1. Introduction

1.1 Overview of Study:

Hot and cold fluid passing through long pipes causes thermal expansion and contraction in the piping system. The fluid passing through pipes also creates fluctuations because of several reasons. The pressure fluctuation and thermal expansion or contraction causes movements in the piping. The differential longitudinal expansion occurs in the piping due to temperature and pressure variations. For long distance piping applications expansion loops are provided to compensate the variations in length. In certain precise applications different types of expansion joints are used in the piping to avoid high stresses caused due to temperature variations and pressure fluctuations. Design of expansion joints is very critical, as the temperature variations and fluid pressure are most variable parameters depending on individual application. Metallic bellows is the most critical and important part of expansion joint assembly. The bellows is formed with convolutions and there are many other geometric features provided. Because of its convolution shape, it is also known as corrugated joint. This present study is intended towards rigorous study of various design aspects of expansion joints, and their effect on the performance through several experiments.

1.2 Introduction:

Piping engineering is very important aspect of engineering for chemical, petrochemicals, and other allied industries. All mega plants consist of hundreds of meters of various pipes. Pipes are used for the purpose of long distance transfer of fluids. At some places the pipes are having limited length but complex layout. For many individual applications, fluid pressure and temperature are main variables. A pipeline designer has to make a judicious layout planning providing for expansion for a pipe line even in a confined space to avoid the problems arising out of a stiff piping system. Due to space limitations many designers make a system semi-rigid or completely free for movements. However, in all cases, the stress values are to be calculated at
various anchors to ensure safe operation and satisfactory service life of the piping system.

In order to make a system flexible, different types of expansion devices or joints are used. The expansion joints are necessary to consider as part of piping systems and they are introduced at appropriate locations in the following circumstances.

- In process industries, where fluid or steam is passing at elevated temperature and pressure through pipes,
- In refrigeration applications like cold storages;
- In a system where space is very limited for a conventional flexible piping system; e.g. in fast-breeder-reactor of nuclear power plant;
- Where minimum pressure drop is desirable;
- Where thermal stresses are excessive at the terminal equipment connection;
- Where variations in length of pipe is expected due to temperature and pressure variations in long distance piping;
- Where it is required to check mechanical vibrations;
- Where it is impossible to align a pipe line exactly;

On heating or cooling the length of pipe changes by 1.2 to 1.8 mm per meter for every $100^\circ C$ variations in temperature. [20] This necessitates the use of compensating devices between two rigid supports to make the pipe flexible. Appendix - A shows variation in length of different materials at various temperatures.

The function of expansion joints in various applications is to provide flexibility in the piping. The performance of expansion joint is mainly depends on the design of bellows. The whole assembly of expansion joint consists of other elements like liner, flanges, cover, collar, control rods, limit rod etc. Bellow is welded with the collar and collar material, which is further welded with the flanges. Generally expansion joints are manufactured along with flanges in order to facilitate the
assembly in long piping. The flanges are connected with flanges of pipe with fasteners.

There are many variations in selection of pipe diameters, length of pipes, fluid which is flowing inside the pipe (may be liquid or gas), properties of fluid, pressure fluctuations, temperature variations, etc. depending upon application. The design of expansion joints should include all these working conditions. Hence the design of expansion joint is very much customized and every individual application is a challenging task to designers. The precise design of bellows leads towards the study of various design parameters of expansion joints and study of different geometric parameters of bellows. The study should include various fundamental design aspects, use of Finite Element Analysis software for stress analysis and various experimental works.

1.3 Expansion Methods in Piping:

There are various expansion devices, which can be used to absorb the movement occurs because of expansion and contraction of piping. They are as follows.

1. Self compensation like L, Z, U types of bends in the piping,
2. Providing expansion loop,
3. Sliding joints (telescopic type)
4. Expansion joints (metallic bellows)
5. Disc compensators

Various bends and expansion loops are wasteful of space and material. Slip type of sliding joint are effective, but they can absorb movement which is only inline with piping. Figure 1.1 shows expansion loop and figure 1.2 shows sliding type expansion joint. Modern industries prefer use of expansion joints instead of conventional arrangements like expansion loop and others due to its higher effectiveness.
1.4 Expansion Joints:

An expansion joint can be defined as a device containing one or more bellows used to absorb dimensional changes in the pipe line, duct or vessel caused by thermal expansion and contraction. The main function of expansion joint is to provide flexibility in the piping in order to compensate for variations in length. The expansion joint possesses several advantages over conventional compensating devices such as capable of absorbing any movement, compact arrangement, and maintenance free long life. Figure 1.3 shows expansion joint assembly and figure 1.4 shows metallic bellow, an important part of expansion joint assembly.
1.5 **Types of movements:** The various dimension changes which an expansion joint is required to absorb are axial motion, lateral deflection, angular rotation and torsion movement. Principally bellows are made to absorb axial movements only, but several combinations of bellows can be used as an expansion joint, which are capable of absorbing several movements.

