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The Development of Methods to Predict Both the Dynamic and the Pseudo-Static Response of Secondary Structures Subjected to Seismic Excitations

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The Development of Methods to Predict Both the Dynamic and the Pseudo-Static Response of Secondary Structures Subjected to Seismic Excitations

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Abstract

Multiple independent support excitation time history formulations have been used to investigate simplified methods to predict the inertial (or dynamic) component of response as well as the pseudo-static (or static) component of response of secondary structures subjected to seismic excitations. For the dynamic component the independent response spectrum method is used with current industry practice for the modal and direction of excitation combinations being adopted and various procedures for the group combination and sequence being investigated. SRSS combination between support groups is found to yield satisfactory results. For the static component, support grouping by elevation for preliminary design followed by support grouping by attachment point for final design assure overall safety in the design.

Introduction

Present nuclear industry practice involves a response spectrum analysis with envelope spectra input for the dynamic response and a seismic anchor movement analysis with specified support displacements representing the support point motion of the buildings. The response spectrum analysis does not necessarily predict the most conservative response. The procedure used to perform the seismic anchor movement analysis, on the other hand, is not well defined. Each organization has developed its own method to calculate this component.

When multiple independent excitations are considered in the analysis of piping systems, the responses can be considered to have two distinct components. One is due to the inertia of masses alone (dynamic component) and the other is due to the time varying differential motion of the support points (pseudo-static component). Since the dynamic characteristics of every piping system are unique and the input earthquake motions are random in nature, deterministic methods to calculate the above components are difficult to define. Therefore, a sample of two piping systems, each subjected to thirty-three earthquakes, were analyzed to develop a statistical assessment of different methods of predicting the dynamic and pseudo-static components of response. The present study involves the comparison of pipe response quantities calculated using several candidate methods with the true time history solutions. The mean and standard deviation for each parameter over the thirty-three responses are obtained to allow an assessment of the adequacy and degree of exceedance associated with each method.

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The results of the study provide a basis for possible revision of the Standard Review Plan. Also the results presented in this paper correspond to two systems studied.

Analysis Methods

The evaluation of the dynamic component of response follows the standard modal approach adopted for a general second order differential equation in matrix form. The final form of the modal equations can be written as:

$$\ddot{q}_{ij}^{(k)} + 2\zeta_i\omega_i\dot{q}_{ij}^{(k)} + \omega_i^2 q_{ij}^{(k)} = L_{ij}^{(k)}\ddot{Z}_j^{(k)} \qquad (1)$$

where $q_{ij}^{(k)}$ represents the ith modal response due to excitation $Z_j^{(k)}$ in the jth direction imposed at the kth support (or group of supports). ζ_i and ω_i are the corresponding modal damping and natural frequency of the system. $L_{ij}^{(k)}$ is the modified modal participation factor and is a function of the modal vector Φ, mass matrix M, stiffness matrix K and the boundary stiffness matrix K_B of the secondary system. The solution to equation (1) is obtained via the conventional response spectrum method. Once $q_{ij}^{(k)}$ are obtained, combination over all modes, directions of excitation and the support groups is carried out to predict the actual response of the structure.

In addition to the uniform response spectrum method (URS), the following fourteen different combinations are carried out for each response quantity. These are:

Case No.	Combination Sequence	Case No.	Combination Sequence
1	Group(ALG)-Direction-Modes	8	Direction-Modes-Group(SRSS)
2	Group(ALG)-Modes-Direction	9	Group(ABS)-Direction-Modes
3	Group(SRSS)-Direction-Modes	10	Group(ABS)-Modes-Direction
4	Group(SRSS)-Modes-Direction	11	Modes-Group(ABS)-Direction
5	Modes-Group(SRSS)-Direction	12	Direction-Group(ABS)-Modes
6	Direction-Group(SRSS)-Modes	13	Modes-Direction-Group(ABS)
7	Modes-Direction-Group(SRSS)	14	Direction-Modes-Group(ABS)

It should be noted that the modal and directional combinations are done as per Regulatory Guide 1.92.

The static response of the system is obtained from the governing equation:

$$(X_s)_{nj}^{(k)} = -K_{nn}^{-1}\,(K_B)_{nj}^{(k)}\,Z_j^{(k)} \qquad (2)$$

where $(Xs)_{nj}^{(k)}$ is the response of the nth degree of freedom due to displacement $Z_j^{(k)}$ of the kth support (or group) in the jth direction. Since at the time of preliminary design of the secondary system the analyst is ignorant of the support attachment points to the primary structure, different cases of grouping the supports and their combination are developed in this study. All response quantities, such as accelerations, moments and forces, are calculated from the solutions of equations (1) and (2).

Five different methods are considered in this study. The first method considers the time-history input at the support points whereas the other four methods consider only the peak support displacements. This information is generally obtained from the time history analysis of the building or structure supporting the piping system. These methods are summarized as:

Methods

1 Random sample, Time History data
2 Supports considered independently
3 Supports grouped by spatial direction
4 Supports grouped by attachment point
5 Supports grouped by elevation

For Methods 2-5 both absolute and SRSS summation between groups was considered.

