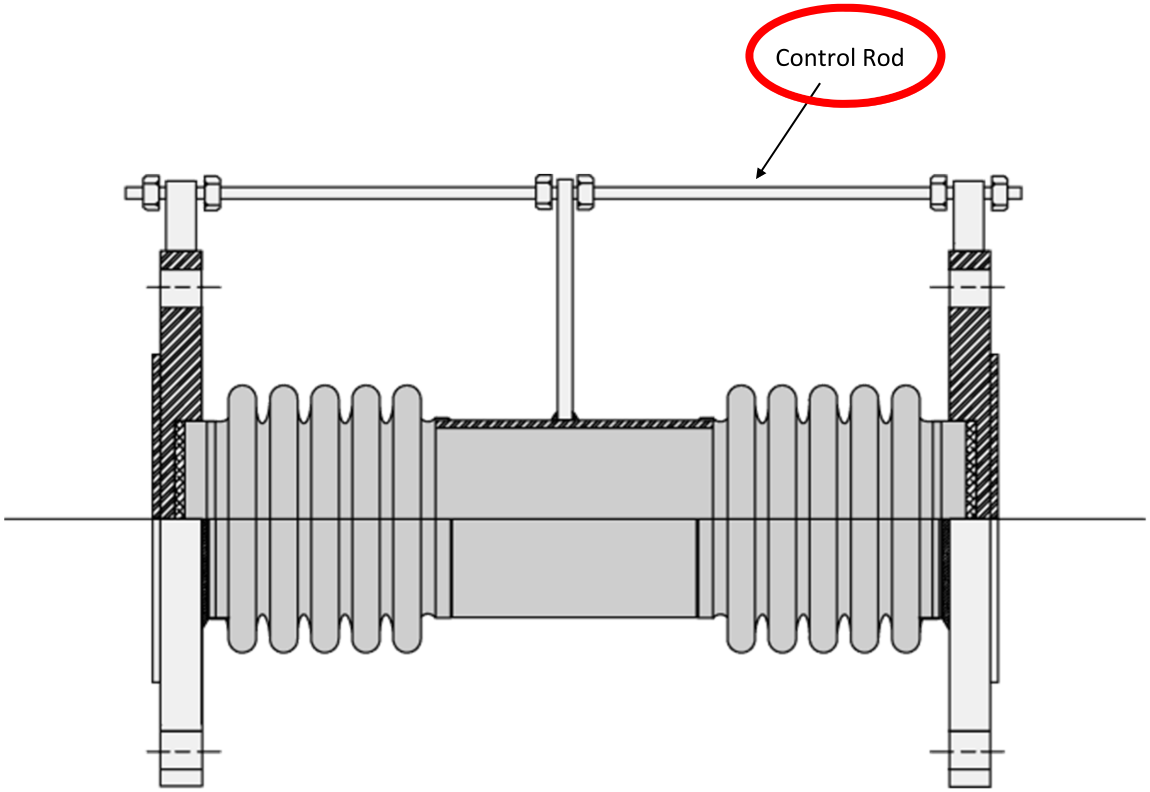
Limit Rods are devices with the primary function of restricting the bellows movement range. The limit rods are designed to prevent bellows over-extension or over-compression while restraining the full pressure thrust in the event of a main anchor failure.



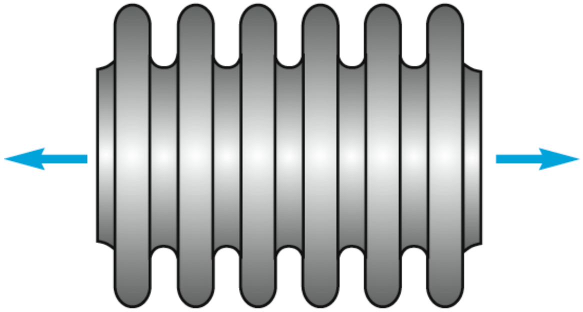
Accessories

Covers Flow Liners Tie Rods Limit Rods Control Rods

Control Rods are devices attached to the expansion joint with the primary function of distributing movement between the two bellows of a universal joint. Control rods are not designed to restrain bellows pressure thrust.

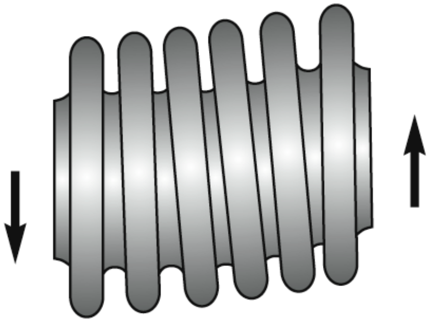


Expansion Joint Movement Capabilities



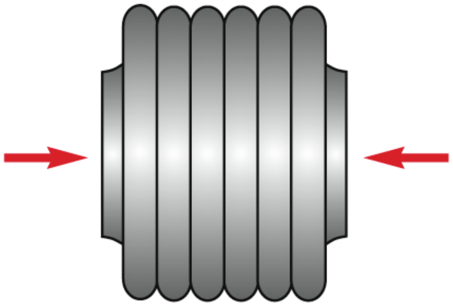
Axial Extension

Extension of the bellows length due to pipe contraction when piping system is anchored properly.



