Engineering in Extreme Environment

Professor Ian Eames

MECH0074 : Extreme Pressure Coursework 2022-2023

This CW is focused around the problem of response of an expansion loop due to a water hammer.

The activity has two parts :

Part A : a written review of expansion loops – where are they used ? how are they designed ?

Part B : a technical analysis of

(a) characteristic pressure changes due to water hammer created by rapid valve closure, and
(b) modal analysis of a cantilevered beam and expansion loop.

The total number of marks for this activity is 100.

This is the Extreme Pressure CW and 40% to your final mark.

Part A : Review of expansion loops in the energy sector

The effect of a change in temperature can lead to a contraction or extension of a pipe, which can potentially lead to buckling for long pipes. To counter this effect, expansion loops are commonly used in piping networks. There are a number of types of expansion loops which are designed using standard design codes.

Write a 3 page review of expansion loops in the context of the low temperature and high temperature configurations. Cover the three elements:

a) Choose an industrial scenario where expansion pipes are important. You should identify materials, pipe size, flow rates and give typical values for expansion. Cover the critical fluid mechanical, solid mechanical and thermal physics.
[30 marks]

b) Summarize the key rules that guide the design of expansion loops. Explain the difference between designing expansion loops for steam pipes and cryogenic systems.
[10 marks]

c) Describe how expansion loops and connecting pipes are usually supported.
[10 marks]

Total 50 Marks

Report should be 12 pt Arial.

Include references and figures.

3 page maximum

The marking scheme for Part A is described below.

Exceptional essay demonstrating in-depth knowledge and understanding on wider range of subjects.	A+	90 - 100
Excellent work is subjected to rigour quality assessment addressing key aspects of the course in an outstanding manner.	A	80 - 89
Work of very good standard, well rounded, reflecting in-depth knowledge and understanding and excellent critical analysis.	A-	70 - 79
Good quality and scope of work well presented and addressing specific aspects of the topic.	B	60 - 69
Satisfactory essay, some achievement but also some significant weaknesses/gaps are evident.	C	50 - 59
Unsatisfactory. A small scope of work inconsistently presented demonstrating unsatisfactory knowledge and understanding with substantial weaknesses/gaps in some key areas are evident.	D	40 - 49

Poor. A small scope of work done, probably poorly presented. The understanding of the subject is not demonstrated	E	30 - 39
Very poor. An unacceptable effort.	F	0-29

The challenge is to describe complex technical information in a concise manner.

Part B : Technical Assessment of Water Hammer for Expansion Loops

The purpose is to analyse the potential for overlap in the excitation frequency and pipe vibration.

(a)

(b)

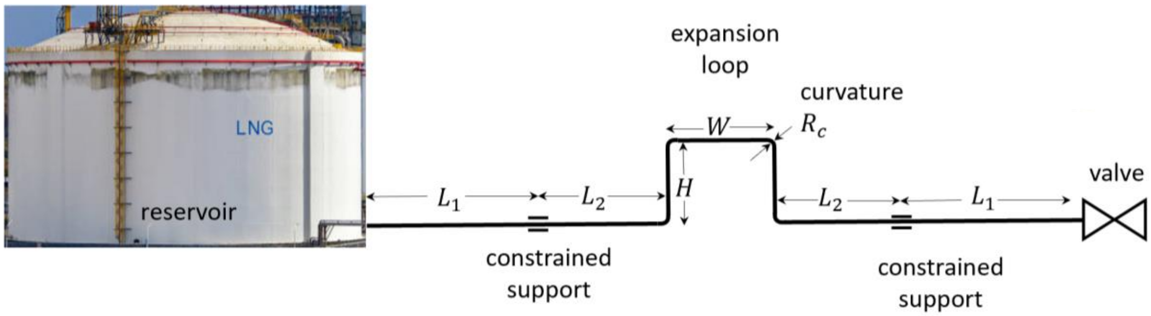


Figure 1: (a) Photograph of a 2D expansion loop, (b) schematic of the problem analysed with the dimensions of the piping network to be analysed shown.

