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DETERMINATION OF THE OPTIMAL PIPE SUPPORT SPANS FOR GEOTHERMAL PIPELINES

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ABSTRACT

Optimising (maximising) the spacing of the supports on geothermal two phase, steam and water pipelines will produce construction cost savings. Equations for calculating the maximum span for design code ASME B31.1 and continuous pipelines are given. A method for optimising the pipe spans on a typical geothermal pipeline expansion loop is described.

1 INTRODUCTION

Geothermal pipelines typically consist of steel piping supported at regular intervals on steel supports embedded in concrete foundations.

The distance between supports is the span.

The supports consist of an upright embedded in the foundation, the slipper (shoe) attached (welded) to the pipe and an optional saddle between the slipper and the pipe. See figure 1. Saddles (reinforcing plates) are used when additional strength is required at the point of attachment of the slipper to the pipe. To allow for the thermal expansion of the pipeline the slipper slides on the support.

Designers use variations on the simple support, shown in figure 1, to control the forces on the pipeline due to thermal expansion, earthquake and other loads. Fully fixed supports (anchors) and supports that prevent sideways movement (guides) are commonly used.

Pipelines are constructed with offsets or bends (elbows) to compensate for thermal expansion. The bends allow the piping to move sideways rather than compress which would happen if the pipeline was run in a straight line between anchors. See figure 2.

A geothermal steamfield may consist of pipelines with hundreds of supports. If each support costs, say $1000 to build then optimising (maximising) spans to give a 10 to 20% decrease in the number of supports is worth while.

2 CALCULATION OF MAXIMUM PIPE SPAN

2.1 General Stresses

The stresses acting through the pipe wall at supports due to sustained loads are:

1. Pressure stresses, longitudinal and hoop.
2. Gross bending stress due to the weight of the pipe, contents and insulation.
3. Local stress at the point of slipper attachment

Piping design codes (eg. B31.1), give limits on the stress due to sustained loads in terms of pressure (P) and bending moments due to pipe and contents weight (M_A)

$$\frac{PD_o}{4t_n} + \frac{1000(.75i)M_A}{Z} \leq 1.0S_h \qquad (1)$$

Where:
- P = Design Pressure. MPa
- D_o = Outside diameter of pipe. mm
- t_n = Wall thickness of pipe less allowances. mm
- i = Stress intensification factor. For straight pipe $0.75i = 1$.
- M_A = the square root of the sum of the squares of the bending moments due to sustained loads. N.m
- S_h = Allowable stress (from code) (MPa)
- Z = Section modulus. mm^3

For an infinitely long pipeline line with equal support spacing.

$$M_A = \frac{wl^2}{12} \qquad (2)$$

Where:
- w = the unit weight of the pipe, insulation and contents. (Nm^{-1})
- l = the pipe span (m)

Substituting for M_A in (1) gives

$$\frac{PD_o}{4t_n} + \frac{10000wl^2}{12Z} \leq S_h \qquad (3)$$

Solving for maximum l and substituting for Z gives

$$l_{\max} \leq \sqrt{\left(S_h - \frac{PD_o}{4t_n}\right)\frac{12}{1000w}\left(\frac{\pi\left(D^4 - (D-2t_n)^4\right)}{32D}\right)} \qquad (4)$$

Applying equation (4) to an example of a 500NPS STD water/brine line, 2mm wall thinning allowance and a design pressure of 25 bar.g gives a maximum span of 18.8m.

The above calculated span is considerably longer than the suggested maximum span in B31.1, table 121.5 of only 9.1m. Table 121.5 is conservative and only allows a bending stress of 15.9MPa, where as the bending stress in the above example is 61.2MPa.

2.2 Local Stresses

Equation (4) does not consider local stresses through the pipe wall at the point of attachment of the support slipper to the pipe. These local stresses must be considered in the calculation of maximum pipe span.

Generally piping codes do not give methods for the calculation of the local stresses. Standard BS5500 gives a method for calculating these stresses (at the supports of a pressure vessel). Finite Element Analysis can also be used.