Axial movement: It is the movement occurs parallel to the centerline of the bellows and can be either expansion or contraction.

Lateral deflections: It is the movement which occurs perpendicular, or at right angles to the centerline of the bellows. Lateral deflection can occur along one or more axis simultaneously.

![Axial movement](image1)

![Lateral Movement](image2)

![Angular movement](image3)

![Torsional movement](image4)

Figure 1.5: Motions of bellows

Angular rotation: It is the bending of an expansion joint along its centerline.

Torsional movement: In addition to axial, lateral and angular movements, an expansion joint may be subjected to torsional or twisting motion. Normally torsional motion of bellows is restricted. Actually bellows are not preferred for torsional movement.

1.6 **Accessories of an expansion joint:** The bellows are used with some accessories or other components.[20] These components are liner, cover, weld
end, flanged end, collar, hollow reinforcing rings, solid root rings, equalizing rings, control rods, limit rods, tie rods, etc. Accessories are shown in figure 1.6. All accessories are provided for specific function, which is mentioned thereafter.

1. Bellow
2. Liner
3. Cover
4. Weld end
5. Flanged end
6. Collar
7. Hollow reinforced rings
8. Solid root rings
9. Equalizing rings
10. Control rods
11. Limit rods
12. Tie rods

**Figure 1.6:** Accessories of an expansion joint

All accessories are having definite function as mentioned below.

**Liner:** Liners are primarily used in high velocity applications, to prevent erosion of the inner surface of the bellows. It also minimizes the likelihood of flow induced vibration. Liners must be installed in the proper orientation considering the flow direction.

**Cover:** This component is used to provide external protection of bellows from foreign objects or mechanical damage.

**Weld end:** The ends of an expansion joint equipped with pipe for weld attachment to adjacent equipment or piping. Weld ends are beveled for butt welding.

**Flanged end:** The ends of an expansion joint equipped with flanges for the purpose of bolting the expansion joint to the mating flanges of adjacent equipment or piping.
Collar: A ring of suitable thickness which is used to reinforce the bellows tangent, or cuff, from bulging due to pressure.

Reinforcing rings: The primary purpose of reinforcing rings is to reinforce the bellows against internal pressure. Hollow or solid rings can be used according to required strength. Hollow rings are usually formed from a suitable pipe or tubing section. Solid rings are made from solid bar stock for greater strength.

Equalizing rings: It consists of T shaped cross section. In addition to resist internal pressure, equalizing rings limit the amount of compression movement per convolution.

Control rods: These components are usually in the form of rods or bars, attached to the expansion joint assembly whose primary function is to distribute the applied movement between the two bellows of a universal expansion joint.

Limit rods: In the case when, main anchor failure, limit rods are designed to prevent bellows over extension or over compression while restraining the full pressure loading and dynamic forces generated by the anchor failure.

Tie rods: Its primary function is to continuously restrain the full bellows pressure thrust during normal operation while permitting only lateral deflection. Angular rotation can be accommodated only if two tie rods are used and located 90° from the direction of rotation.

1.7 Types of expansion joints: There are several types of expansion joints; each is designed for various applications or set of conditions. Followings are most basic types of expansion joints.[20]

1.7.1 Single expansion joint: This is the simplest type of expansion joint. It is a single bellow construction, which can absorb all types of movements of pipe sections. Single expansion joint can have axial and lateral movements as shown in above figure. The principal restriction upon the use of single expansion joint for lateral deflection or combined axial movement and lateral deflection is the limited amount of lateral deflection which such an expansion joint can absorb. The allowable lateral deflection is directly proportional to the ratio of convoluted length to diameter which, in turn is restricted by considerations of stability and manufacturing limitations.
Figure 1.7 shows single expansion joint and its application with piping layout is shown in figure 1.8.

