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EFFECTIVENESS OF SEISMIC SUPPORT IN PIPING

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ABSTRACT

A basis for design of piping systems with energy-absorbing seismic supports has been proposed. Vibration control of each non-interacting segment is separately attempted in this approach. The optimal parameters of Wen's model for the seismic support can also be determined. It is shown that the proposed procedure results in a robust design with low sensitivity to variations in support parameters. This method can be used to design new piping as well as retrofit existing piping using seismic supports.

KEYWORDS

Piping; seismic support; energy absorber; snubber; vibration control.

INTRODUCTION

Piping in nuclear power plants often carry radioactive fluids and their integrity under seismic loading is essential. Traditionally, snubbers are used with these piping to ensure seismic resistance. The snubbers, however, are unreliable and often fail. Inspection of power plants following earthquakes has shown that damage to piping system can be directly attributed to inadequate performance of snubbers in a large proportion of cases (Hardy *et al.*, 1988). In order to overcome the disadvantages of snubbers, some special seismic supports have recently been proposed. These nonlinear seismic supports, such as hysteretic and friction dampers and gap supports, can be used to dissipate excess energy under excitations and thereby limit piping deformations in Nuclear Power Plant to within acceptable range (Cloud *et al.*, 1989; Khalafallah and Lee, 1987; Kunieda *et al.*, 1987; Nomura *et al.*, 1989a, 1989b, Takayama *et al.*, 1989).

The presence of nonlinear supports makes the piping behaviour nonlinear and the corresponding analysis using traditional computational techniques is very cumbersome to carry out. The analysis can be considerably simplified if the piping is considered to remain linear while the only nonlinearity is due to the response of seismic supports. On the basis of this assumption, efficient analysis procedures for response of piping with nonlinear supports have recently been proposed (Igusa *et al.*, 1989; 1993). However, efficient design of piping also requires quantitative information on the behaviour of nonlinear supports under excitation. In this paper, the effectiveness of these supports is investigated to form an analytical basis for determining the desired properties of seismic supports.

An examination of the hysteresis curves of different available seismic supports show wide variation in shape. Due to the constraints imposed by the materials available and the manufacturing process, it is not possible to easily obtain a specific hysteretic characteristic. The effect of change in material properties due to ageing and environmental conditions such as high radiation also affect the hysteretic properties. As a result, it has become imperative to fully evaluate the sensitivity of piping response to the support properties. This study is aimed at assisting in the determination of optimal support properties for typical piping configurations. These concepts have been illustrated through the example of a simple piping segment whose response characteristics for seismic loading has been investigated.

The procedure suggested in this paper can be used to choose appropriate seismic supports for piping in new power plants. The proposed technique can also be used to determine the seismic capacity of existing piping and to use seismic supports for retrofitting. The methods of analysis that have been used herein can also be used for other situations requiring vibration control using energy dissipating seismic supports. These results can form a powerful basis of designing robust vibration control techniques for flexible subsystems such as pumps and heat exchangers in power plants.

CHARACTERISTICS OF SEISMIC SUPPORTS

Several different types of seismic supports have been proposed to be used. These supports can be broadly divided into three main categories: (1) Smoothly hysteretic supports, in which the force-displacement is smoothly varying; (2) Friction supports, in which the force-displacement is elasto-plastic with very high initial stiffness; and (3) Gap supports, which have very low initial stiffness, and are smoothly hysteretic or elasto-plastic at large deformation levels. The mechanisms and properties of typical supports has been presented by Buckle (1985) and Chiba and Kobayashi (1990b).

The properties of smoothly hysteretic supports have been considered in this investigation. The hysteretic component of the restoring force in these supports can be expressed by the parameteric equation (Wen, 1976)

$$\dot{f} = k_0\, \dot{x} - \beta\, |\dot{x}|\, |f|^{n-1} f - \gamma\, \dot{x}\, |f|^n \tag{1}$$

where k_0 is the initial stiffness of the support and β, γ and n are model parameters. For commonly available seismic supports whose details have been published in literature, the exponent n can be taken as unity. The other parameters are chosen to give the desired shape of hysteresis curve.

