First, we look at heat exchanger construction

Expansion Joints in Heat Exchangers

BASICS

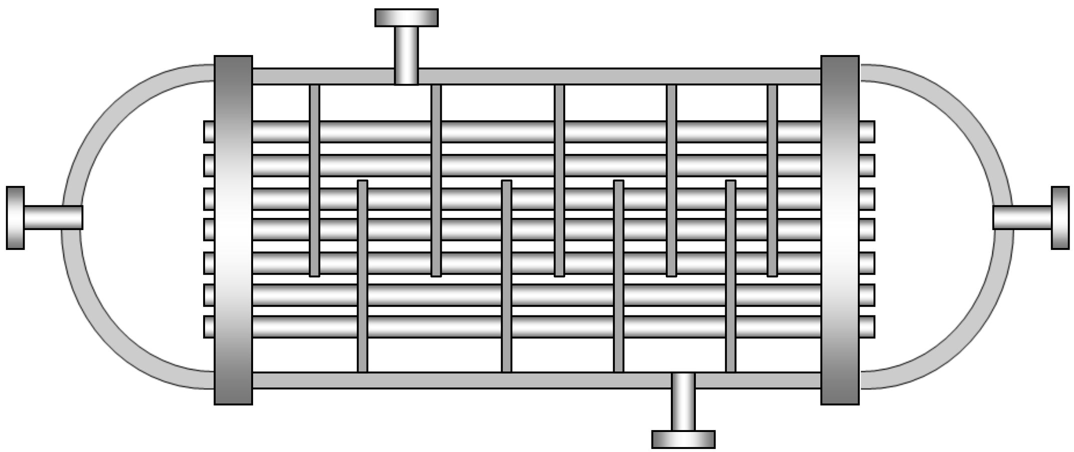
Presented by: Ray Delaforce

First, we look at heat exchanger construction

This is the floating head type heat exchanger

Comprises these main components:

- Tubesheets
- Exchanger tubes
- The shell – the shellside
- The channel – the tubeside
- Tube supports – often called baffles
- Nozzles



This is fixed heat exchanger

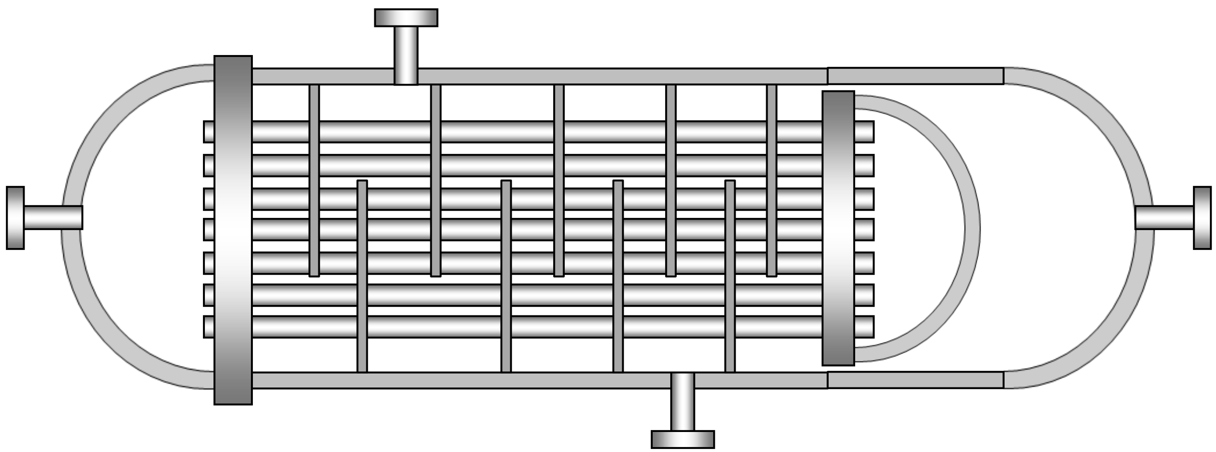
We discuss the problems with the fixed heat exchanger in a moment

First, we look at heat exchanger construction

There is a major difference between the two heat exchangers

This is the floating head type heat exchanger

- **Floating tubesheet – can slide inside the shell**
- **Floating head - contains the tube side fluid**
- **The shell closure – contains the shell side fluid**



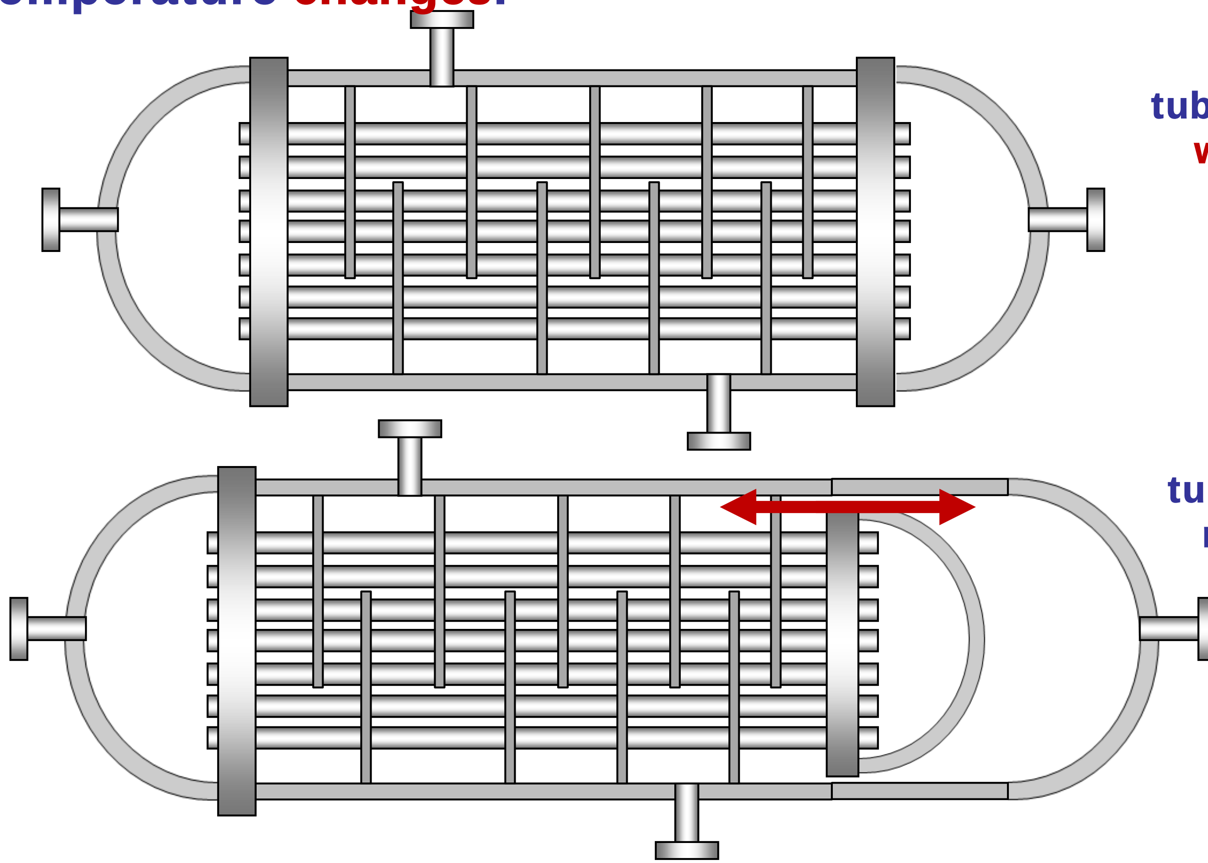
This is the floating head heat exchanger

First, we look at heat exchanger construction

There is a major difference between the two heat exchangers

Problems with the fixed heat exchanger

As the temperature changes:



Fixed the tubesheets moves with the shell

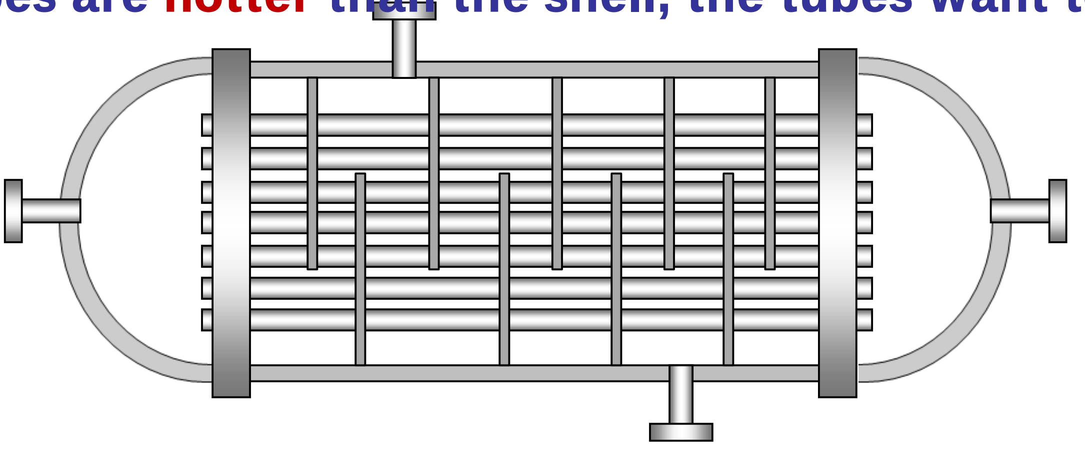
Floating tubesheets do not move with the shell

The tubesheet is free to slide inside the shell

First, we look at heat exchanger construction

Problems with the fixed heat exchanger

If the tubes are hotter than the shell, the tubes want to expand



First, we look at heat exchanger construction

First we cut the shell

Problems with the fixed heat exchanger

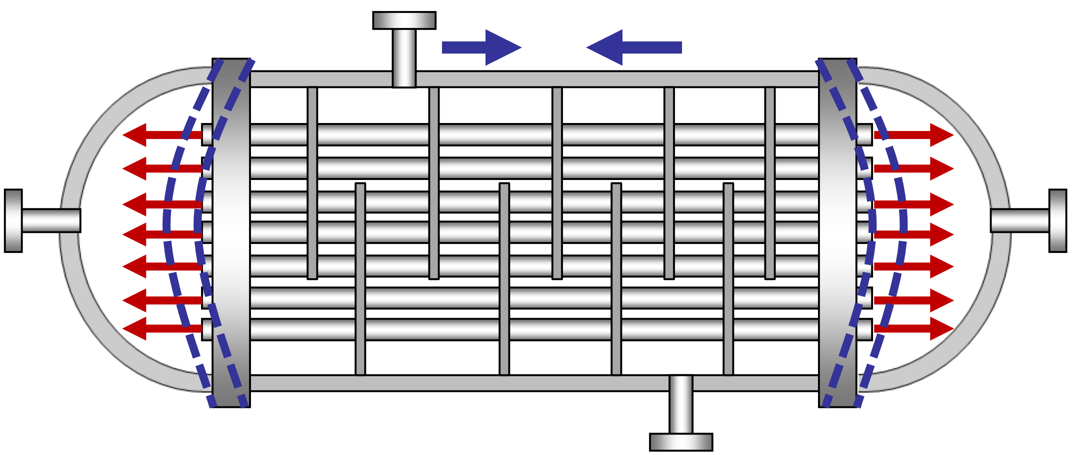
If the tubes are hotter than the shell, the tubes want to expand

Relatively: the shell may try to contract

Creating a bending stress in the tubesheets

Also tensile stresses in the shell, and compressive stress in the tubes

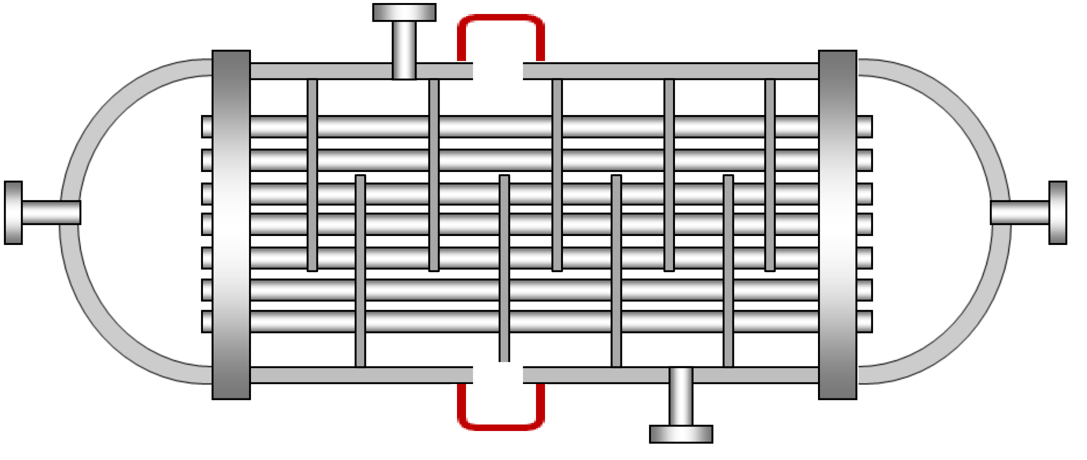
An Expansion Joint can reduce these stresses



First, we look at heat exchanger construction

First we cut the shell, then the Expansion Joint is installed

Now we can see the benefit of the expansion joint



First, we look at heat exchanger construction

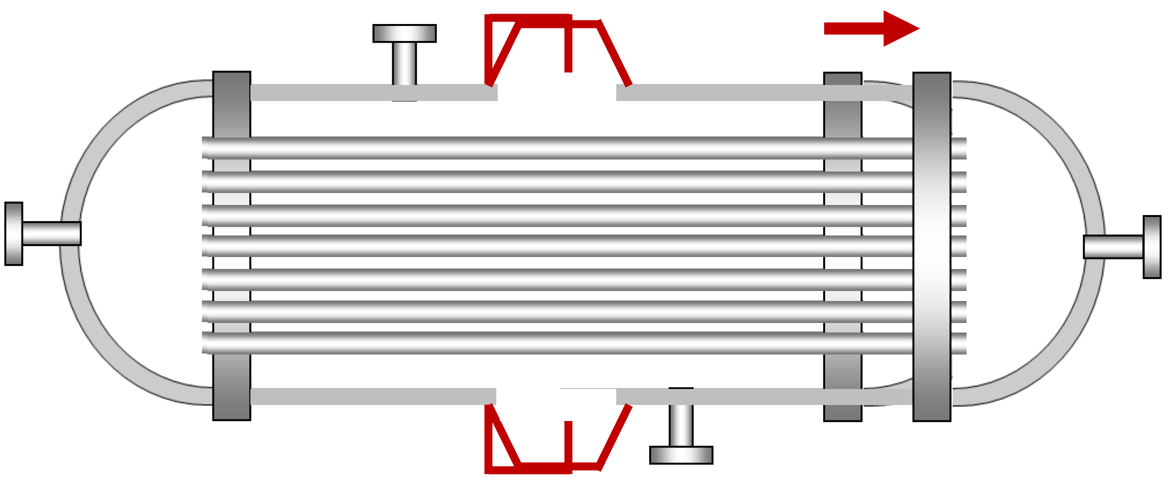
There two types of Expansion Joint

First we cut the shell, then the Expansion Joint is installed

Now we can see the benefit of the expansion joint

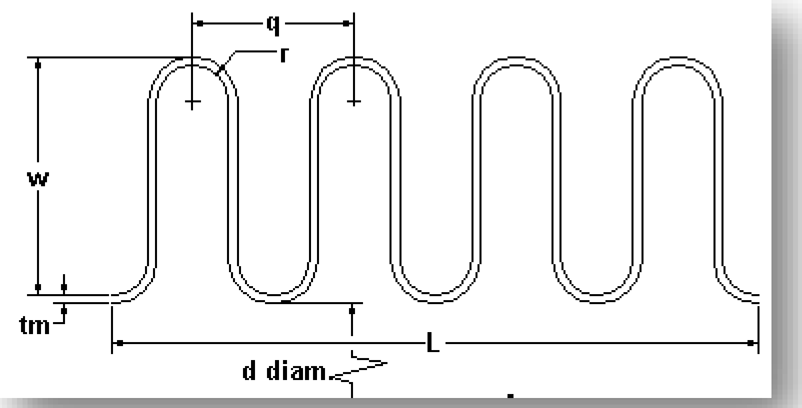
This is what happens , shell moves independently of the tubes