1.7.2 Double expansion joint: The double expansion joint is consists of two bellows joined by a common connector, which is anchored to some rigid part of the installations by means of an anchor base. The anchor base may be attached to the common connector either at installation or time of manufacturer. Each bellows of a double expansion joint is functions independently as a single unit. Figure 1.9 shows double expansion joint.
1.7.3 Universal expansion joint: A universal joint is one containing two bellows joined by a common connector for the purpose of absorbing any combination of the three basic movements. A universal expansion joint is used in cases to accommodate greater amounts of lateral movement that can be absorbed by a single expansion joint. The universal expansion joint is particularly well adapted to the absorption of lateral deflection. In addition, this design may be used to absorb axial movement, angular rotation or any combination of the three. A common application of the universal expansion joint is its use as a tied expansion joint in a right angle piping offset with the tie rods adjusted to prevent external axial movement. Numerous variations are possible in the design of universal expansion joints. Rods, pantographic linkages, slotted hinges or external structure members may be used in a horizontal installation.
Despite versatility of the universal expansion joint, its use is sometimes precluded by the configuration of the piping, the operating conditions or even by manufacturing limitations. Figure 1.10 shows universal expansion joint.

**1.7.4 Universal tied expansion joint:** Tied expansion joints are used when it is necessary for the assembly to eliminate pressure thrust forces from the piping system. This type of expansion joint will absorb lateral movements and will not absorb any axial movement external to the tied length. Figure 1.11 shows universal tied expansion joint.

![Universal Tied Joint](image1.png)

**Figure 1.11:** Universal Tied Joint

**1.7.5 Swing expansion joint:** A swing expansion joint is designed to absorb lateral deflection and/or angular rotation in one plane only by the use of swing bars, each of which is pinned at or near the ends of the unit. Figure 1.12 shows swing type expansion joint.

![Swing Expansion Joint](image2.png)

**Figure 1.12:** Swing Expansion Joint
1.7.6 **Hinged expansion joint:** A hinged expansion joint contains one bellows and is designed to permit angular rotation in one plane only by the use of a pair of pins running through plates attached to the expansion joint ends.

Hinged expansion joints should be used in sets of two or three to absorb lateral deflection in one or more directions in a single plane piping system. Each individual expansion joint in such a system is restricted to pure angular rotation by its hinges. Figure 1.13 shows hinged expansion joint.

![Figure 1.13: Hinged Expansion Joint](image)

1.7.7 **Gimbal expansion joint:** A gimbal expansion joint is designed to permit angular rotation in any plane by the use of two pairs of hinges affixed to a common floating gimbal ring. The gimbal ring, hinges and pins must be designed to restrain the thrust of the expansion joint due to internal pressure and extraneous forces. Universal, swing, hinged and gimbal types of expansion joints are used for restraint of pressure thrust forces. Figure 1.14 shows gimbal expansion joint.

![Figure 1.14: Gimbal Expansion Joint](image)
1.7.8 **Pressure balanced expansion joint:** A pressure balanced expansion joint is designed to absorb axial movement and/or lateral movement while restraining the bellows pressure thrust force. This type of joint is installed where a change of direction occurs in a run of pipe.

![Image of Pressure Balanced Expansion Joint]

**Figure 1.15:** Pressure Balanced Expansion Joint

This expansion joint is used most frequently in applications similar to those for the single expansion joint, but where pressure loading upon piping or equipment is considered excessive or objectionable. The major advantage of the pressure balanced design is its ability to absorb externally imposed axial movement without imposing pressure loading on the system. The force resulting from the bellows spring rate is not eliminated. In fact, it is usually increased over that of a single expansion joint. Figure 1.15 shows pressure balance bellow while figure 1.16 shows application of pressure balanced expansion joint in piping.

![Image of Arrangement of Pressure Balanced Bellow]

**Figure 1.16:** Arrangement of Pressure Balanced Bellow
1.8 Selection of Expansion Joints:

For the selection of specific type of expansion for particular applications, designers should divide the piping system into simple configurations like straight run, L shape, Z shape as shown in Figure 1.17. Then position of anchors should be decided in the piping system. Additional anchors are located at valves, at changes of direction of pipes, at blind end of the pipe and at major junction of piping connection as shown in figure 1.18. A final decision on anchor locations should be made after comparing various alternatives of lay out, space restrictions, number of expansion joints required, force requirements etc.\[20\]

The next step is to calculate the actual change in length of each leg of each individual pipe section due to temperature changes. The minimum and installation temperatures are assumed to be room temperature unless and otherwise specified for any special application.
Estimate of thermal growth (or thermal expansion and contraction) is made from actual temperature of flowing fluid and piping material. Accordingly, axial and lateral movement due to thermal expansion and contraction of pipe material may be calculated. These values are helpful for selection of expansion joints. Following recommendations are helpful for selection of expansion joint.