BS5500 Annex G gives a method of finding the local stresses as function of the geometry of the pipe/vessel support slipper and the weight (force) on the pipe slipper. Annex G also allows the stresses to be calculated when a reinforcing pad (saddle) is used.

The equations and graphs in BS5500 are complex and presenting these here would be tedious.

To find the maximum span the maximum local, general bending and pressures stresses are combined and must be less than the appropriate design stress.

This combination can be reduced to:

$$K_a F_A + K_b M_A + K_c P < S \qquad (5)$$

For any given pipeline the design stress and pressure are constant, therefore equation (5) can be reduced to:

$$K_1 F_A + K_2 M_A < 1 \qquad (6)$$

Where:
F_A = the force on the pipe support (N)
K_1, K_2 = Factors dependent on design stress and pressure and the pipe and slipper geometry.

Factors K_1 and K_2 can be calculated from consideration of the equations and graphs in BS5500 Annex G.

For an infinitely long pipeline with equal support spacing

$$F_A = wl \qquad (7)$$

Substituting F_A and M_A in equation (6) gives.

$$K_1 wl + \frac{K_2 wl^2}{12} < 1 \qquad (8)$$

Applying equation (8) to the example above and assuming a slipper 150mm wide and no saddle gives a maximum span of only 7m. Adding a saddle gives a span of 15.2m.

3 EARTH QUAKE LOADS

In B31.1 earthquake loads are regarded as Occasional Loads and the moments generated from these loads must meet the requirement of:

$$\frac{PD_o}{4t_n} + \frac{1000(.75i)M_A}{Z} + \frac{1000(.75i)M_B}{Z} \le kS_h \qquad (9)$$

Where:
M_B = the square root of the sum of the squares of the bending moments due to occasional loads. N.m
k = 1.2 for earth quake loads.

The simplest method for modelling earthquake loads is to apply a static horizontal load to the pipeline which is a factor, C, times the vertical gravity force. C is location and risk dependent can typically range from 0.3 to 0.9.

For an infinitely long pipeline line with equal support spacing.

$$M_B = \frac{Cwl^2}{12} \qquad (10)$$

The first two terms in equation (9) are the same as the terms of equation (1). Also substituting for M_B, Z, and k and solving for l gives.

$$l_{\max} \le \sqrt{\left(1.2S_h - \frac{PD_o}{4t_n}\right)\frac{12}{(1+C)1000w}\left(\frac{\pi\left(D^4 - (D-2t_n)^4\right)}{32D}\right)} \qquad (11)$$

Applying equation (11) to the example above of a 500NPS STD water/brine line, 2mm wall thinning allowance and a design pressure of 25 bar.g and earthquake coefficient of 0.5g gives a maximum span of 17.8m.

4 LOCATING SUPPORTS

Equations (3), (8) and (11) apply to infinitely long pipelines with equal support spacing. In practice, pipelines will not have equal spans and loads, therefore moments and forces at each support will vary. The sustained moments and forces at each support have to satisfy both equations (1) and (6).

Designers often design a pipeline using the maximum span from equations (3), (8) and (11) as a guide. Experience is then used to reduce the spans close to elbows or valves etc. The pipeline is then analysed with a piping design program. The program calculates the forces and moments at each support and tests for compliance with equations (1) and (9). The forces and moments usually need to be manually checked against equation (6).

If the forces and moments are excessive (or unnecessary low) the designer then has to reposition the supports (and analyse again) or change the design of the slipper at the problem supports. Using thicker pipe at supports can also reduce high stresses.

4.1 Reducing Thermal Stresses

Careful locating of supports will also reduce thermal stresses and allow the designer to use smaller offsets for expansion and reduce the total length of the pipeline.

B31.1 (and other codes) allows the difference between the maximum allowable stress and actual stress for sustained loads, at a given point, to be added to the maximum allowable stress for thermal expansion. (B31.1 clause 102.3.2 (D))

Therefore, if an elbow (for example) has low sustained stress it can have higher expansion stress. Careful placement of supports near elbows will minimise the sustained bending moments/stresses and maximise the allowable thermal expansion stress.