However, stresses are induced in the expansion joint

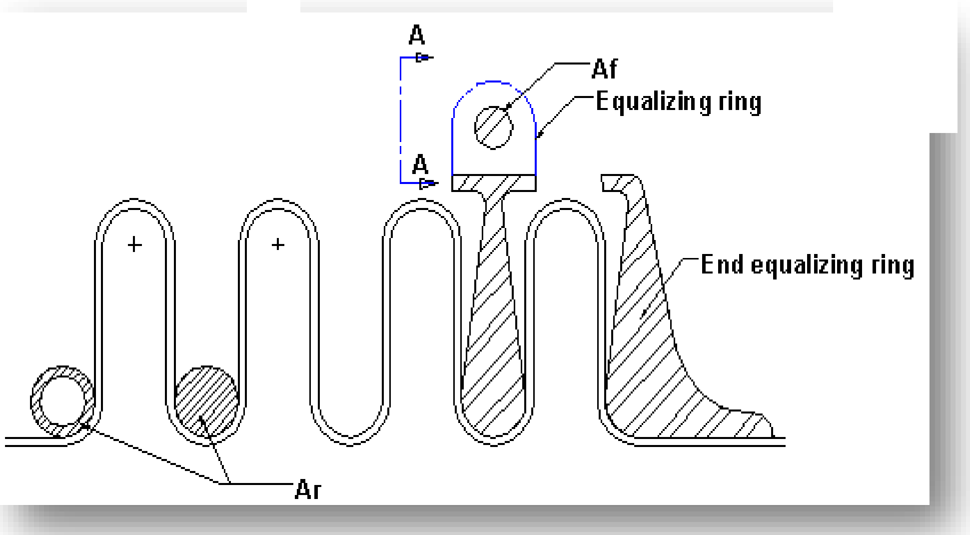


There two types of Expansion Joints, first, difficult to manufacture

Toroidal joint is used less often, the thin joint

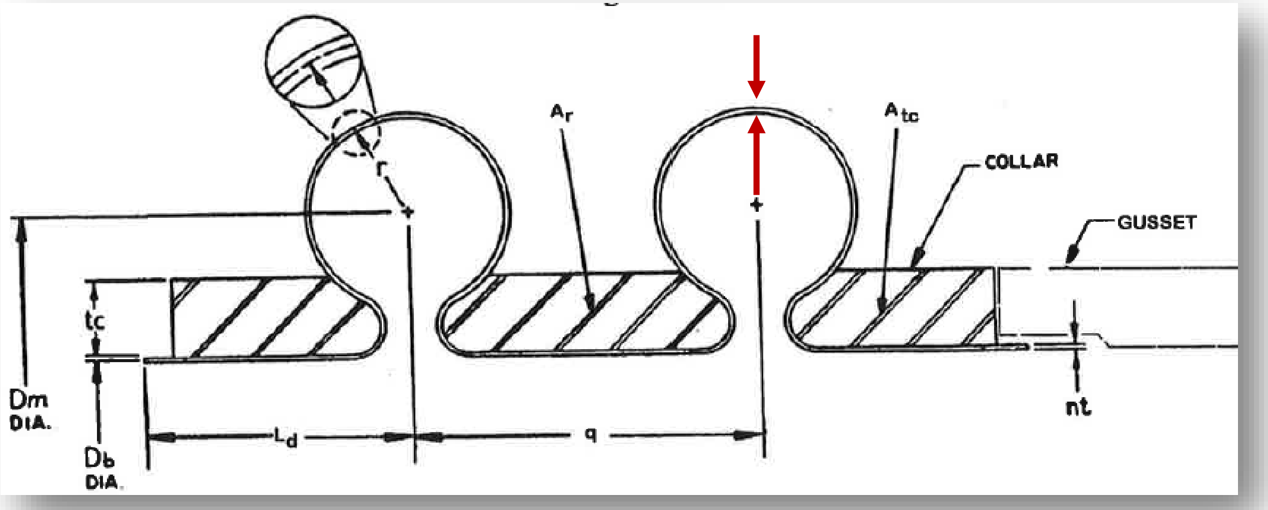


And with reinforcement elements , limits expansion stresses



The Toroidal joint, as the name suggests, is difficult to manufacture

The thick joint, this joint is used less often, thicker



The thin joint is so name because of:

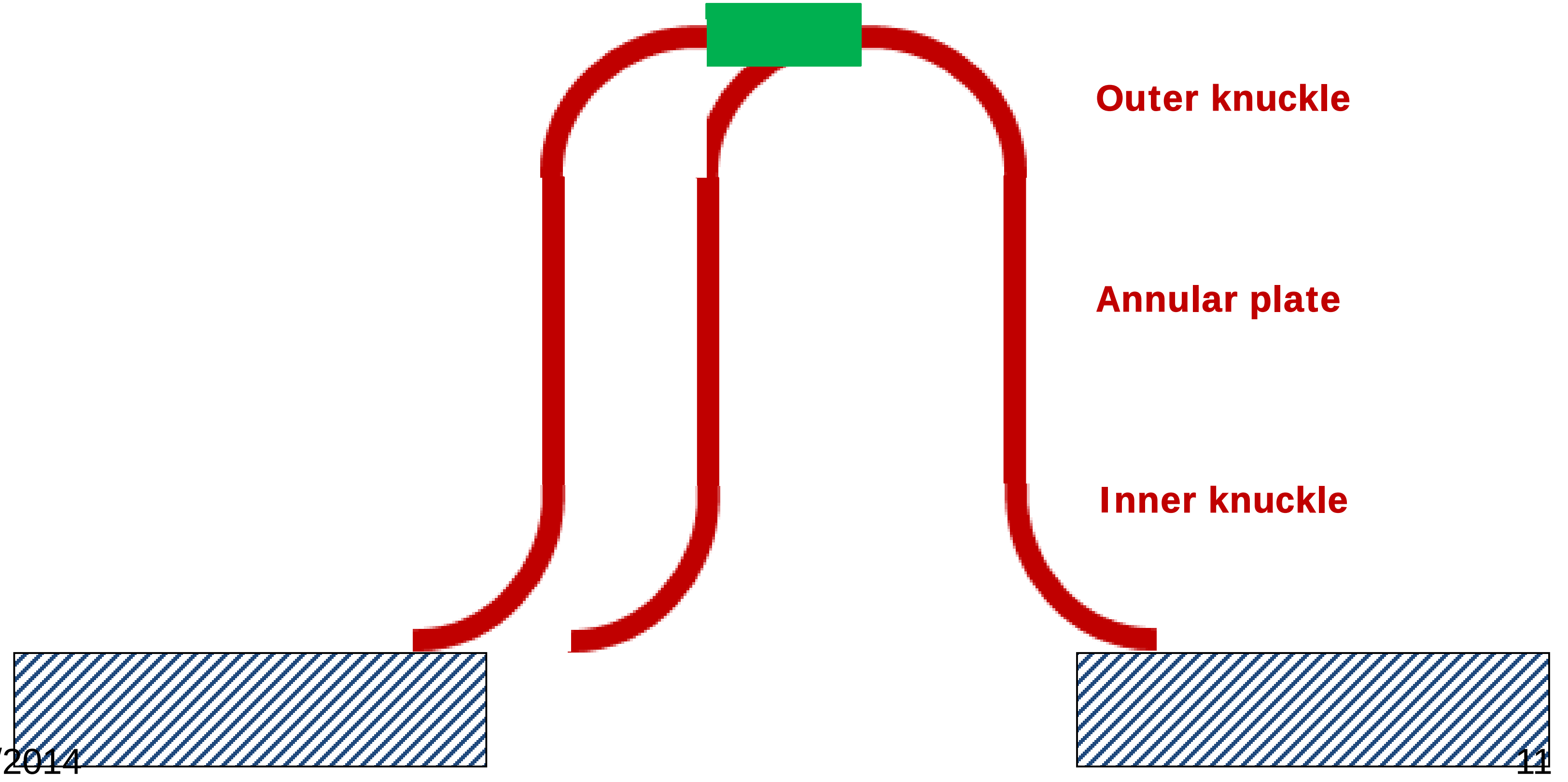
- **Relatively thin material from which it is manufactured**
- **The many convolutions is comprises**