The pipe is DN800 and so has an external diameter of 813mm, internal diameter 793.94 mm, fluid is LNG, and the piping material is structural steel (density $\rho_s = 7850\ \mathrm{kg\ m^{-3}}$ and Young's modulus $E = 200\ \mathrm{GPa}$). The water hammer is generated by a rapid valve closure. The pipes are assumed to be constructed of steel.

Step 1: Frequency of the water hammer pressure fluctuation in a pipe

In the first step, you need to run a given Matlab program to determine

(i) pressure jump caused by the water hammer, and

(ii) the relationship between the frequency of water pressure, at a specific point, pipelength and speed of sound.

Tasks

The typical values for LNG are $\rho_f = 455\ \mathrm{kg\,m^{-3}}$, speed of sound $c_0 = 1100\ \mathrm{m\,s^{-1}}$. For flow in a pipe, take initial static pressure as $p_0 = 1\ \mathrm{M\,Pa}$, $V_0 = 1.5\ \mathrm{m\,s^{-1}}$, pipe length as $s_{max} = 100\ \mathrm{m}$.

(a) Run the Matlab script up to $t = 1\ s$, plot out pressure versus time at point distance s= 10, 25, 50 m from the inlet valve.

(i) From this determine the pressure fluctuation and compare with Joukowski prediction.

(ii) Determine the frequencies associated with the pressure fluctuation and compare with an analytical prediction.

[5 marks]

(b) Estimate the

(i) force acting on a bend due to the reflection of the pressure wave, and

(ii) the direction of the total force on the expansion loop.

[5 marks]

Step 2: Modal analysis of expansion loop

The purpose of the second task is to understand the relationship between the theoretical modal frequencies, real problems and typical values for expansion loops.

Tasks

(a) Perform a modal analysis on a cantilevered pipe of length L =4, 10 and 20 m filled with LNG and compare with the theoretical predictions of frequency from the lectures. Incorporation of fluid density is achieved through adjustment of the effective density of the pipe material.

(i) List the unique frequencies as a table

Model

Mode	L=4m	10m	20m	Theory
1				
2				
3				
4				
5				
6				

Perform a basic mesh sensitivity test on the results.

[4 marks]

(ii) Discuss in the differences and similarities between the theoretical and calculated vibrational modes.

[6 marks]

For this exercise you will be using ANSYS Workbench with Modal Analysis, and given an example of this problem. A video of how this is done is given in the supplementary material, in addition to an example test case. The pipes may be treated as beam elements.

(b) Perform a modal analysis on the expansion loop (filled with LNG) shown in figure 1(b) and figure 2. Note the location of fixed joints and lateral constraints. You need to decide and justify the choice of the constraints applied here.

[15 marks]

$L_1 = 20\,m$

$L_2 = 10\,m$

$H = 10\,m$

$W = 15\,m$

$R_c = 1.4\,m$

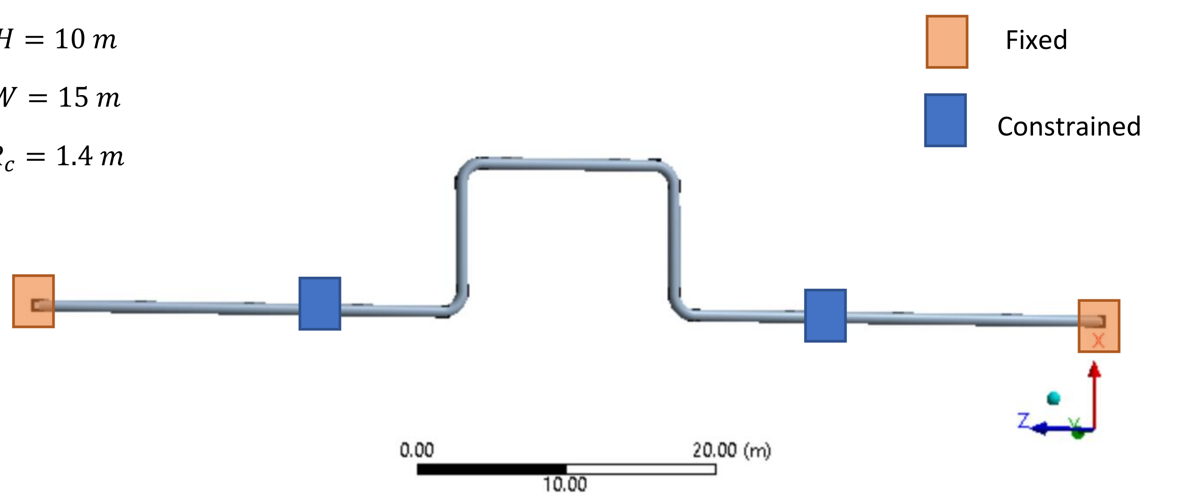


Figure 2: Schematic of the model in ANSYS Modal workbench.