1. Only axial movement is required in straight pipe, then single expansion joint should be selected. If axial movement is very large, can not be met with single expansion joint, double expansion joint should be selected.

2. If small amount of axial and greater amount of lateral combined movement is required from the piping loop, then universal type of expansion joint should be selected.

3. Tied universal expansion joints are used when it is necessary for assembly to eliminate pressure thrust forces from the piping system. This expansion joint is selected for restraint of pressure thrust forces.

4. A swing expansion joint is designed to absorb lateral deflection and/or angular rotation in one plane only by use of swing bars, pinned near the ends of the unit. This expansion joint is selected for restraint of pressure thrust forces.

5. A hinged expansion joint is designed to permit angular rotation in one plane only by use of a pair of pins running through plates attached to the expansion joint ends. This expansion joint is selected for restraint of pressure thrust forces.

6. A gimbal expansion joint is designed to permit angular rotation in any plane by the use of two pairs of hinges affixed to a common floating gimbal ring. This expansion joint is selected for restraint of pressure thrust forces.

7. Universal, swing, hinged and gimbal types of expansion joints are used for restraint of pressure thrust forces.

8. A pressure balanced expansion joint is designed to absorb axial movement and/or lateral deflection while restraining the bellows pressure thrust force by means of the device interconnecting the flow bellows with an opposed
bellows also subjected to line pressure. This type of joint is selected where a change of direction occurs in a run of pipe.

Table 1.1 shows capabilities of various expansion joints, which can be useful for the selection of expansion joint.

<table>
<thead>
<tr>
<th>Type of Expansion Joint</th>
<th>Axial</th>
<th>Lateral</th>
<th>Rotation</th>
<th>Pressure Thrust</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>Yes</td>
<td>Small</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Universal Tied</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Hinged</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Gimbal</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Pressure balanced</td>
<td>Yes</td>
<td>Small</td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>

1.9 Design Variables:

Expansion joints are highly specialized for individual application as there are many design variables and parameters. [20] Each expansion joint is custom made for an intended application. Hence it becomes necessary to study accurate information regarding the conditions of design that an expansion joint will be subjected to in service. Because many of these design conditions interact with each other, designing a bellows is much like a solving puzzle before deciding their final dimensions. Following are some important design conditions that should be supplied to the manufacturer when specifying an expansion joint.

Size: Size refers to the diameter of the pipeline into which the expansion joint is to be installed. The size of an expansion joint affects its pressure-retaining capabilities, as well as its ability to absorb certain type of movements. Specifying pipe diameters may create confusion like which diameter is to specify. Actually outside diameter and wall thickness must be supplied to supplier, so that this data may be utilized in design of expansion joints.

Flowing Medium: The substances that will come in contact with an expansion joint should be specified early by the user. In some case due to excessive erosion, corrosion potential or higher viscosity or any specific materials must be specified before design.
Pressure: Pressure is the most important factor determining expansion joint design. Minimum and maximum anticipated pressure should be accurately determined. Specified pressure should not increase by unreasonable safety factors as this could result in a design which may not adequately satisfy the other performance characteristics.

Temperature: The operating temperature of the expansion joint will affect its pressure capacity, allowable stresses, cycle life, and material requirements. All possible heat sources should be investigated when determining minimum and maximum temperature requirements.

Motion: Movements due to temperature changes or mechanical motion to which the expansion joint will be subjected must be specified. Other extraneous movements, such as wind loading or installation misalignment must be considered.

1.10 Thermal growth Estimation:

Data: Length of pipe = 100 feet (30.48 meters)

Material: carbon steel pipe with carbon up to 0.3%

Operating between temperatures: -5°C to 190°C.

According to properties of material and table given in appendix 1.

Expansion at 190°C = 63 mm / 100 feet (30.48 meter) length of pipe

Contraction at -5°C = -8 mm / 100 feet (30.48 meter) length of pipe

Total thermal growth is (63 + 8) = 71 mm in 100 feet (30.48 meter) length of pipe.