PV Elite can analyse all the thin joint configurations

The thick joint, as the name suggests is thicker

It is commonly called a shell element , it comprises

- An annular plate
- Two knuckles
- Two shell elements make one convolution
- There might be an Outer cylinder
- Here is the main shell of the heat exchanger



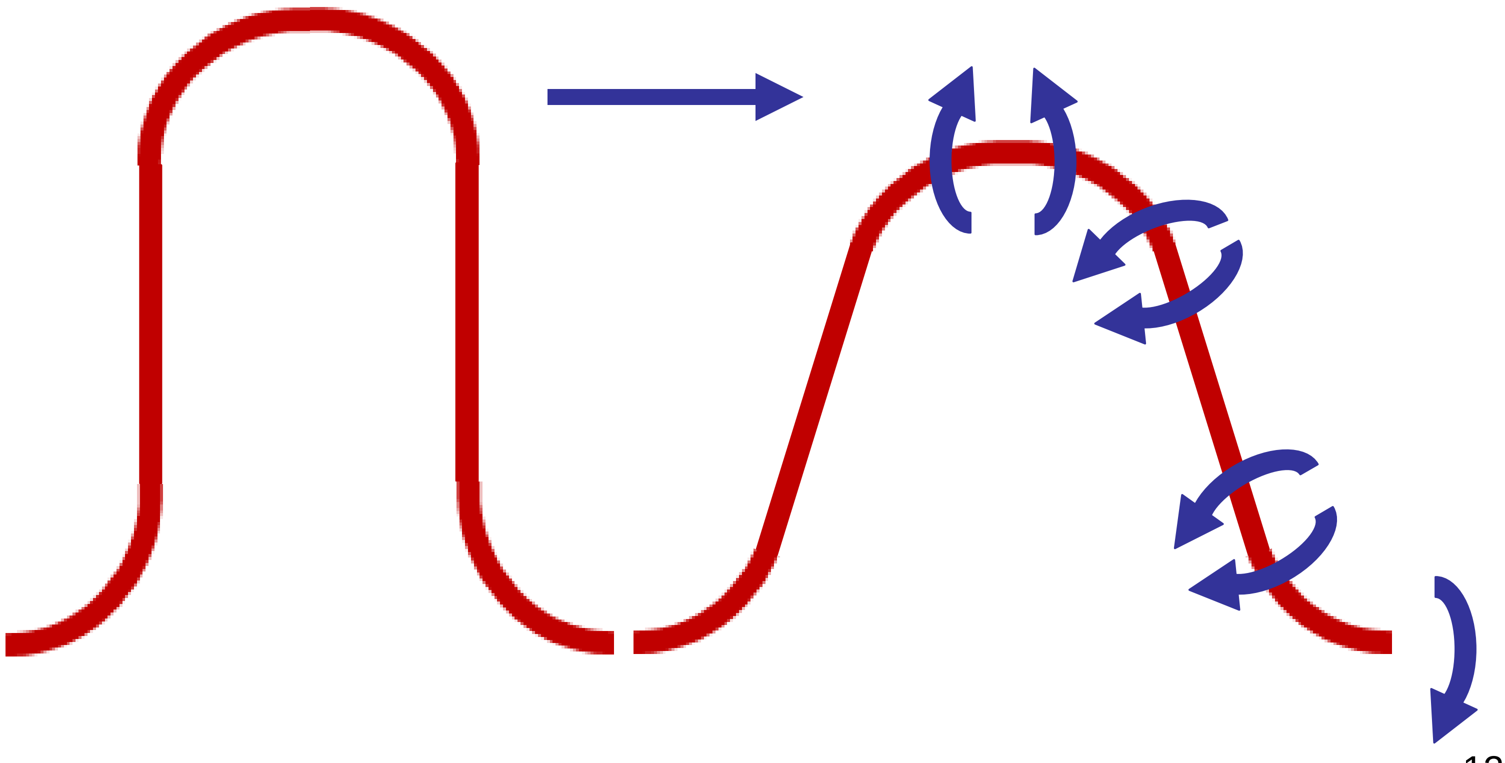
Consider for example the thin shell element joint

The thick joint, as the name suggests is thicker

As it opens with the shell movement, there are bending moments

This gives rise to bending stresses

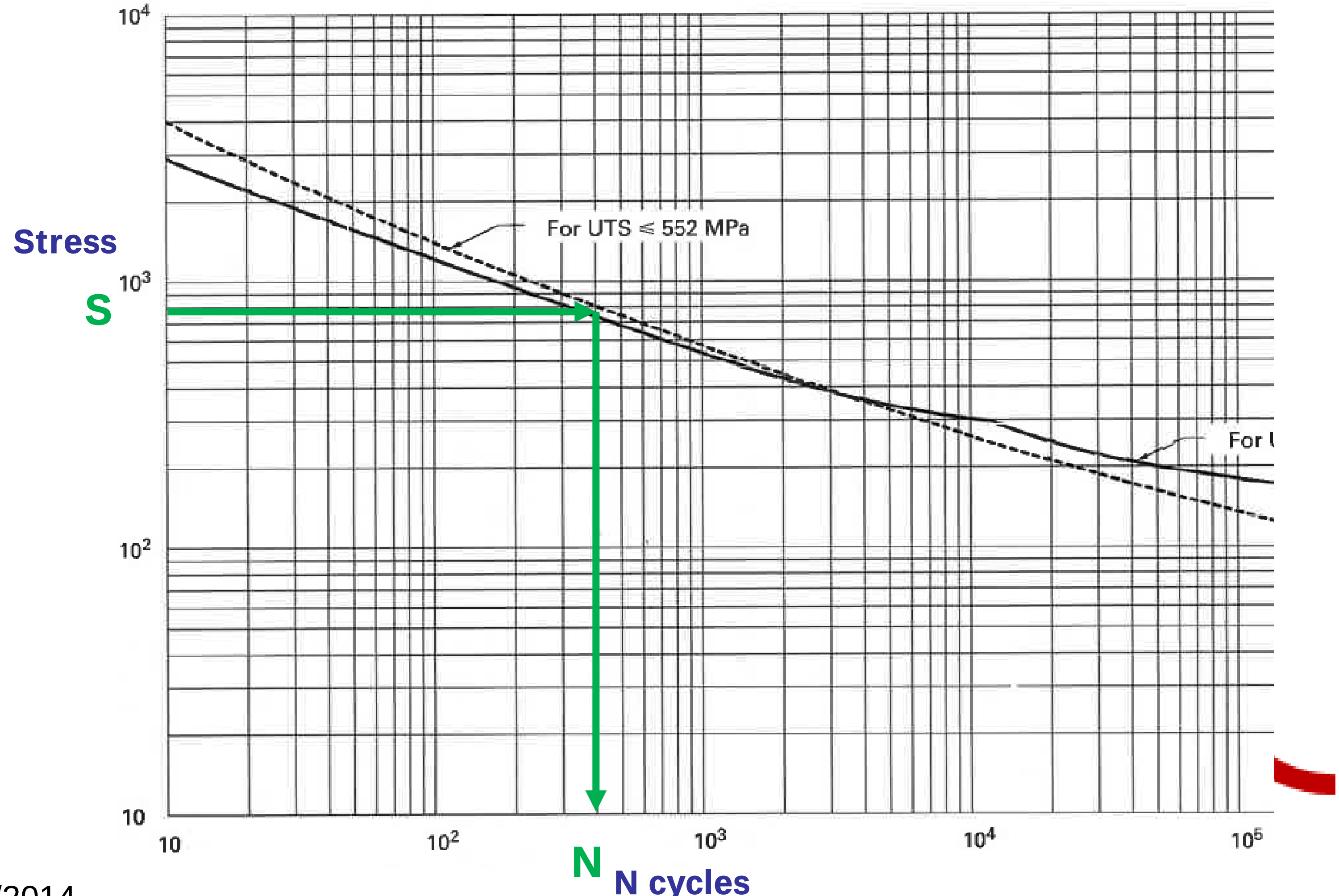
- **The joint may be overstressed – this is an obvious problem**
- **The joint may have a very short fatigue life**