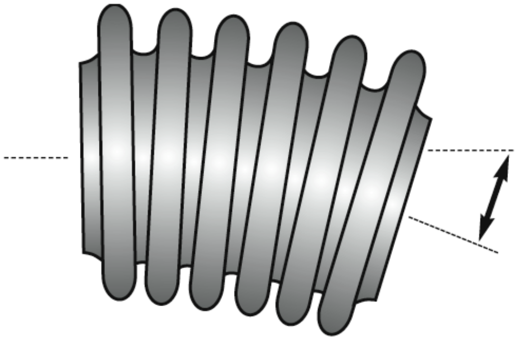
Lateral Offset

Motion which is perpendicular to the plane of the pipe with the expansion joint fittings remaining parallel.



Axial Compression

Compression of the bellows length due to pipe expansion when piping system is anchored properly.



Angular Rotation

Bending about the longitudinal centerline of the expansion joint.

Installation Misalignment

Misalignment of the expansion joint on installation reduces the total movement capacity of an expansion joint. Misalignment of the piping system should be corrected prior to installation of the expansion joint. If the misalignment can not be corrected, please contact Flex-Hose Co. for technical support.

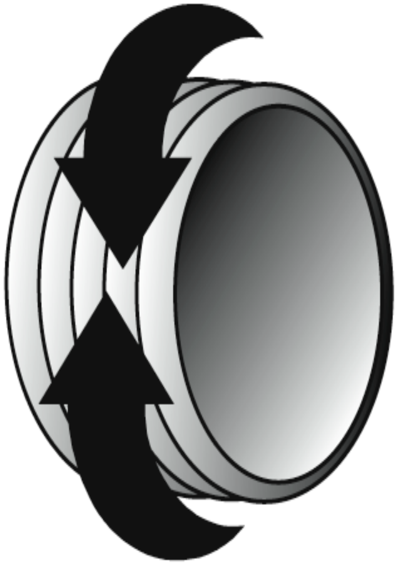
Concurrent Movements

Expansion joint movement capacity published in the catalog is maximum capacity for non-current movement. Axial, lateral, and angular movements can occur simultaneously, i.e. on reactor vessels or piping systems utilizing expansion joints at building/seismic interfaces. If your application involves concurrent motions it is essential that the movement capacity of the expansion joint be determined. The sum of these values may not exceed 100%.

Expansion Joint Movement Capabilities

WARNING

TORSION: Twisting about the longitudinal axis of a metal expansion joint will reduce bellows life or cause expansion joint failure and should be avoided. Expansion joints should not be located at any point in a piping system that would impose torque to the expansion joint device.



TORSION

Bending about the longitudinal centerline of the expansion joint

For example:

