Resolution of Issues Related to Simplified Piping Seismic Analysis

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SUMMARY

A simplified static analysis approach has been adopted by the industry to conduct piping analysis on a cost effective basis, resulting in piping design relying more by rules than by exhaustive dynamic analyses.

This paper presents a study of the technical issues related to the simplified analysis approach applicable to deadweight-hung piping.

INTRODUCTION

Deadweight-hung piping designed to the ANSI B31.1 (ASME, 1983) span rules tends to be very flexible, consists of few seismic supports and has many natural frequencies in the range of 0.1 to 15 Hz. A static load coefficient method (LCM) (Stevenson, 1989) has been written into ASME Code case N-468 (ASME, 1989) for determining earthquake loads.

This paper presents a study of hanger uplift and piping lateral restoration issues related to the LCM approach.

Approach

Simple piping arrangements are studied herein.

A. Hanger Uplift

Three contributing factors which could potentially cause the hanger to uplift are: the vertical building response motion, the motion of adjacent spans acting as moment arms lifting the hangers, and the axial pipe motion at a different elevation acting as a moment arm.

a. Vertical Pipe Motion

Consider a simply supported beam with a span length L and

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the modeshape $\phi = \sin(\pi x/L)$. One may arrive at the following parameters:

Participation factor

$$P = 4/\pi \tag{1}$$

Reaction at one support

$$F_A = (4L/\pi^2)\ (W/g)\ S_a \tag{2}$$

Moment at the center of the span

$$M_{cD} = (L^2/\pi^2)\ (W/g)\ S_a \tag{3}$$

where S_a is the response spectral value and W is the unit weight per length.

For a statically loaded span, the maximum moment at the center of span is

$$M_{cs} = (L^2/8)\ (W/g)\ S_a \tag{4}$$

Therefore,

$$M_{cs}/M_{cD} = \pi^2/8 \tag{5}$$

Equation (5) indicates that the static approach will over-predict the response moment by about 23% due to dynamic load distribution.

On a static basis, the vertical input coefficient should only be $(8/\pi^2)\ S_a$. This indicates that uplift as a result of vertical response is unlikely for low seismicity sites if S_a is less than 1g. For higher seismicity sites, the potential for uplifts will require evaluation on a case basis.

b. <u>Uplift due to actions from adjacent Spans</u>

Two types of actions are possible: a span moving downward which creates a moment lifting the supports in adjacent spans; an axial motion of one horizontal span which produces a moment in another horizontal span located at a different elevation from the moving span.

The first case can be studied using the simple model shown in Figs. 1(a) and 1(b).

In order for M_2 to produce an uplift for span L_2, angle Θ should be more than the angle from the deadweight less the upward response.

From the three moment equation, the slopes Θ_L and Θ_r at the left and right spans of support B are

$$EI\ \Theta_L = M_2L_1/3 + WL^3_1/24 + WCL^3_1/24 \qquad (6)$$

$$EI\ \Theta_r = -\ M_2L_2/3 - WL^3_2/24 - WCL^3_2/24 \qquad (7)$$

where C represents the vertical response as a percentage of the deadweight load.

Equating the two angles and solving for M_2, the rotation at either side of the support B becomes

$$\Theta = L_2\ W\ [L_1^3\ (1+C)+L_2^3\ (1-C)]\ /8EI\ (L_1+L_2) \qquad (8)$$

Eq. (8) can be studied to identify the relationship of L_1 and L_2 when Θ would become positive, indicating uplift. Or, on a conservative basis, one may assess the maximum deflection at the span L_2 for any given C to identify the span ratio (L_1/L_2) where uplift may occur.

c. Uplift due to axial pipe motion at different elevations

The effect of axial pipe motion at one elevation could produce uplift motion of the hanger at the horizontal span through the moment couple at vertical drop. To eliminate such an uplift force, an axial restraint at the horizontal segment may be required. However, each axial restraint will need to include the potential thermal expansion force into account which may not be a small amount. It should be noted also that any amount of sagging from deadweight or constrained expansion at an elbow will relieve the substantial portion of the force. Therefore, it is more likely for the pipe to bow than for the axial support to fail. This item nevertheless, requires evaluation.

B. Pendulum Restoration Effect of a Hanger

Although a deadweight hanger is intended to provide support for only the vertical downward force, it will provide a restoring effect to piping with substantial lateral motion. This restoring effect can be evaluated using Fig. 2(a) where the boundary conditions at B and C are full lateral hinges along the beam axis. Only one end is restrained axially.

The fundamental natural frequency of the beam, having the modeshape of a half sine wave with maximum modal displacement at A when the hanger is assumed not acting, can be written as

$$\Omega_{L1} = (K_{PL}/M_p)^{1/2}/2\pi \qquad (9)$$

where K_{PL} represents the pipe lateral stiffness at A and M_p is the effective mass.

Assuming also that the vertical piping response is smaller than deadweight, then the hanger will act as a vertical spring.

Assuming further that the hanger axial stiffness is far greater than the lateral stiffness for the pipe span at A, the fundamental lateral pipe motion can be simplified to Fig. 2(b).