The effect of variation of parameter values in the parameteric equation given above is difficult to physically interpret. The equivalent linear support properties give a much better physical understanding of the properties of these supports at different peak response levels (Sinha, 1991). The typical curves for equivalent stiffness and damping for k_0 = 20 kN/m and n = 1 are shown in figure 1. It is seen that the choice of these parameters strongly influences the equivalent properties. It can also be observed that relatively large displacements are necessary for significant nonlinear behaviour. However, at very large response levels, all stiffness curves asymptotically approach the post-yield stiffness of 0.05 k_0.

PIPING BEHAVIOUR WITH SEISMIC SUPPORTS

Piping systems, particularly in pressurised water reactor plants, are relatively flexible systems and have long unsupported spans. In typical layouts, the number of supports are minimised since these induce stresses due to thermal gradient. As a result, the typical piping configuration can often be subdivided into several non-interacting segments. The location and capacity of snubbers or seismic supports in each segment are determined such that the stresses are minimise during a seismic event. At the same time, it is essential that minimum extra stressed be induced during thermal gradients due to the presence of these seismic supports. It is also essential that the presence of seismic supports not introduce significantly higher stresses in other segments of the piping (i.e., increase interaction between segments).

As a design basis, it is proposed that the seismic supports be introduced at locations with maximum deformation in the segment under consideration. For instance, a bent flexible segment of piping will exhibit maximum deformation near the elbow, necessitating a seismic support close to the elbow. The capacity of the seismic support is chosen to ensure adequate seismic performance as well as acceptable performance under other loading conditions. However, it is essential that the placement of seismic supports do not result in significant modification of characteristics of different segments.

EXAMPLE SYSTEM

For the example system, a simple flexible piping segment is chosen on which the effect of different seismic supports is investigated. The example system consists of a straight segment of steel piping 8 m long and fixed at both ends (figure 2). The outer diameter of the pipe is 100 mm and its thickness is 5 mm. Even though more complicated piping configurations can also be chosen, this system effectively illustrates the performance of a piping segment. Consequently, it permits excellent investigation of the effect of seismic support on response at different points on the piping. These results can be directly interpreted in terms of the effect of seismic support on a local segment.

The properties of supports that are considered have been described earlier (figure 1). The piping system is assumed to have 2% damping, and the initial stiffness of the seismic support is 20 kN/m. The piping is subjected to El-centro (NS) excitation in vertical direction. The input excitation has been scaled to give useful response at different sections of the piping (reasonably large nonlinearity in support).

The following response quantities are considered: (1) Displacement and acceleration at quarter-span from end, (2) Displacement and acceleration at mid-span; and (3) Force in seismic support. All the results have been normalised with the corresponding maximum response of piping in which the seismic support has been replaced by a linear support with the same initial stiffness.

The maximum displacement and acceleration at the centre of the piping are shown for different support parameters in figure 3. It can be seen that the displacement is minimum at a critical value of β beyond which it increases linearly. For small values of β, the displacement is also minimum for a critical value of γ. However, for large values of β, the response linearly increases with increasing γ. From displacement control consideration, it is therefore desirable to use seismic supports that can be represented using the critical values of these parameters. An examination of the maximum acceleration at mid-span (figure 4) shows that the minimum acceleration occurs at a different critical values of support parameters. For large values of these parameters, the maximum acceleration values are found to be relatively insensitive to the parameters.

From design considerations, these results indicate that seismic supports that are used should have the parameters between the brackets of critical values determined from the displacement and acceleration response. This interval depends on the dynamic characteristics of the piping system, and is $\beta=\{0.3, 0.6\}$ and $\gamma=\{0.45, 0.9\}$ for the example problem.

The maximum displacement and acceleration at quarter-span are shown for different support parameters in figures 5 and 6. It can be seen that except for very small values of β and γ, all other choices of support parameters give similar responses. This clearly shows that the chosen seismic support exerts a local influence on the response only near the location of the support. This characteristic has also been verified for more complicated piping configuration and can form a useful basis for choosing appropriate supports and their locations.

The effects of change in initial stiffness is shown in figure 7. It can be seen that decrease in k_0 results in higher response at the support location. However, the response at quarter-span shows very low sensitivity to this change. This also shows that the change in response at centre is a local effect and the centre is thus an appropriate location for the seismic support.