Expansion Joint design parameters

Non-concurrent

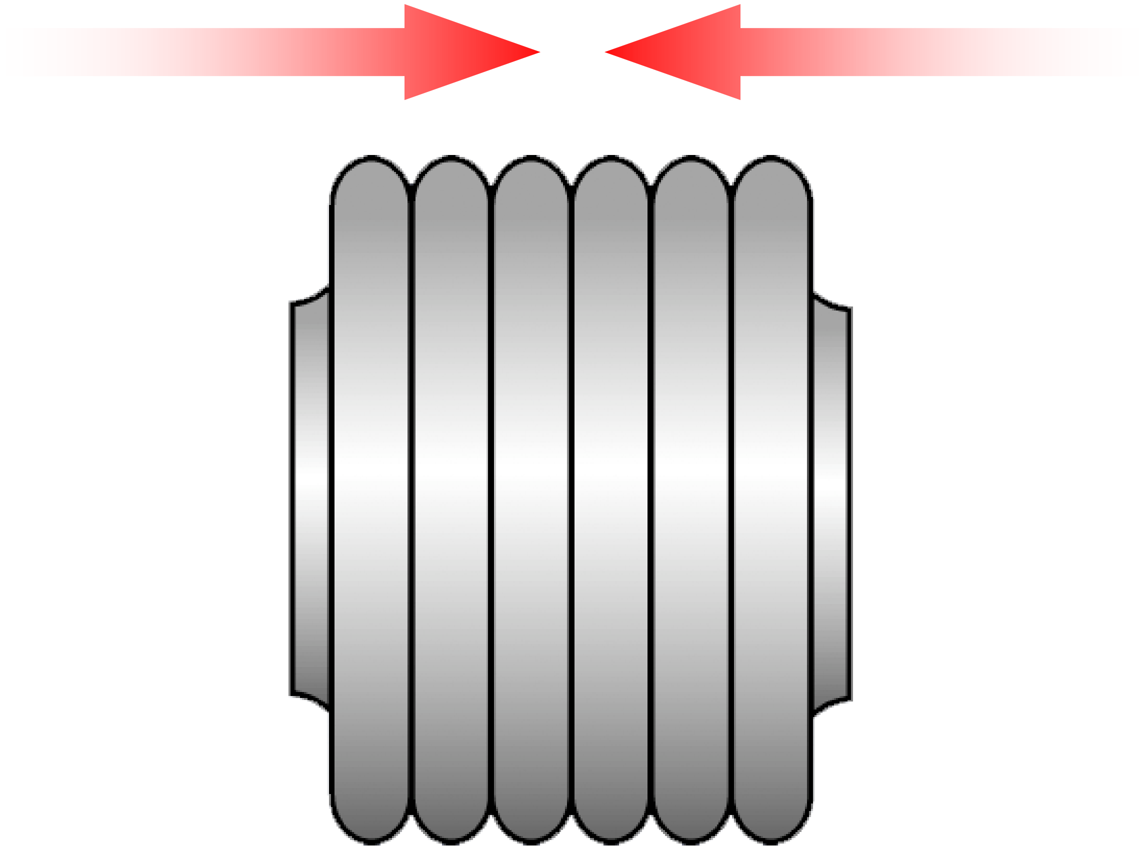
Axial	1.5″
Lateral	.50″
Angular	10°

Concurrent

Axial	**.75″**	**=**	**50%**
Lateral	**.125″**	**=**	**25%**
Angular	**2.5°**	**=**	**25%**
	TOTAL	**=**	**100%**

Thermal Movement

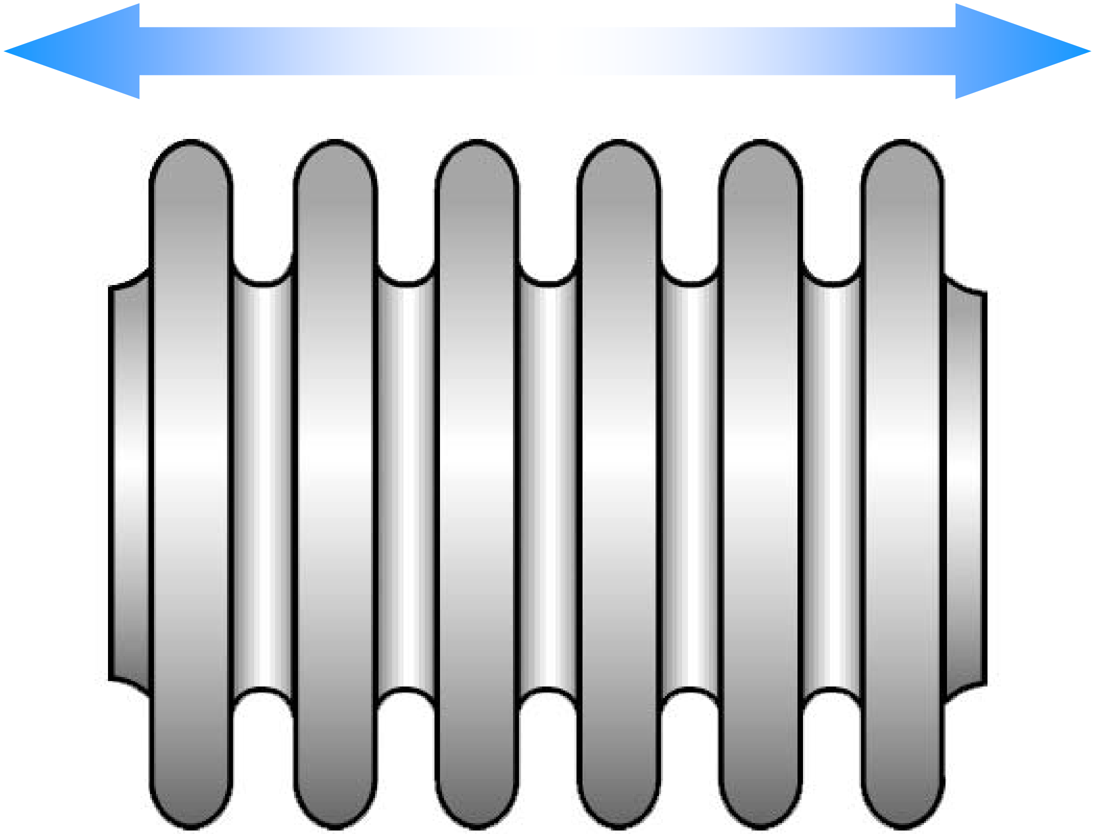
Axial compression



Heat in a piping system causes the expansion joint to compress axially when piping system is properly anchored.