Consider for example this stress at the shell element of the **expansion joints** joint

We can estimate the number of **fatigue cycles** it can withstand

Here is a **fatigue curve** from ASME VIII, Division 2



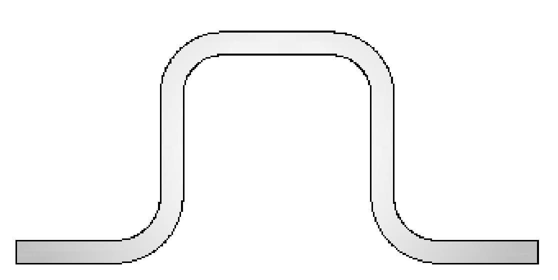
Here are examples of thin and thick expansion joints

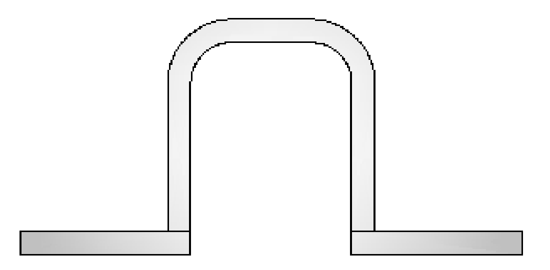
These are examples of the basic design of **expansion joints**
Here are some of the thick **joints**

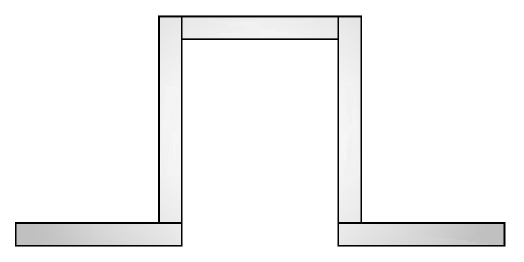
Example of a square expansion joint

Let us look at the **history of the design** of the expansion joints

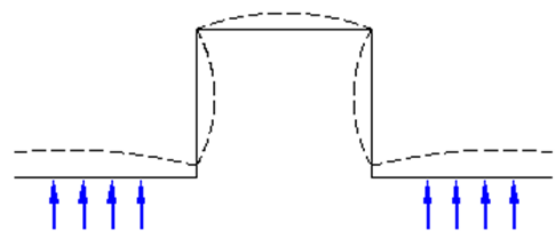
These are some of the basic designs of these joints

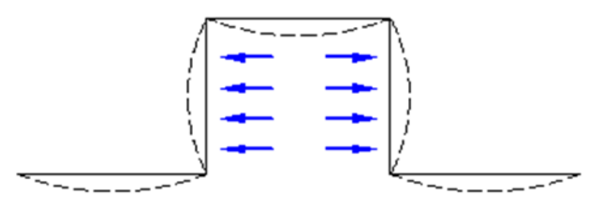

Flanged and Flued

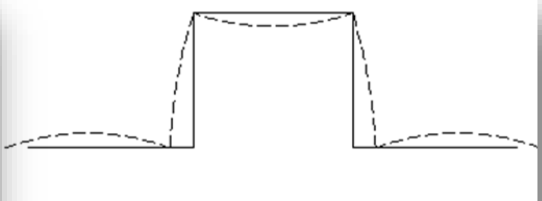

Flanged Only

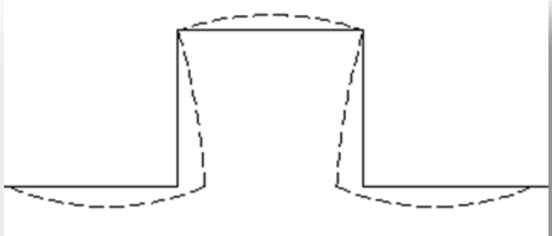

Plain Joint

These are the loads to which the expansion joint can be subjected


Pressure Acting on Shell
(Annular act like stiffeners)