The apparent insensitivity of piping response to the change in support parameters can be explained in terms of energy dissipation. Support response to earthquake has frequent reversals and excursions into nonlinear range. As a result, a significant amount of energy is dissipated through hysteresis, even at small response amplitude (figure 8). Thus, the use of seismic support causes a general lowering of piping response. It should be noted that the properties of seismic support should be chosen such that a significant response nonlinearity should be present at peak response levels. However, the peak response level should not be high enough to make the effective stiffness approach post-yield stiffness (figure 1).

DISCUSSIONS AND CONCLUSIONS

A basis for selection of nonlinear seismic supports for flexible piping systems has been proposed in this paper. This approach is aimed at determining the optimal support parameters and the sensitivity of peak response to variations in these parameters. Based on this investigation, the following can be concluded.

1. Vibration control techniques should separately tackle each non-interacting segment of piping system.
2. Seismic supports should be placed close to the location of maximum deformation in piping.
3. Seismic supports are effective only if significant nonlinear response is present. This should be used to determine the capacity of the seismic supports at different locations.
4. Peak responses show very low sensitivity to slight variation in support parameters from their optimal values. This shows that the performance of hysteretic seismic supports is robust.
5. Properly placed seismic supports only have a localised effect on the response. Response at several locations in a piping may be independently controlled through the use of seismic supports.

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REFERENCES

Buckle, I. G. (1985). New Zealand Seismic base isolation concepts and their application to nuclear engineering. *Nucl. Engrg. Des.*, **84**, 313-326.

Chiba, T. and H. Kobayashi (1990a). Response characteristics of piping system supported by visco-elastic and elasto-plastic dampers. *ASME J. Pres. Ves. Tech.*, **112**, 34-38.

Chiba, T. and H. Kobayashi (1990b). Dynamic response studies of piping-support systems. *ASME J. Pres. Ves. Tech.*, **112**, 39-45.

Cloud, R. L. *et al.* (1989). LWR piping : advances in design, analysis and performance. *Proc. 10th SMiRT*, **F**, 187-217.

Hardy, G. S., P. D. Smith and Y. K. Tang (1988). Piping seismic adequacy criteria recommendations based on performance during earthquakes. *Nucl. Engrg. Des.*, **107**, 155-160.

Igusa, T. *et al.* (1989). Methods of analysis of piping systems with nonlinear vibration absorbers. *Proc. 10th SMiRT*, **K(b)**.

Igusa, T. *et al.* (1993). Analysis of piping with hysteretic supports using response spectra. *Nucl. Engrg. Des.*, **143**, 187-199.

Khalafallah, M. Z. and H. M. Lee (1987). Energy absorbing supports - an alternative piping support system, *Proc. 9th SMiRT*, **K(2)**, 817-824.

Nomura, T. *et al.* (1989a). Study on friction damper as a seismic support. *Proc., 10th SMiRT*, **K(b)**, 727-732.

Nomura, T. *et al.* (1989b). Study on lead extrusion damper as a seismic support. *Proc., 10th SMiRT*, **K(b)**, 733-737.

Sinha, R. (1991). *Analysis of Secondary Systems with Nonlinear Supports*, Ph.D. Dissertation, Dept. Civil Engrg., Northwestern Univ., Evanston, Illinois, USA.

Takayama, Y. *et al.* (1989). Comparison of effects of energy absorbing supports to seismic piping system design, *Proc. 10th SMiRT*, **K(b)**, 715-720.

Wen, Y.-K. (1976). Method of random vibration for hysteretic systems. *ASCE J. Engrg. Mech.*, **102**, 249-263.