Thermal Movement

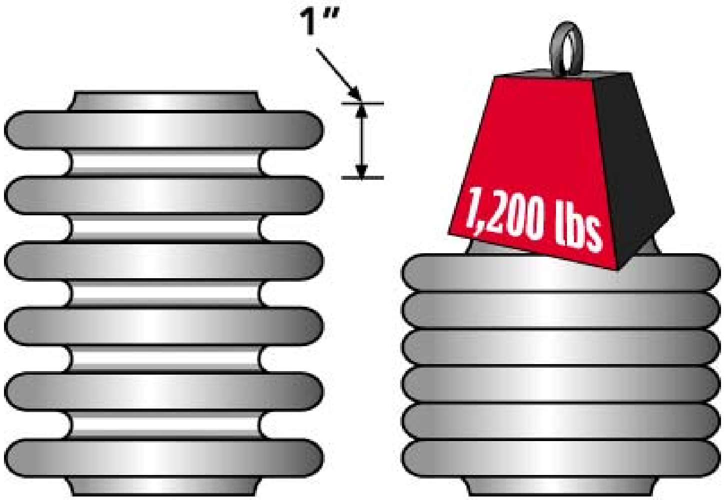
Axial extension



Cold in a piping system causes the expansion joint to extend axially when piping system is properly anchored.

Spring Rate

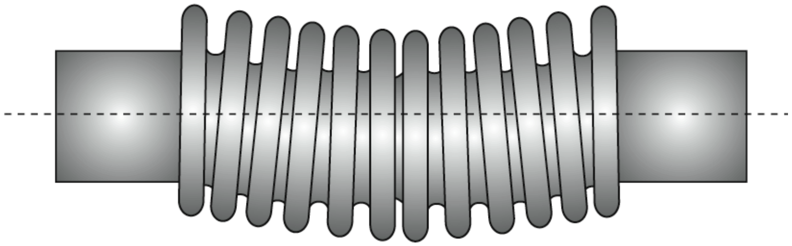
In very low pressure application the more significant force may be the spring rate (force to compress the bellows) which isexpressed in pounds per inch of motion. Thus, as the pipe grows due to increasing temperature, the bellows will resist compression by the force noted in the spring rate. A comparison of pressure and force data tospring rate will show that it does notrequire very much line pressure for pressurethrust to be the dominant factor of the twoin expansion joint applications.



Squirm

Convolutions can be added to increase movement without sacrificing cycle life, but there is a limit to this process which is reached when the bellows, under internal pressure, exhibits a condition known as squirm (bellows instability).

Externally pressurized bellows are not subject to this condition, as they become more stable under pressure. A bellows is a a flexible seal. This convoluted part of the expansion joint is designed to flex when thermal movement in the piping system occurs. Therefore, by determining the thermal movements that will occur in the piping system, expansion joints may be specified, manufactured, and installed in the system to accommodate these movements.