Pressure Acting on Annular Plates


Axial Extension of Joint

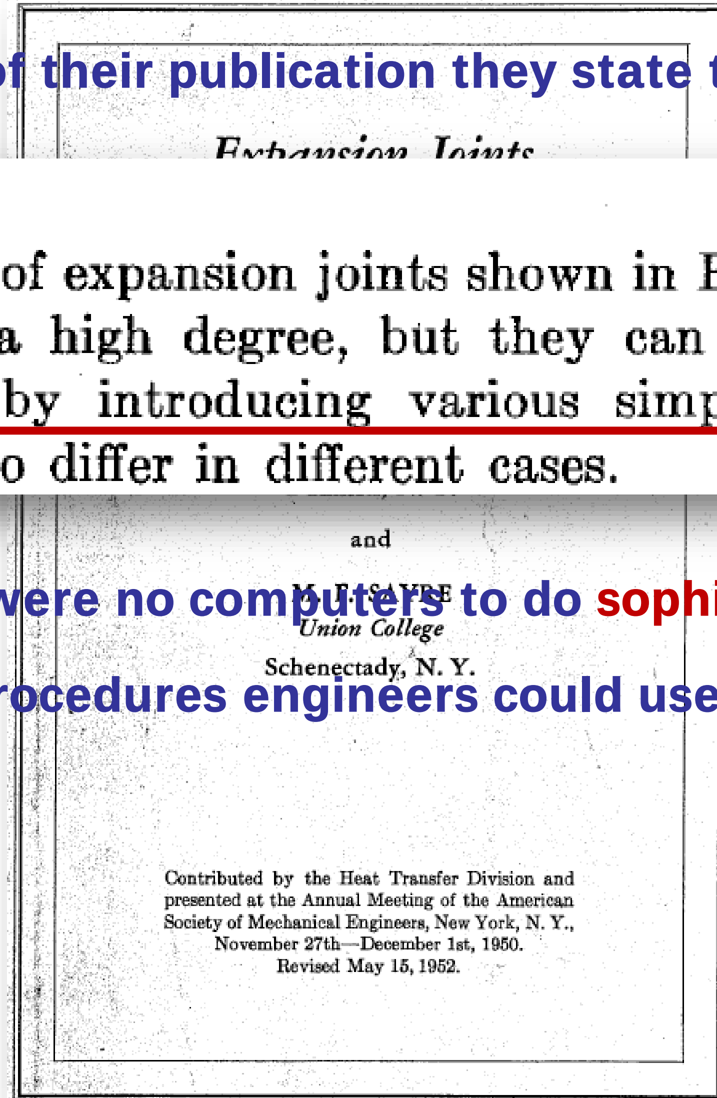

Axial Compression of Joint

Let us look at the history of the design of these expansion joints

They used mechanical gages to check their work

1950's: Work was done by Kopp & Sayre

At the beginning of their publication they state the design method


Expansion Joints

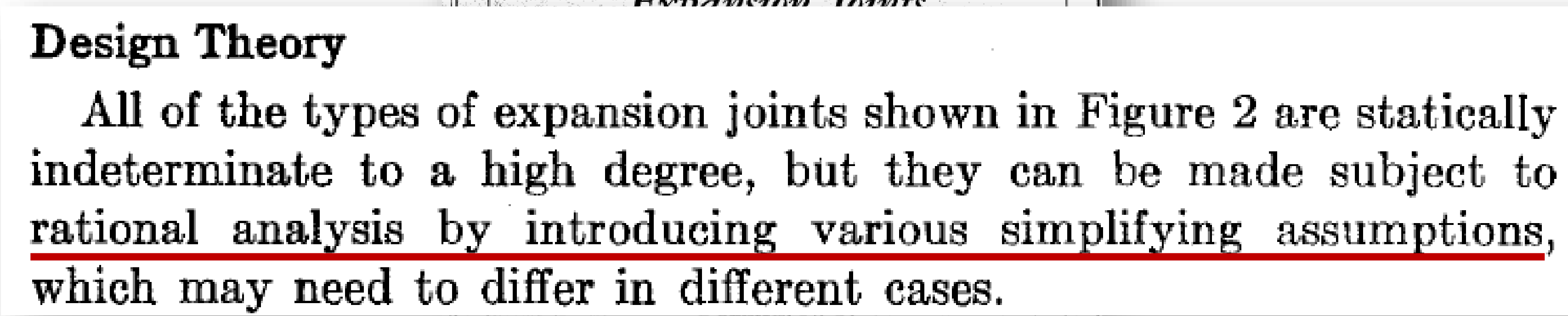
and

M. P. SAYRE

Union College

Schenectady, N. Y.

Contributed by the Heat Transfer Division and presented at the Annual Meeting of the American Society of Mechanical Engineers, New York, N. Y., November 27th—December 1st, 1950. Revised May 15, 1952.


Design Theory

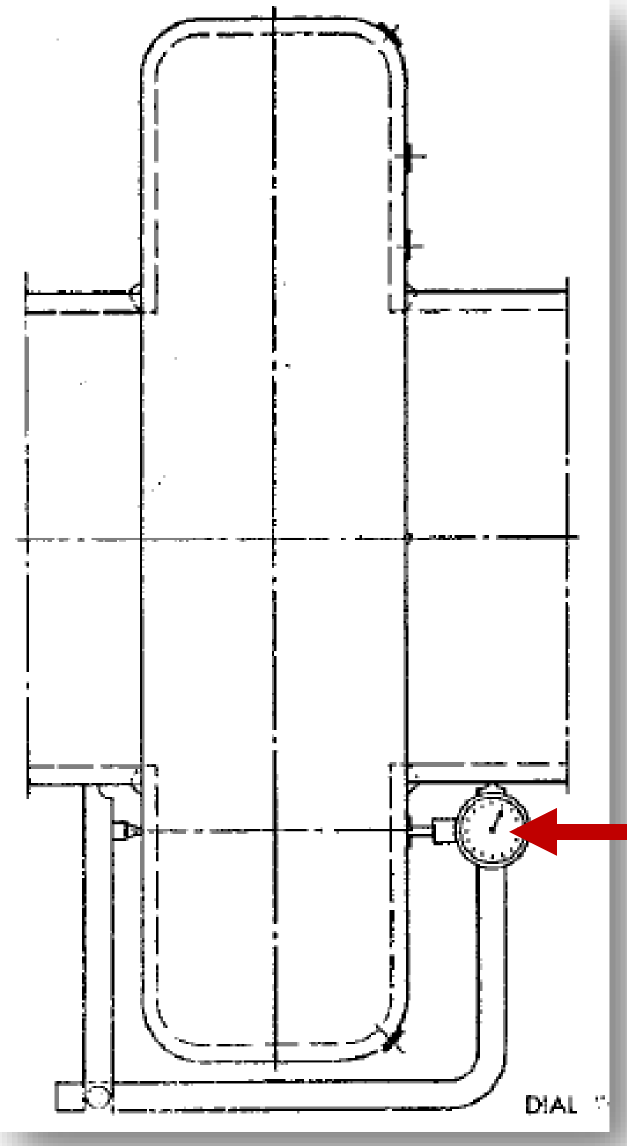
All of the types of expansion joints shown in Figure 2 are statically indeterminate to a high degree, but they can be made subject to rational analysis by introducing various simplifying assumptions, which may need to differ in different cases.

In the 50's there were no computers to do sophisticated work

They had to use procedures engineers could use with a slide rule

They used mechanical gauges to check their work

They used **equations** with which **engineers** are familiar



1998 edition of TEMA had an expansion joint analysis

They used equations with which engineers are familiar

Happily, engineers do not have to solve these equations

Figure 9-b represent... r a strip in the shell assumed to be 1 in. w... aper. The deflections are, of course, greatly ... taken at A, with the x-axis along the shell a... , the following beam equation results:

$$\frac{d^2 ...}{dx^2} = -p = -Cy.$$

Second differential of the deflection y

First differential of the shear stress p

Combining the two equations:

$$\frac{d^4y}{dx^4} = -\frac{Cy}{E'I}.$$

The solution (in this case) for this differential equation is

$$y = Ae^{-ax}\sin ax.$$

Solution

A is a constant which depends on the initial angle of the strip, and

$$a = \sqrt[4]{C/4E'I}.$$

The **1998 edition of TEMA** had an expansion joint analysis

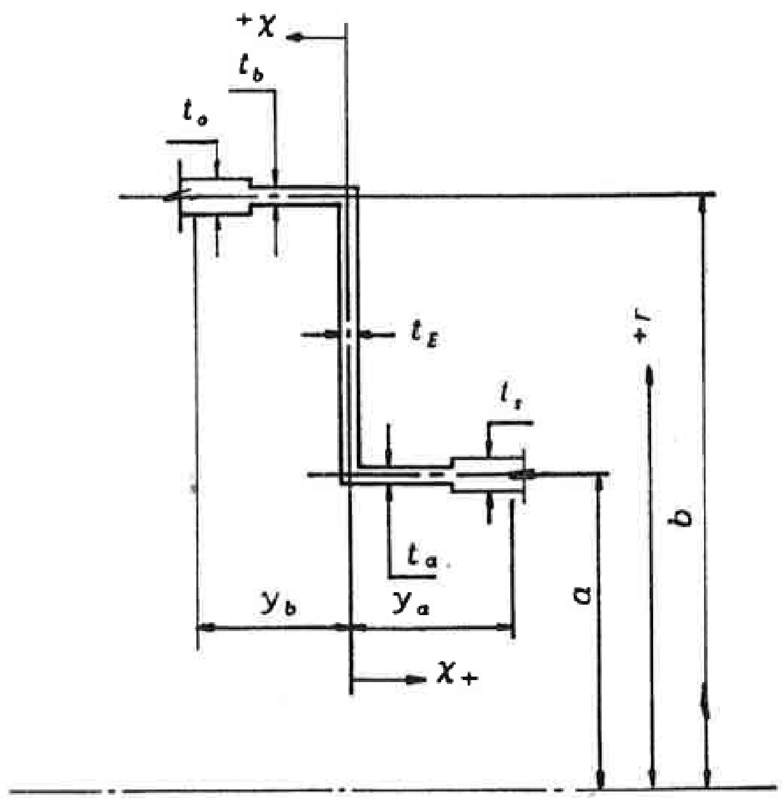
They also simplified the model for easier analysis

However, the TEMA method is **so conservative**, the expansion joint often fails the analysis.