1.11 Determination of Pressure Thrust Force:

As expansion joint is pressurized from inner surface. Also the movement of expansion joint is controlled by anchors, the thermal growth is required to be calculated up to the anchor.\[20\]

The magnitude of pressure thrust force (N) is determined by following relation.

\[ F_s = \text{Pressure} \times \text{area} \]

Where, \(\text{area} = \frac{\pi}{4} d^2\), and ‘d’ is the diameter of pipe.
Let, Pressure = $2 \times 10^5 \text{ N/m}^2$

Mean diameter of pipe = 64.77 cms = 0.6477 m

Thrust Force = $2 \times 10^5 \times 0.785 \times (0.6477)^2$

= 65864 N

= 65.864 kN

1.12 Movements absorbed by bellows: $^{[20]}$

**Axial motion:** Bellow subjected to axial movement only is shown in figure 1.19. The total axial movement is absorbed by a uniform displacement of all the convolutions of a single bellow expansion joint.

![Axial movement of a bellow](image)

Figure 1.19: Axial movement of a bellow

Let x is the total axial movement of a bellow.

Axial movement per convolution, $e_x = \frac{x}{N}$

**Lateral Motion:** Figure 1.20 shows a bellow subjected to lateral movement. The total lateral movement is absorbed by all convolutions of a single bellow expansion joint.

![Lateral movement of a bellow](image)

Figure 1.20: Lateral movement of a bellow
Let Y be the total lateral movement.

Maximum Lateral deflection, \( e_y = \frac{3Dm y}{N (Lb \pm x)} \)

Angular Motion: Figure 1.21 shows an expansion joint bellows absorbs pure angular rotation by extending uniformly on one side and compressing uniformly on the other. The movement of any convolution may be expressed by

![Figure 1.21: Angular movement of a bellow](image)

Angular movement per convolution, \( e_\theta = \frac{\theta Dm}{2N} \)

Combined equivalent movements:

The effect of combined movement can be calculated as

Total equivalent compression movement = \( e_y + e_\theta + [e_x] \)

Total equivalent extension movement = \( e_y + e_\theta - [e_x] \)

Where x is axial compression, and y and θ occurs in the same plane. Positive x indicate extension and negative sign indicates compression.
1.13 Force Analysis of Expansion Joints:

Case 1: Single Expansion joint subjected to axial movements:

![Diagram](image)

Figure 1.22: Piping layout with expansion joint and anchors

Material: Carbon Steel Pipe

Pipe Diameter = 24 inches = 60.96 cm = 0.6096 m

Mean diameter, Dm = 64.77 cm = 0.6477 m

Pipe length = 60 feet = 18288 mm = 18.288 m

Inside Pressure = 150 psig = 150 x (7.031 x 10^{-4}) = 0.105 kg/mm^2

= 10.54 kg/cm^2 = 10.54 x 10^5 N/m^2.

Temperature = 500°F = (500 – 32 / 1.8) = 260°C

Thermal Growth = (60 / 100) x 91.95* = 55.17 mm

(* Selecting thermal expansion at 260°C from appendix - A)

Bellows effective area = Ae = \( \frac{\pi}{4} \) d^2 = \( \frac{\pi}{4} \) 0.6477^2 = 0.3295 m^2

Spring rate = fw = 65800 N/cm

Number of Convolutions, N = 12
Forces on anchors A and B

Axial Force on Anchor A

\[ F_x = -F_s - F_a \]

Static thrust due to internal pressure = \( F_s = A_e \times P_d = 0.3295 \times 10.54 \times 10^5 \)

= 347293 N

Axial movement per convolution, \( e_x = \frac{x}{N} = \frac{5.52}{12} = 0.46 \text{ cm} \)

Force required to deflect expansion joint, \( F_a = f_w \times e_x \)

= 65800 \times 0.46 = 30268 \text{ N.} \)

Anchor A

\[ F_x = F_s - F_a = -347293 - 30268 \]

= -377561 N.