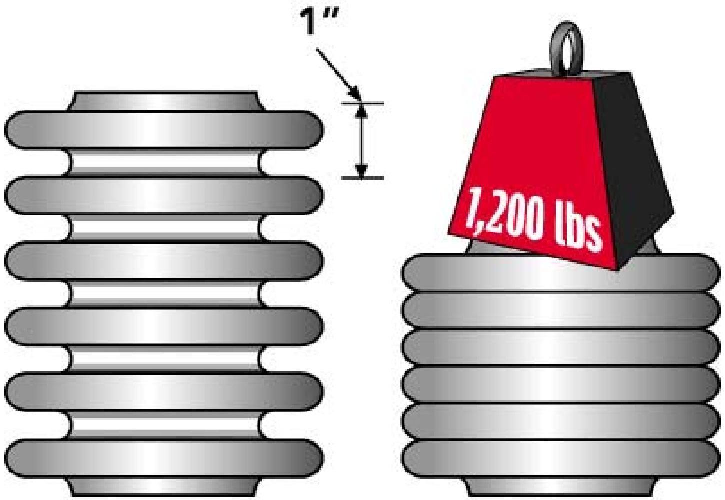


Squirm/Bellows Instability

Design Considerations

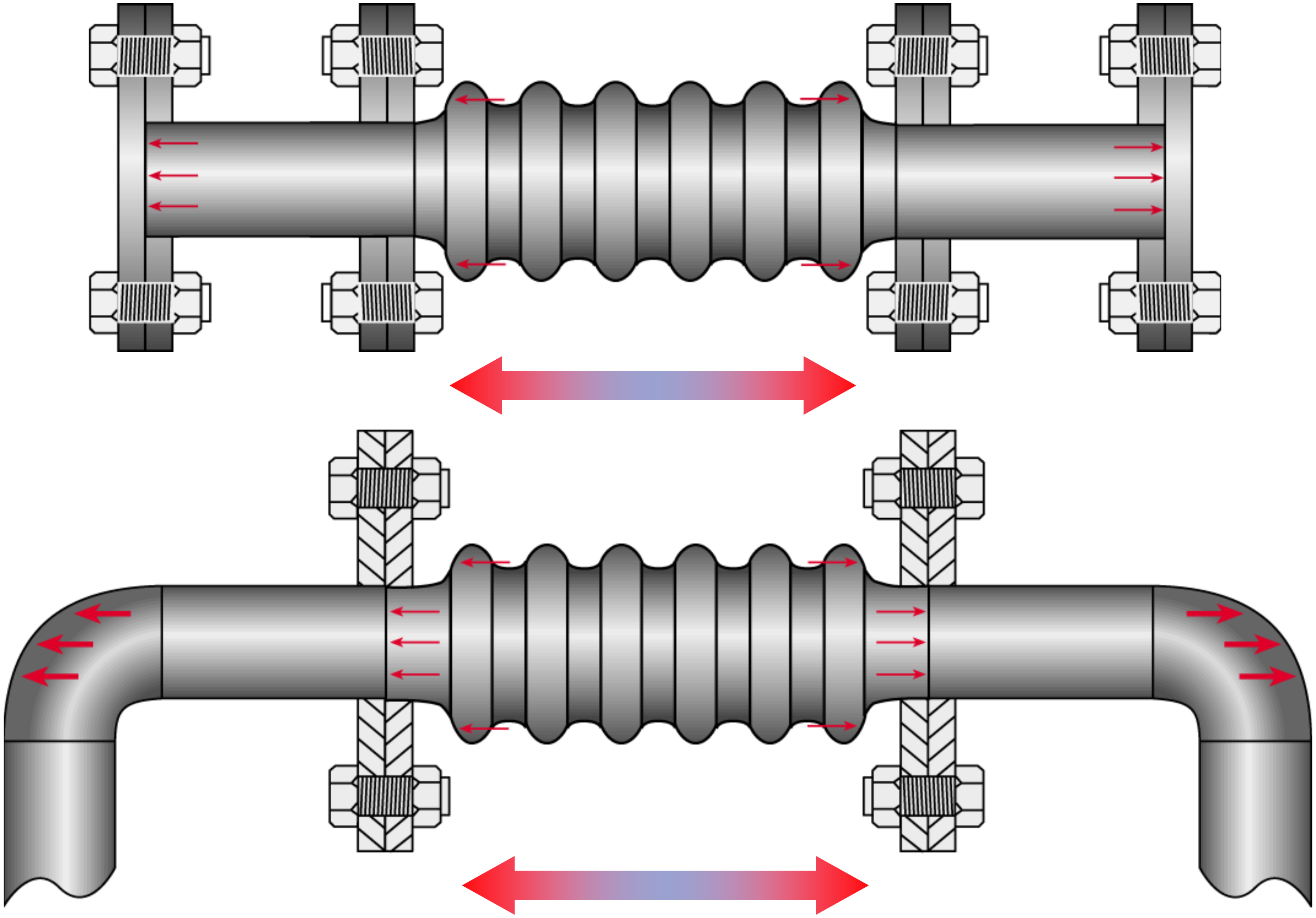
Spring Rate *Pressure Thrust* *Squirm* *Main Anchor*

In very low pressure application the more significant force may be the spring rate (force to compress the bellows) which is expressed in pounds per inch of motion. Thus, as the pipe grows due to increasing temperature, the bellows will resist compression by the force noted in the spring rate animation.