Since it is assumed that the hanger tension stiffness is substantially greater than the lateral stiffness, M_p will move along the arc represented by the angle Θ.

For small angle Θ one has

$$\Delta = a\ (1 - \cos \Theta_m) \approx a\ \Theta_m^2/2 \tag{10}$$

The maximum potential energy of the system where the higher order term (Θ_m^4) can be neglected is

$$(PE)max = (K_{pL}\ a^2\ \Theta_m^2 + M_p\ ga\ \Theta_m^2)/2 \tag{11}$$

The maximum kinetic energy when the pipe is at the vertical position is

$$(KE)max = M_p\ (a\ \Theta_m)^2 \tag{12}$$

where Θ_m is the maximum angular velocity.

Equating equations (11) and (12), one has

$$M_p\ a\ \Theta_m^2 = (K_{PL}\ a + M_p\ g)\ \Theta_m^2 \tag{13}$$

which can be solved to yield the frequency Ω

$$\Omega = (K_{PL}/M_p + g/a)^{1/2} \tag{14}$$

Equation (14) shows that the pendulum effect will increase the frequency and shorten the period of the system. This is different from the pendulum with the mass at the top and the pivot point at the bottom. In such a case, the frequency is reduced since the weight effect is to increase the movement of the pendulum.

When the restoring force of the hanger is not considered the span frequency Ω_o becomes

$$\Omega_o = (K_{PL}/M_p)^{1/2} \tag{15}$$

The frequency ratio of equations (14) and (15) can be written as

$$(\Omega/\Omega_o) = (1 + g/(a\Omega_o^2))^{1/2} \tag{16}$$

Equation (16) is evaluated in Table 1 for various combinations of "a", the pendulum arm length, and the span frequency Ω_o (where no restoration force of the hanger is assumed). From Table 1, it is obvious that only piping less than 3 Hz would have the natural frequency increased by more than 5% for a hanger at least 10 inches in length. The hanger restoration force is largest when the span frequency is less than 1 Hz.

One should note that in the above analysis, the hanger is assumed to act as a free swinging pendulum. In reality, the hinged end normally connects with the support which is typically bolted. Any binding or restrain at the connection would produce further resistance to the lateral movement of the pipe. This same restraining motion would also become the potential failure mechanism especially if fatigue is involved.

Concluding Remarks

A study has been presented to address the pipe uplift and lateral restoration force issues for deadweight-hung piping subjected to seismic loads. Simple equations have been derived to allow these effects be accounted for in the simplified piping analysis approach.

REFERENCES

ANSI B31.1, ASME Code for Pressure Piping, 1983.

Stevenson, J.D. (1989). Further Development of the Load Coefficient Method (LCM) for Rational Seismic Design of Nuclear Facilities, Nuclear Engineering and Design III, pp. 363-370.

ASME Section III, Code Case N-468, Alternate Method of Earthquake Description for Class 2 and 3 Piping at Low Seismicity Sites, March 8, 1989.

Table 1 Pipe Frequency Increase Due to the Hanger Restoration Force

Ω_o (Hz)	Ω_o (Rad/Sec)	a (in)	$g/(a\Omega_o^2)$ --	Ω/Ω_o --
0.2	1.26	10	24.47	5.05
		30	8.16	3.03
		50	4.89	2.43
0.4	2.51	10	6.12	2.67
		30	2.04	1.74
		50	1.22	1.49
0.6	3.77	10	2.72	1.93
		30	0.91	1.38
		50	0.54	1.24
0.8	5.03	10	1.53	1.59
		30	0.51	1.23
		50	0.31	1.14
1.0	6.28	10	0.98	1.41
		30	0.33	1.15
		50	0.20	1.09
3.0	18.85	10	0.11	1.05
		30	0.04	1.02
5.0	31.42	10	0.04	1.02

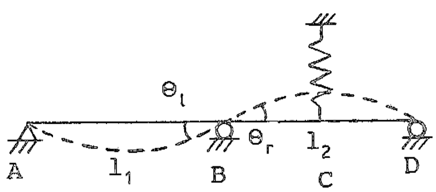

Fig. 1(a)

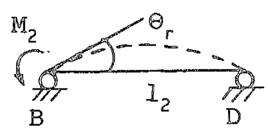

Fig. 1(b)

Figure 1 Simply supported beam with a deadweight hanger

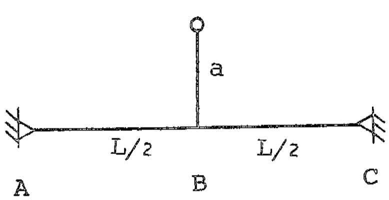

Fig. 2(a)

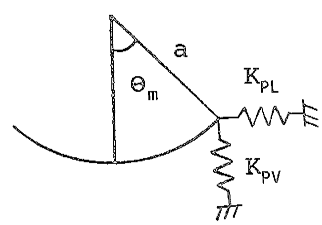

Fig. 2(b)

Figure 2 Simplified representation of the pipe span with fundamental lateral motion