= -377.561 kN

Anchor B

\[ F_x = F_s + F_a = 347293 + 30268 \]

= 377561 N

= 377.561 kN
Case 2: Single Expansion joint subjected to axial and lateral movements:

![Diagram of piping layout with expansion joint and anchors](image)

Figure 1.23: Piping layout with expansion joint and anchors

**Carbon Steel Pipe**

Inside diameter of pipe = 24 inches = 60.96 cm = 0.6096 m

Mean diameter, Dm = 64.77 cm = 0.6477 m

Operating Pressure = 125 psig = 125 x (7.031 x 10^-2) = 8.79 x 10^5 N/m²

Temperature = 400°F = (400 – 32 / 1.8) = 205°C

Thermal Growth expected axially = 1.03 cm

Thermal Growth expected laterally = 0.55 cm

Pipe length

L1 = (8 ft) 244 cm,
L2 = (2 ft) 60 cm,
Lb = (1 ft) 30.4 cm,
L3 = (12 ft) 365 cm.

Bellows effective area = \( A_e = \frac{\pi}{4} d^2 = \frac{\pi}{4} 0.6477^2 = 0.3295 \text{ m}^2 \)

**Forces and moments on Anchors A, B & C**

Axial movement / convolution = \( e_x = \frac{x}{N} = \frac{1.03}{12} = 0.086 \text{ cm} \)
Lateral movement / convolution = $e_y = \frac{3Dm y}{N(Lb-x)} = \frac{3 \times 64.77 \times 0.55}{12(30-1.03)} = 0.308 \text{ cm}$

Static force, $F_s = Ae \times Pd = 0.3295 \times 8.79 \times 10^5 = 289630 \text{ N} = 289.630 \text{ kN}$

Axial force, $F_a = fw \times e_x = 65800 \times 0.086 = 5660 \text{ N} = 5.66 \text{ kN}$

Lateral force, $V_l = \frac{fw Dm e_y}{2 \times Lb} = \frac{65800 \times 64.77 \times 0.308}{2 \times 30} = 21880 \text{ N} = 21.880 \text{ kN}$

**Anchor A**

$F_x = 0, \quad F_y = 21880 \text{ N}, \quad F_z = 0$

$M_x = F_z y - F_y z = 0$

$M_y = F_x z - F_z x = 0$

$M_z = F_y x - F_x y = (21880 \times 75) - (0) = 1641000 \text{ N cm}$

**Anchor B**

$F_x = -F_s - F_a = (-289630 - 5660) = -295290 \text{ N}$

$F_y = 0, \quad F_z = 0$

$M_x = F_z y - F_y z (\text{As } y = z = 0) = 0$

$M_y = F_x z - F_z x = 0$

$M_z = F_y x - F_x y = 0$

**Anchor C**

$F_x = F_s + F_a = 289630 + 5660 = 295290 \text{ N}$

$F_y = -21880 \text{ N}$

$F_z = 0$

$M_x = F_z y - F_y z = 0$

$M_y = F_x z - F_x x = 0$

$M_z = F_y x - F_x y = (-21880 \times 350) - (0) = -7658000 \text{ N cm}$

Where $x = -(L3 - Lb/2) = -(365 - 15) = 350 \text{ cm}$. 

Case 3: Expansion joint with tie rods:

Carbon Steel Pipe with tied expansion joint:

Inside diameter of pipe = 24 inches = 60.96 cm = 0.6096 m

Mean diameter, $D_m = 64.77$ cm = 0.6477 m

Operating Pressure = 135 psig = $135 \times (7.031 \times 10^{-2}) = 9.5 \times 10^5$ N/m$^2$

Temperature = $550^0 F = (550 - 32 / 1.8) = 288^0 C$

Thermal Growth expected axially = 0.728 cm

Thermal Growth expected laterally = 2.50 cm

Pipe length $L_1 = (2 \text{ ft}) 61 \text{ cm}, L_b = (2 \text{ ft}) 61 \text{ cm}, L_2 = (3 \text{ ft}) 91.5 \text{ cm}$.

Bellows effective area = $A_e = \frac{\pi}{4} d^2 = \frac{\pi}{4} 64.77^2 = 0.3295 \text{ m}^2$

Equivalent axial movement per convolution

Figure 1.24: Piping layout with expansion joint and anchors
Axial movement / convolution, \( e_x = \frac{x}{N} = 0 \) (As tied rod prevents axial movement)

Lateral movement / convolution = \( \frac{3Dm_y}{N(Lb-x)} = \frac{3 \times 64.77 \times 2.50}{18(61-0)} = 0.442 \text{ cm}. \)

Lateral force, \( V_l = \frac{fw Dm e_y}{2 Lb} = \frac{65800 \times 64.77 \times 0.442}{2 \times 61} = 15450 \text{ N.} \)