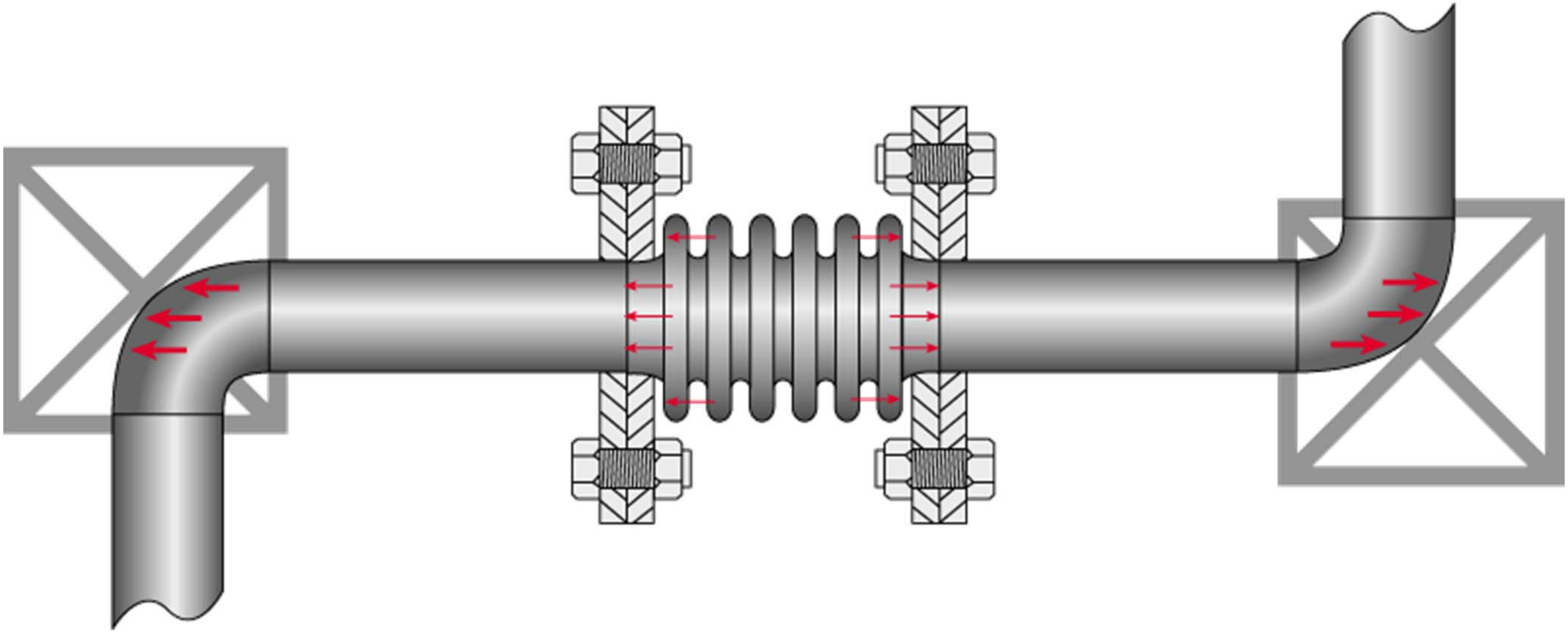


A comparison of pressure and force data to spring rate will show that it does not require very much line pressure for pressure thrust to be the dominant factor of the two in expansion joint applications.

Pressure thrust pushes the bellows apart at the end convolutions and pulls the bellows apart by pushing on the blind flanges.



The pressure thrust force acts the same way when pushing on the elbows where the pipe changes direction.

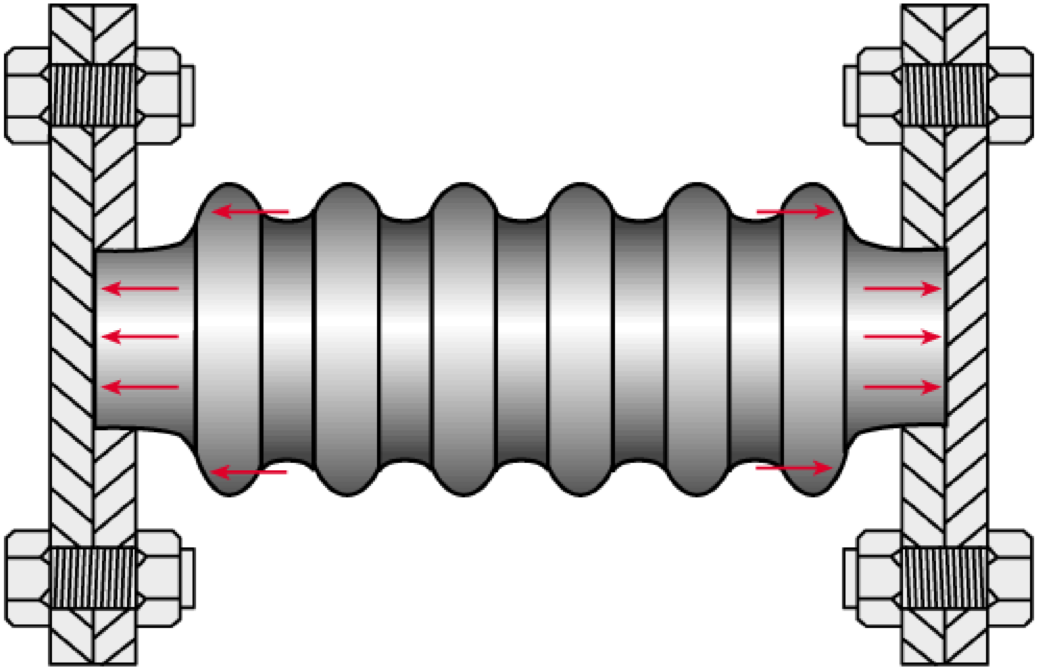


The pressure thrust force acts on the piping system as shown. The amount of force varies directly with pressure in the line. The pipe must be anchored to react to the pressure thrust force for the maximum test pressure.

Design Considerations

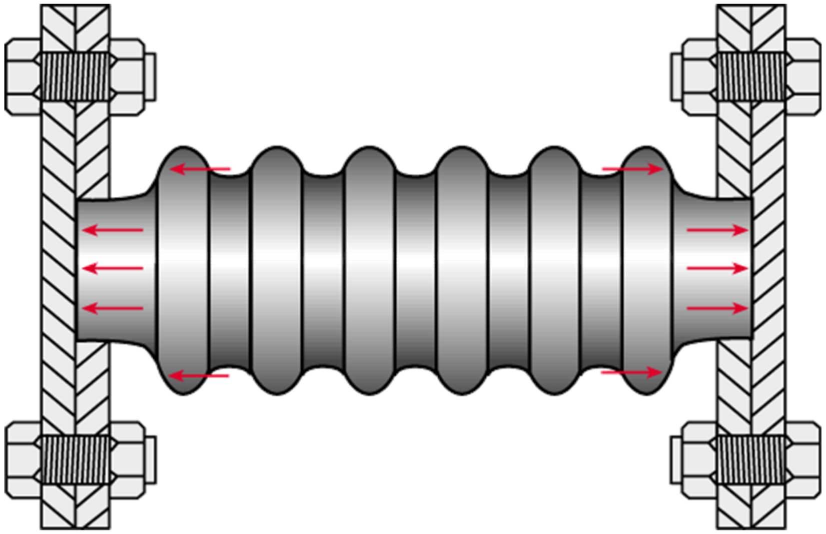
Spring Rate *Pressure Thrust* *Squirm* *Main Anchor*

The bellow’s very nature of being flexible (to absorb movement) will extend (straighten out) due to the line pressure, see example.