RCB-8.22 EFFECTIVE GEOMETRY CONSTANTS

Figure RCB-8.22 defines the nomenclature used in the following paragraphs based upon the equivalent flexible element model.

FIGURE RCB-8.22



The **1998 edition of TEMA** had an expansion joint analysis

They also simplified the model for easier analysis

However, the TEMA method is **so conservative**, the expansion joint often fails the analysis.

In the 2007 version of TEMA the analysis was removed in place of a **Finite Element** Method.

The FEA software was written by the **Paulin Research Group**

We take a brief look at this later

Let consider the thin joint for a moment

The thin joint is analysed in accordance with the ASME VIII, Division 1 Appendix 26

It is based upon the method found in EJMA - Expansion Joint Manufacturer’s Association

In this presentation we do not show the detailed analysis

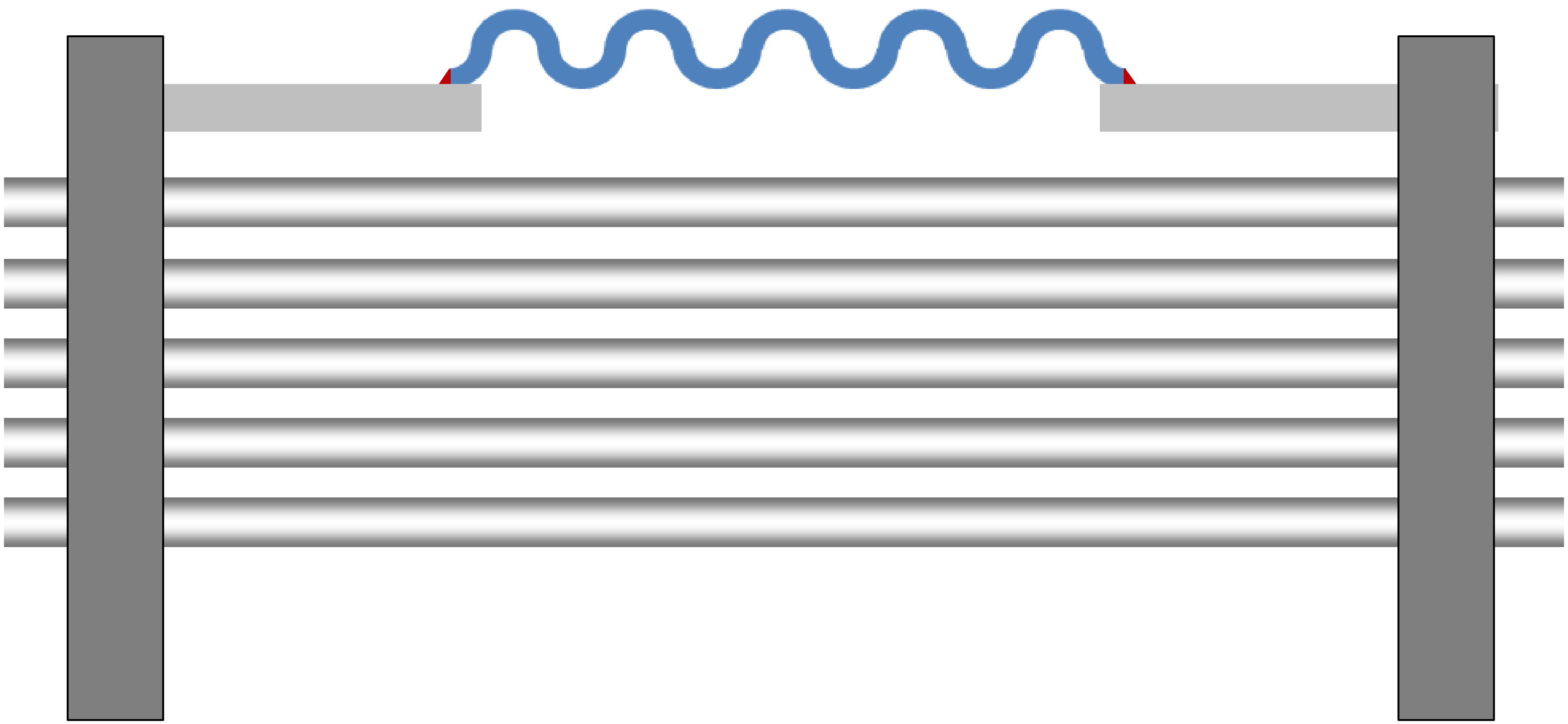
Let consider the thin joint for a moment