Step 3: Discussion and context.

Discuss the potential overlap of driving frequency and modal frequency for driving resonance.

[5 marks]

Determine the approximate regime where resonance is likely to occur and its dependence on s_{max}, c_0, and expansion loop geometry.

[10 marks]

Total 50 Marks

Appendix : Resources

(a) Documented Matlab programme to calculate the pressure fluctuation in a pipe due to valve closure. The nonlinear inviscid flow is calculated using Lax-Wendroff.

(b) ANSYS problem file

(i) Modal analysis for cantilevered pipe example
(ii) Modal analysis for expansion loop.

Useful equations

(1) Effective density of the pipe
The pipe response needs to take into account the mass of the LNG which is achieved using an effective pipe wall density of

$$\rho_{eff} = \rho_s + \rho_{LNG} \frac{d_i^2}{d_e^2 - d_i^2}.$$

(2) Bending modes of cantilevered pipe

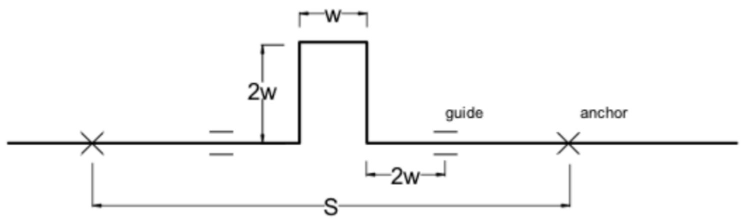
$$f_n = \frac{\alpha_n^2}{2\pi} \left(\frac{EI}{\rho_{eff} A L^4} \right)^{\frac{1}{2}},$$

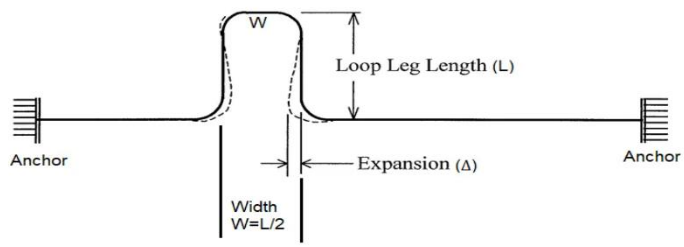
where the second moment of area,

$$\frac{I}{A} = \frac{1}{16}(d_e^2 + d_i^2)$$

The coefficients, $\alpha_1 = 1.875, \alpha_2 = 4.694, \alpha_3 = 7.855.$

Notes





Expansion loops is a common way to absorb the are typically fashioned from standard pipe fittings. There are a number of variants (2D versus 3D) with flare and condensate lines usually being 2D. A typical distance from the guide to the loop is $2w$, with the loop height $2w$. The U loop calculation is based on

$$w = 0.015\,(\alpha \Delta T\; S\; D)^{\frac{1}{2}}$$

where α is the thermal expansivity, S length of expanding pipe and ΔT is the increase in temperature. The increase in pipe length due to a change in temperature is $\alpha \Delta T$.

The allowed displacement or movement of the pipe is typically 250-300 mm inside a loop and 75-100 mm in outside turns. The allowed expansion stress is normally around 80% of code allowable. There are usually loop supporting requirements. Line sagging criteria are usually specified (limiting to 3-5mm, in some cases up to 15mm) for steam, condensate and two phase lines etc.

Design guidance for expansion loops can be found in the following:

a) ASME B31.8, Paragraph 832

b) Piping Engineering (1976) pages 141-155, published by Tube Turns Division of Chemetron Corporation

c) Pressure Vessel and Piping Design—Collected Paper 1929-1995, published by ASME