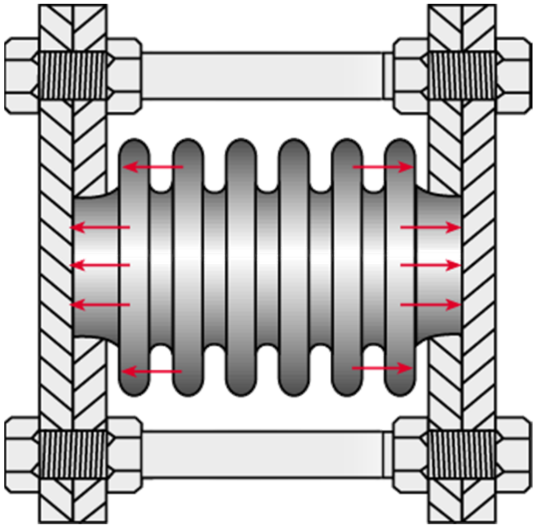


This pressure thrust must then be absorbed by some means or the line pressure will cause the bellows to over extend and tear itself apart. This force may be accommodated by anchoring the pipe or by using an expansion joint which incorporates tie rods or limit rods.

PRESSURE THRUST



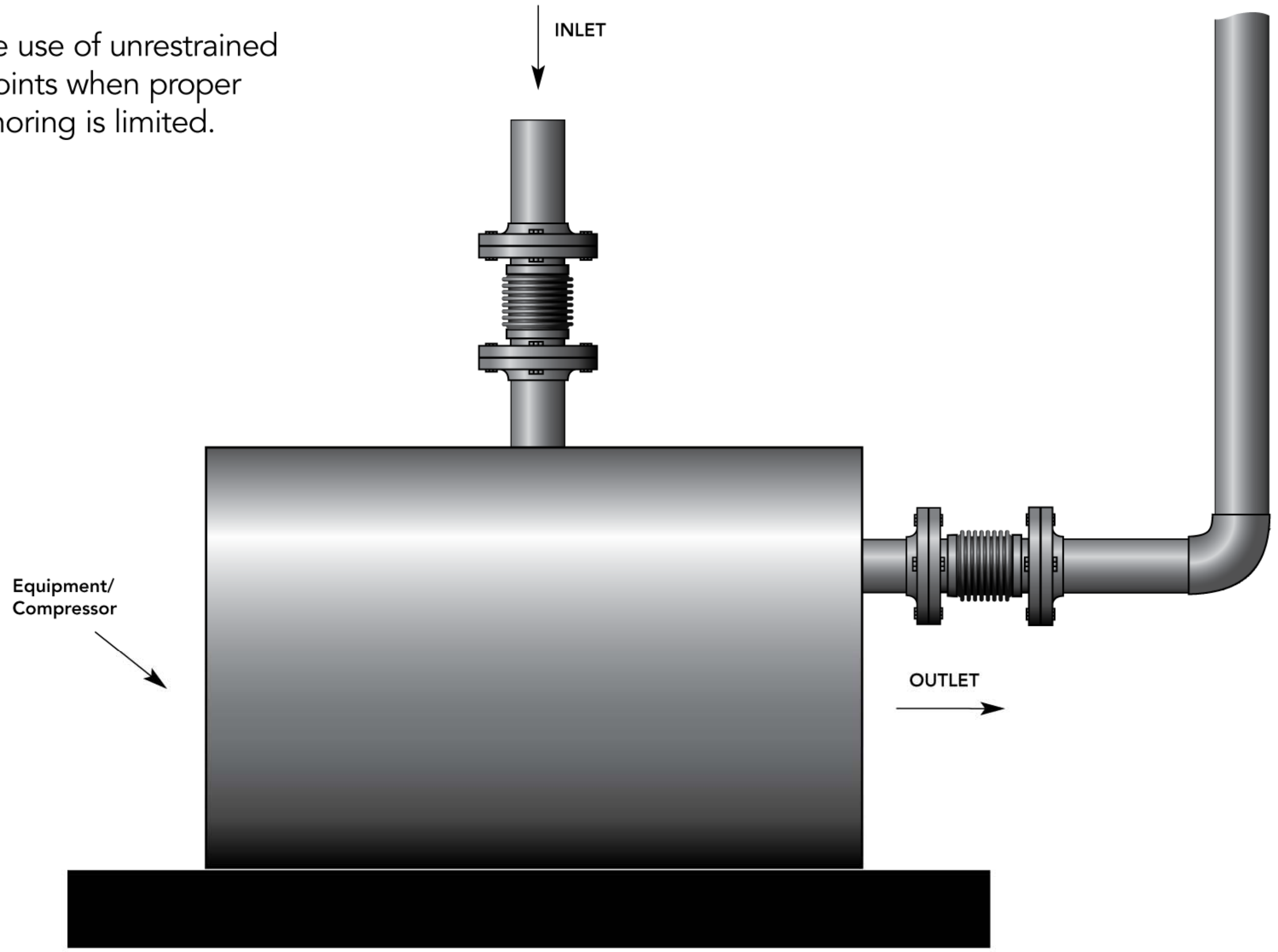
Unless restrained, the pressure thrust force will stretch the bellows of the expansion joint back into a cylinder.