Results and Conclusions

Two piping systems were analyzed, each subjected to thirty-three earthquake excitations. All response quantities calculated by the above procedures were compared with the time history solutions. Statistical parameters, mean and standard deviations, are derived over the thirty-three sets of responses. Pipe resultant moments for the piping systems are shown in Fig. 1 and Fig. 2 for the RHR model and Fig. 3 and Fig. 4 for AFW model. All figures display three response points of the piping system. Each data shows the mean value at the center of each vertical line with one standard deviation spread in either side.

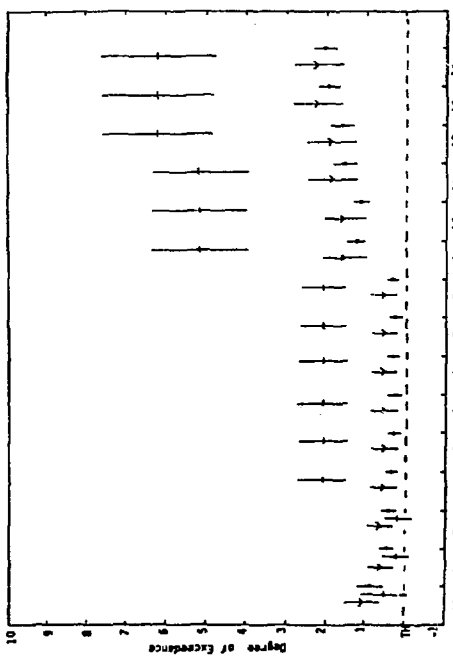

Fig. 1. Dynamic Pipe Resultant Moment Responses for RHR Model

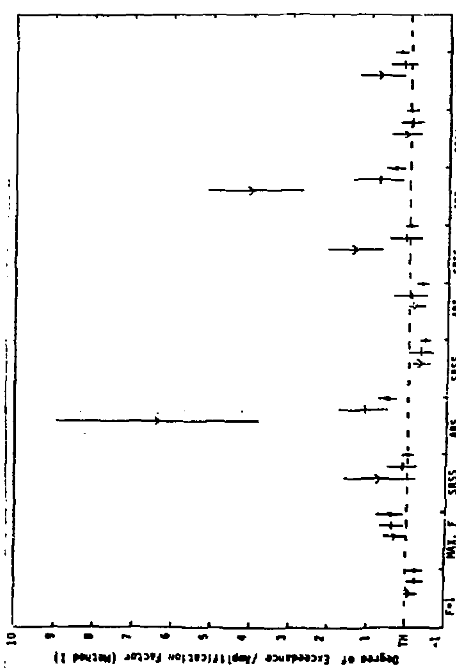

Fig. 2. Static Pipe Resultant Moment Responses for RHR Model

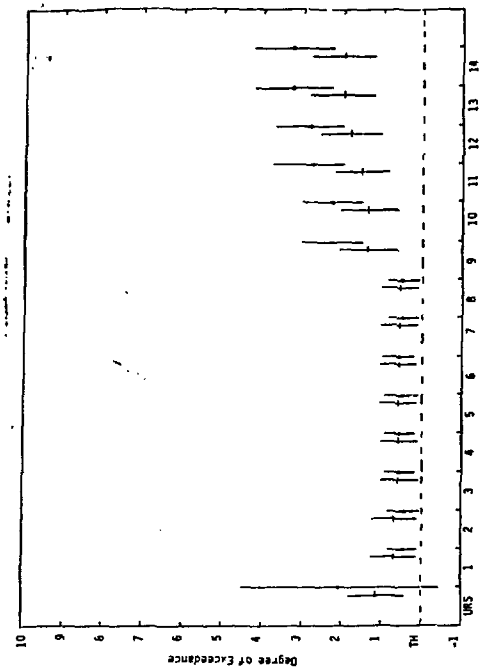

Fig. 3. Dynamic Pipe Resultant Moment Responses for AFW Model

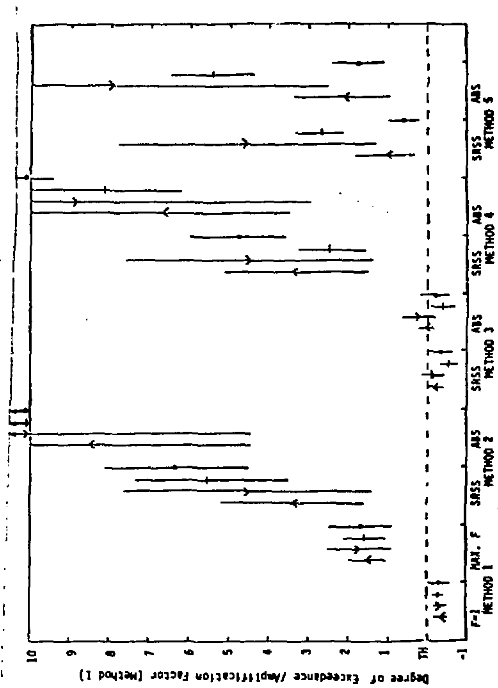

Fig. 4. Static Pipe Resultant Moment Responses for AFW Model

Based on the above studies, the SRSS combination between supports (or groups) is an acceptable method for dynamic response. Similarly, the method 5 in which supports grouped by elevation is a viable procedure for preliminary design. For a better estimate, the final design could use method 4 in which supports are grouped by an attachment point.

References

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