Consider a piping layout like this

In the case of a tube bundle the thin joint held in alignment

The tube bundle keeps the alignment

Piping attached to nozzles can cause bellows to mis-align

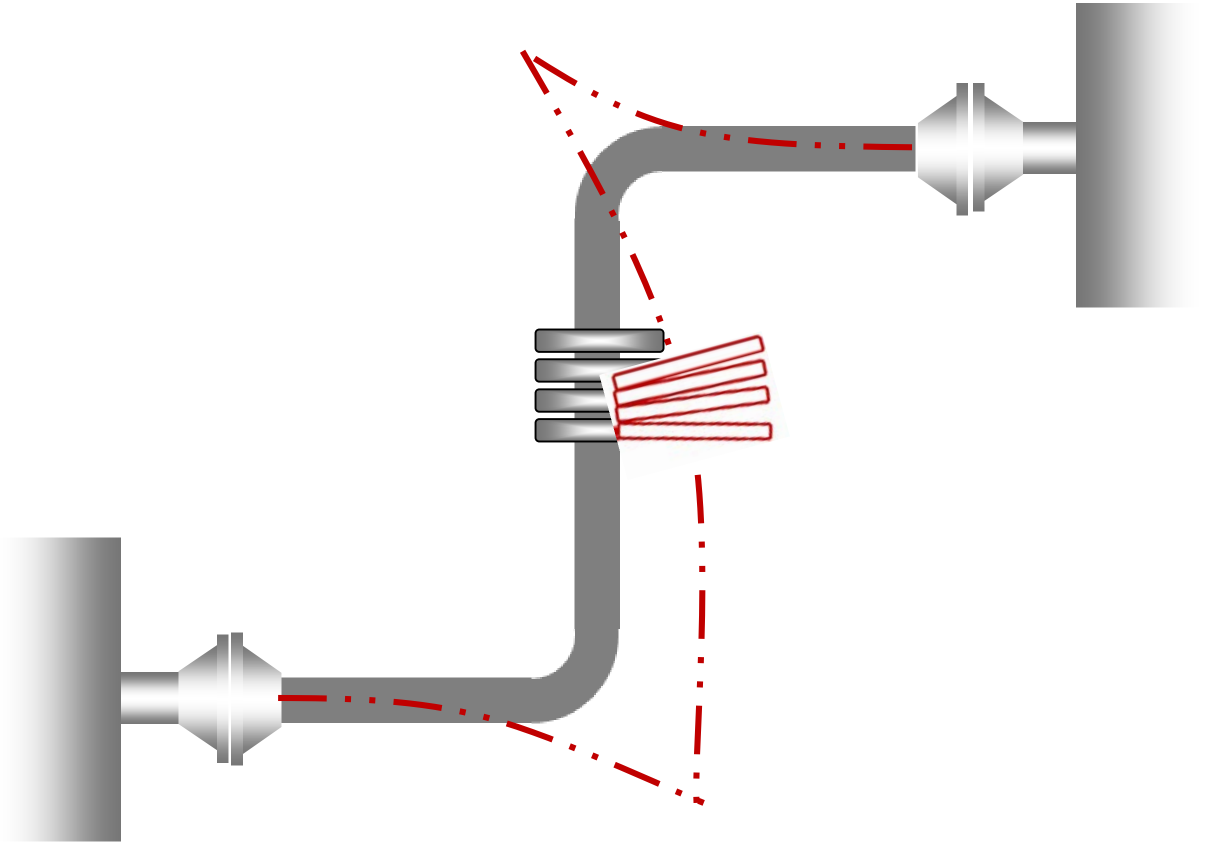


Let consider the thin joint for a moment

Consider a piping layout like this, see what happens when heated

These are the failure modes of these unsupported bellows

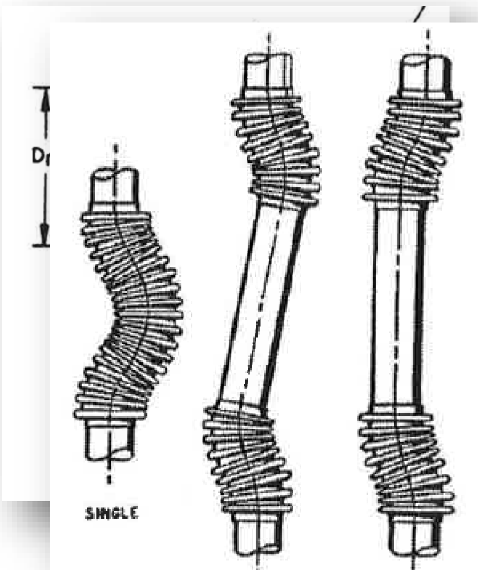
The bellows are not supported, and could fail

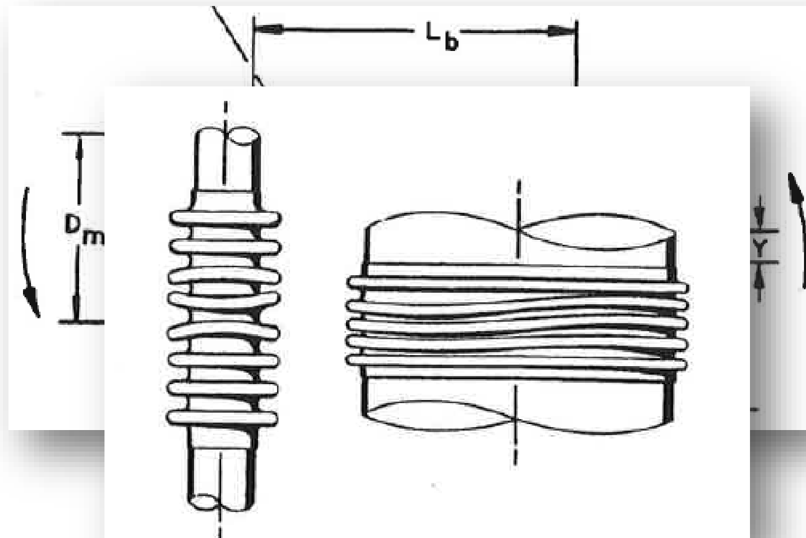


Let consider the thin joint for a moment

These are the failure modes of the unsupported bellows

This is an example of Column Squirm Bending In-Plane Lateral deflection Axial In-Plane Squirm





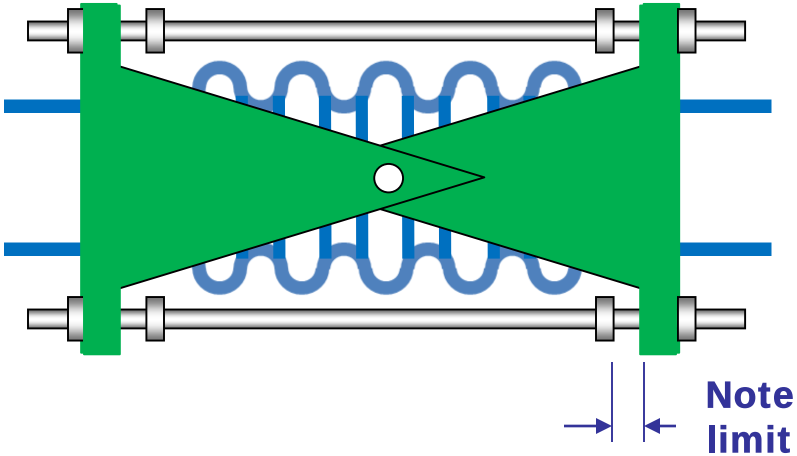
In all these movements the bellows can fail

The bellows have to be supported somehow

Let consider the thin joint for a moment

These are methods of support, to prevent lateral angular excessive expansion

We could have support in the form a a gimble arrangement



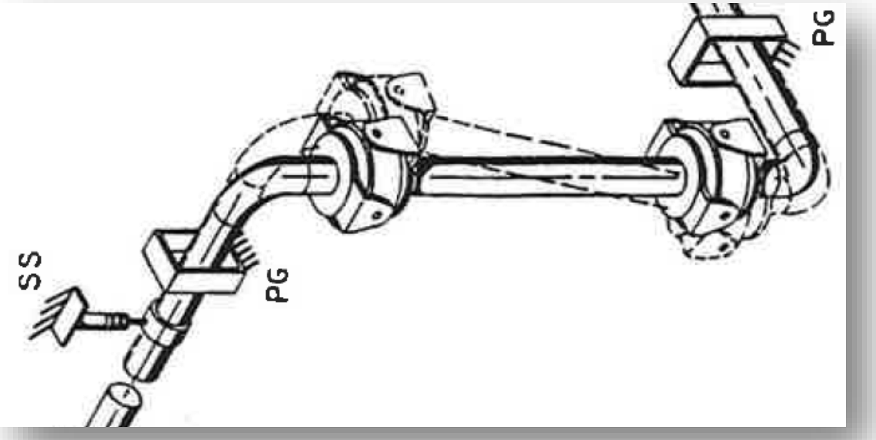
Note the gap to limit expansion

Let look at a problem with the arrangement of Expansion Joints

We consider a **thin joint** for a **design**

These are methods of support

We could have support in the form a a **gimble** arrangement



We look at a problem with the design of Expansion Joints

- Pressure design and flexibility design are conflicting requirements and create a circular design logic:
- For expansion joints, thicker is not always better.
  - Flexibility is required to reduce loads on tubesheet and tubes.
  - Flexibility is provided by reducing thickness or increasing outside diameter of expansion joint.
  - However, either of these approaches result in diminished pressure capacity.
  - Pressure capacity is satisfied by adding thickness, but this causes increased joint stiffness.
- The circular logic can be overcome with a few iterations. Some cases where pressure and displacement loads are equally important may require a finely balanced design.

We again look at the history of the design of Expansion Joints
Looking at a problem with the expansion joint analysis

- **For expansion joints, thicker is not always better.**
  - **A common misconception is that increasing the thickness will eliminate a stress problem.**
  - **Increasing the thickness of a thick walled expansion likely increases the stiffness, leading to increased stresses.**
  - **Identify the cause of the high stress, then address it by changing the geometry.**

We again look at the history of expansion joint analysis

We can now look at a PV Elite example

- Some common design methods for thick walled joints:
  - Kopp and Sayre (1950, 1952)
    - Original paper to address thick walled expansion joints.
    - Widely used.
  - Wolf and Mains (1972)
    - Introduced a more analytical approach using “ring finite elements”.
  - Singh and Soler (1984)
    - Extended Kopp and Sayer method using shell theory.
  - TEMA , ASME, and other codes and guidance
  - K-Shell (Dr. Arturs Kalnins)
  - Finite Element Analysis (Flanged+Flued)

We can now look at a PV Elite example

We are going to have a look at some expansion joints

Thank you for watching this presentation