Rods are installed temporarily to restrain the expansion joint during the hydrostatic test.

Typical Piping Layout

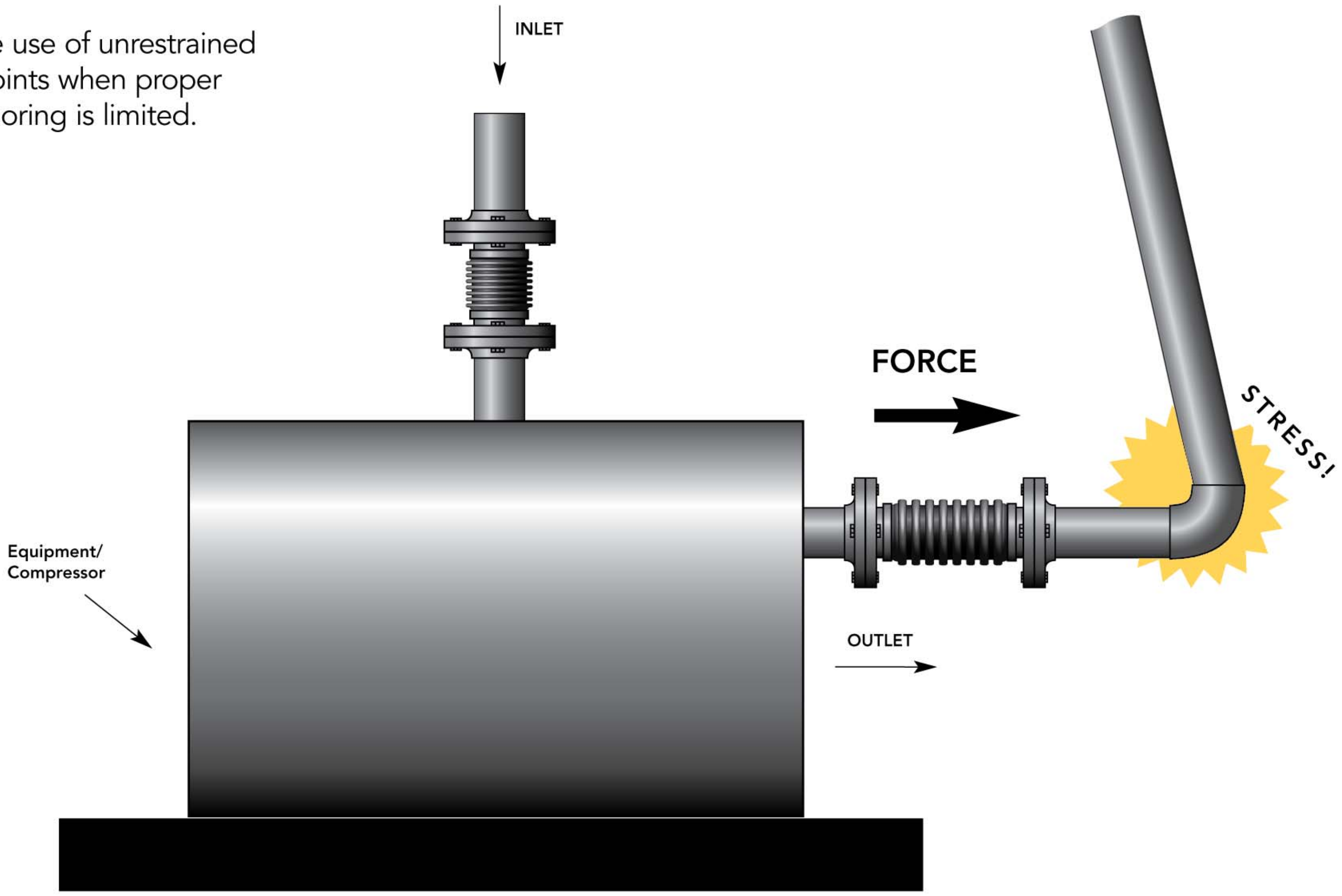
Showing the use of unrestrained expansion joints when proper system anchoring is limited.



Expansion joints without limit rods

Typical Piping Layout

Showing the use of unrestrained expansion joints when proper system anchoring is limited.



Over extension due to pressure thrust