4.2 Optimisation

It is possible to mathematically model a typical expansion loop like the one shown in figure 2 and optimise the placement of each support.

The model would consist of three-moment equations (Roark pg 115) for each support, anchor and elbow in the loop.

The boundary conditions, at the anchors at the start and finish of the loop, are that the slope/rotation of the pipe is zero.

The variables to alter are the pipe support spans and the length of the expansion loop.

The conditions to satisfy would be:

- Forces and moments at supports satisfy equation (8)
- The bending moment at any point satisfies equation (1)
- The support spans are maximised
- The bending moments at the elbow are minimised
- The length of the expansion loop offset is minimised.

The next step would be to form a set of simultaneous equations from the above equations and conditions. A computer algorithm could then find the optimum solution.

4.3 Reducing Earthquake Stresses

As shown in equation (9) above, stresses due to earthquake contain a sustained stress component. Reducing the pipeline spans around a point with high earthquake stress will lower these stresses.

5 OTHER CONSIDERATIONS

5.1 Lost Support Case.

When determining maximum span some designers consider the situation where a single pipe support may be lost, due to land subsidence for example. This does not mean that the maximum span would be only half span calculated above. In this case the design does not have to consider the lost support case a sustained load or an earthquake happening at the same time and can apply a suitable factor to the allowable design stress.

5.2 Wind

The effect of wind loads on the maximum span can be calculated the same way earthquake loads are calculated above.

5.3 Sag & Pipeline Drainage

Generally, pipelines need to be free draining. If the sag in the pipe between supports is not overcome by the slope of the pipeline then the pipeline will not drain fully.

The sag can be calculated. For an infinitely long pipeline line with equal support spacing the deflection at the mid point of the span is:

$$y = \frac{w_e l^4}{384EI} \times 10^9 \qquad (12)$$

Where:
y = The defection at mid span. mm
E = Elastic modulus MPa.
w_e = the unit weight of the pipe without contents. (Nm^{-1})
I = Pipe Moment of Inertia, mm^4

To allow the pipe to drain, then the slope of the pipeline must be greater than $2y/l$. For the example above with a 15.2m span the pipeline slope needs to be greater than 1:1300.

5.4 Other loads

The pipeline may be subject to loads in addition to the loads considered above. For example, small lines may become over stressed if personnel walked on the pipeline or the weight of valves and or flanges could over stress the pipe. The spans would need to be reduced to allow for this.

Design of support slippers needs to consider local stress due to horizontal and vertical components of thermal and earthquake forces.

6 CONCLUSIONS

The author and his colleagues have developed and used the above design methods on New Zealand geothermal projects over the past 20 years. This has seen a steady reduction in the construction cost of geothermal pipelines over this time.

The optimisation method described in section 4.2 above has not been used in practise. More work is required to develop the equations for the forces and stresses at the elbow of a typical piping offset.

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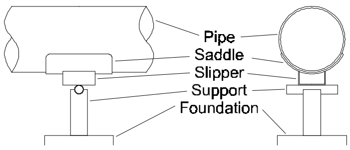

Figure 1. Pipe Simple Support Details

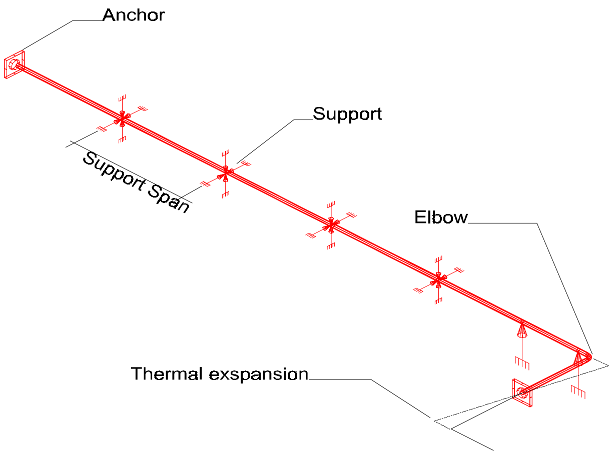

Figure 2. Typical pipeline expansion loop