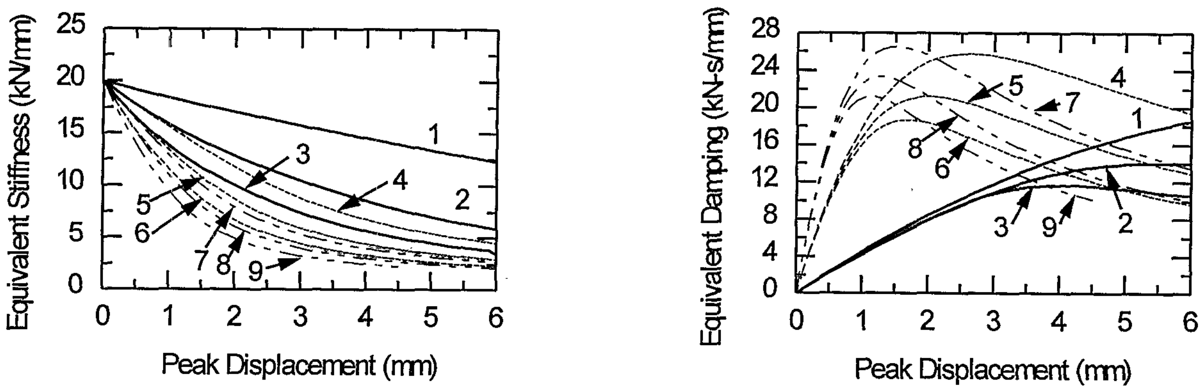

Fig. 1. Equivalent support properties for different support models. (a) Stiffness, and (b) Damping. (1: β=0.1, γ=0.1; 2: β=0.1, γ=0.5; 3: β=0.1, γ=0.9; 4: β=0.5, γ=0.1; 5: β=0.5, γ=0.5; 6: β=0.5, γ=0.9; 7: β=0.9, γ=0.1; 8: β=0.9, γ=0.5; 9: β=0.9, γ=0.9)

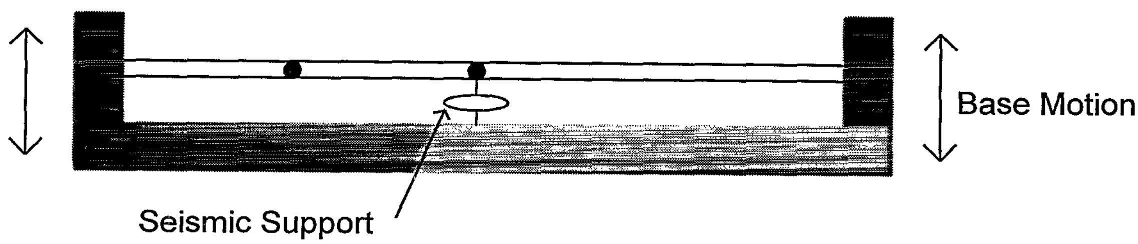

Fig. 2. Example segment of piping with seismic support at mid-span.

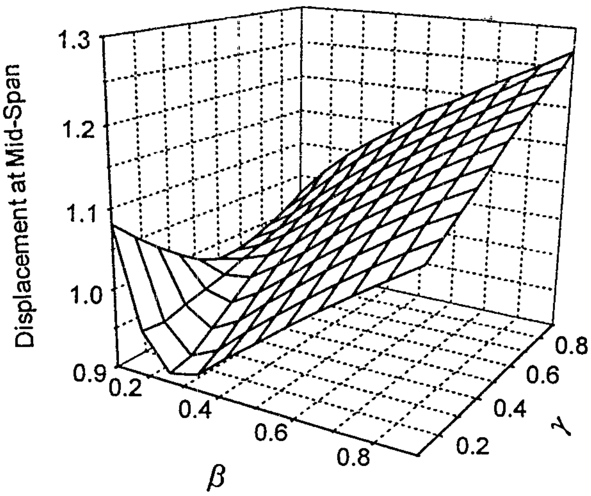

Fig. 3. Normalised maximum mid-span displacement of piping with different support model parameters.

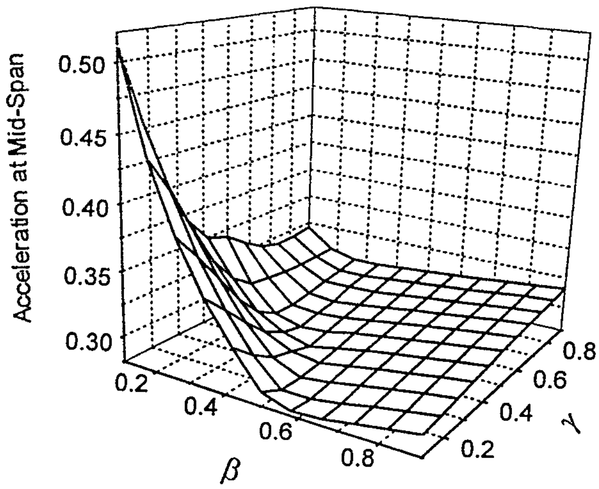

Fig. 4. Normalised maximum mid-span acceleration of piping with different support model parameters.