Forces and moment acting on Anchor “A”

\( F_x = 0, \quad F_y = V_l = 15450 \text{ N, } F_z = 0 \)

\( Y = Z = 0; \quad X = L1 + (Lb / 2) = 91.5 \text{ cms.} \)

\( M_x = F_z y - F_y z = 0 \)

\( M_y = F_x z - F_z x = 0 \)

\( M_z = F_y x - F_x y = (\cdot 15450 \times 91.5) - (0) = -1413675 \text{ N cm} \)

Forces and moment acting on Anchor “B”

\( F_x = 0; \quad F_y = V_l = 15450 \text{ N}; \quad F_z = 0 \)

Where \( z = 0, \quad Y = -L3 = 731.5 \text{ cms}; \quad X = -L2 - (Lb / 2) = 122 \text{ cms.} \)

\( M_x = 0; \quad M_y = 0; \)

\( M_z = F_y X - F_x Y = (15450 \times 122) - 0 = -1884900 \text{ N cm} \)

\( = -1884.9 \text{ kN cm} \)
1.14 Expansion Joint Manufacturers Association (EJMA): Expansion Joint Manufacturers Association was founded in 1955 by a group of manufacturers having a combined total of more than 250 years of successful experience in the design and fabrication of metal bellows expansion joints and their applications. By combining their knowledge and experience in this association’s technical committee, these manufacturer’s have created a concentration of expansion joint “know-how” which is unequalled anywhere in the world and which is available to any user upon request. The first edition of “The Standards of the Expansion Joint Manufacturer’s Association” was published in 1958. Since then, each succeeding edition has been expanded to contain more detailed design and application specifications and to further define the nature and capabilities of expansion joints. The engineering Standards recommended by EJMA to assist users, engineers, architects and others who specify, design and manufacture the expansion joints. These standards are based upon sound engineering principles, research and field experience in the manufacture, design, installation and use of Expansion Joints. These standards help manufacturers for accurate design of expansion joints. These standards are available for industrialists based on membership only.

1.15 Chapter Plan:

First chapter describes basic information about expansion joints. It includes function of expansion joints, various types of expansion joints, accessories of expansion joints, and selection parameters of expansion joint. This chapter also includes the mathematical calculation of thermal growth in the piping, based on temperature variations. It describes methodology to determine pressure thrust force and moment analysis at anchors. Roles and objectives of Expansion Joints Manufacturing Association (EJMA) are also mentioned.

Second chapter includes the review of many research papers about the design, manufacturing and testing aspects of expansion joints. Overall summary is made from review study and probable areas are exposed for the further research work. This chapter also indicates tentative objectives of the study. These objectives indicate direction of further research work.

Third chapter describes about bellows, which is an important part of expansion joints assembly. Further details are included about construction, components, geometry, convolution shapes of bellows, raw material of bellows, manufacturing
methodology, single / multiply layer arrangement, and reinforcement of bellows. This chapter also discusses about design features of bellows like cold springing, stability, spring rate, and fatigue life expectancy of bellows. EJMA suggests the customized design approach of bellows. This strategy is analyzed for the application. Finally testing methods of bellows are mentioned.

Fourth chapter describes the objectives of study. Here probable research methodology is also discussed. Three methodologies are finalized for the research work. They are parametric study with analytical approach, Finite Element Analysis (FEA), and design verification by testing of bellows.

Fifth chapter is about the Finite Element Analysis (FEA). Basic method of FEA is explained and important theories are elaborated. The FEA is carried out and various results are obtained like displacement and stresses. Various case studies are considered for analysis like axi-symmetry, repetitive symmetry, thermal expansion etc. The FEA results are validated and analyzed.

Sixth chapter describes about purpose of testing bellows. Various non-destructive testing methods are mentioned. Some destructive testing methods, which are suggested by EJMA are elaborated with set-up diagram and methodology steps are developed for testing. Mainly squirm test, yield rupture test and fatigue life cycle test are important for the bellows. Some tests are performed practically on bellows for the study and their results are analyzed.

Seventh chapter is about the results and discussion of the research work. The discussions are elaborated about analytical work, FEA and experimental work.

Finally eighth chapter is devoted for the conclusions of the study. Important conclusions are mentioned along with justification and previous references. The limitations of study are confessed and directions of further scope of the study are mentioned.