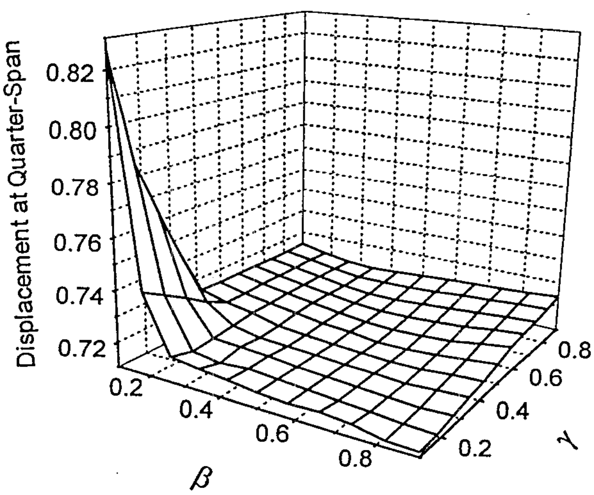

Fig. 5. Normalised maximum quarter-span displacement of piping with different support model parameters.

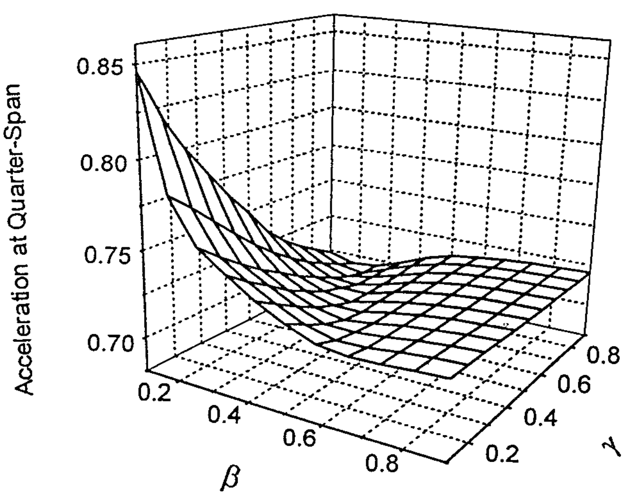

Fig. 6. Normalised maximum quarter-span acceleration of piping with different support model parameters.

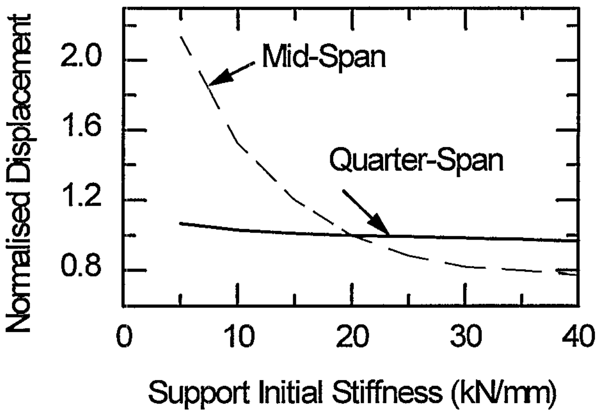

Fig. 7. Variation of maximum mid-span displacement with initial stiffness of seismic support (β=0.3, γ=0.5).

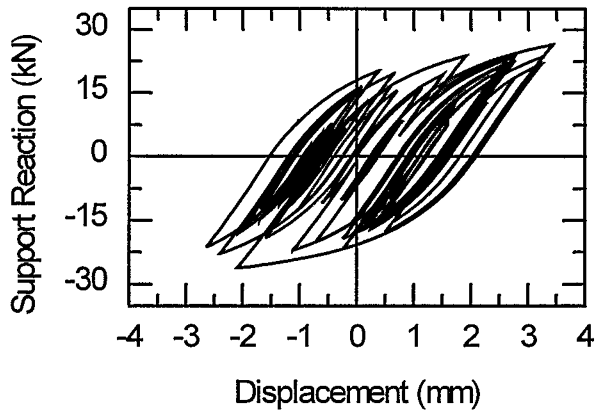

Fig. 8. Hysteresis curves of reaction in seismic support for example problem (k_0=20 kN/m, β=0.5, γ=0.1).