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ALTERNATE PROCEDURES FOR THE SEISMIC ANALYSIS OF MULTIPLY SUPPORTED PIPING SYSTEMS

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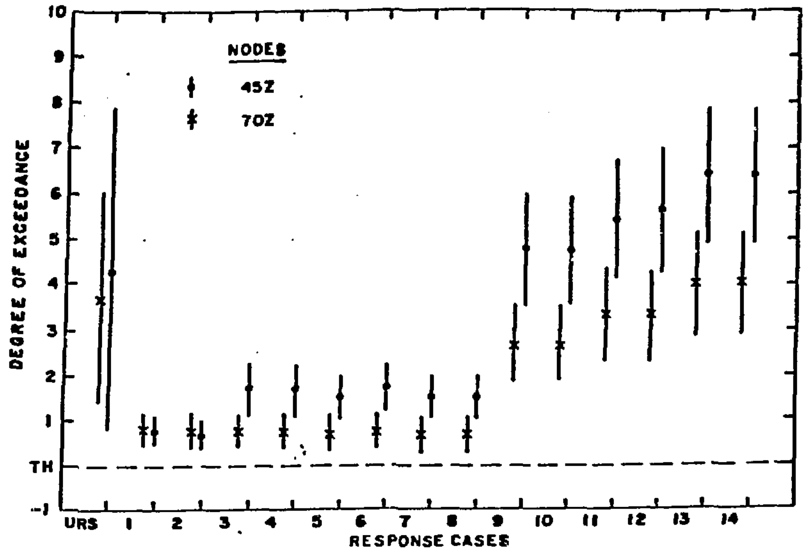

Fig. 1 - Dynamic Acceleration Responses for AFW Model

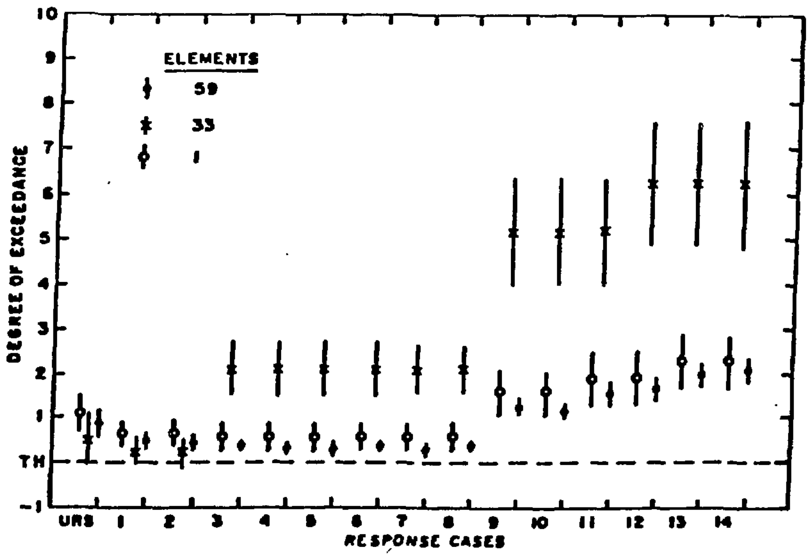

Fig. 2 - Dynamic Pipe Resultant Moment Responses for RHR Model

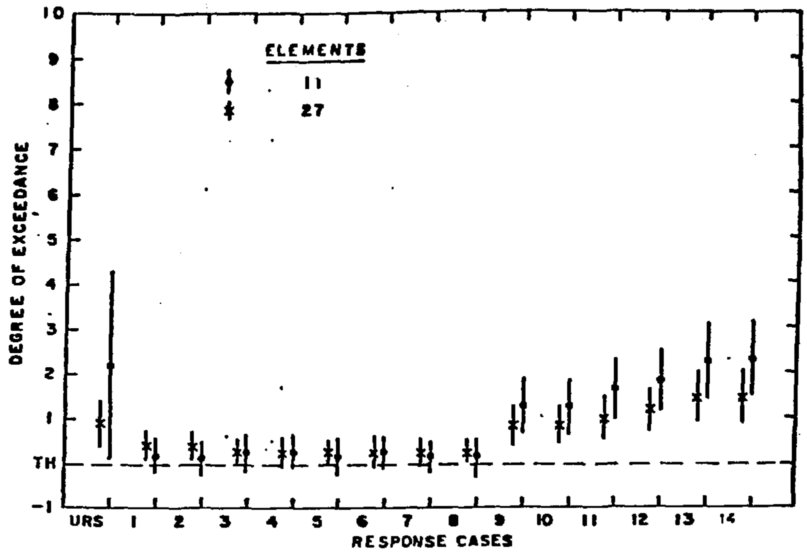

Fig. 3 - Dynamic Support Force Responses for AFW Model

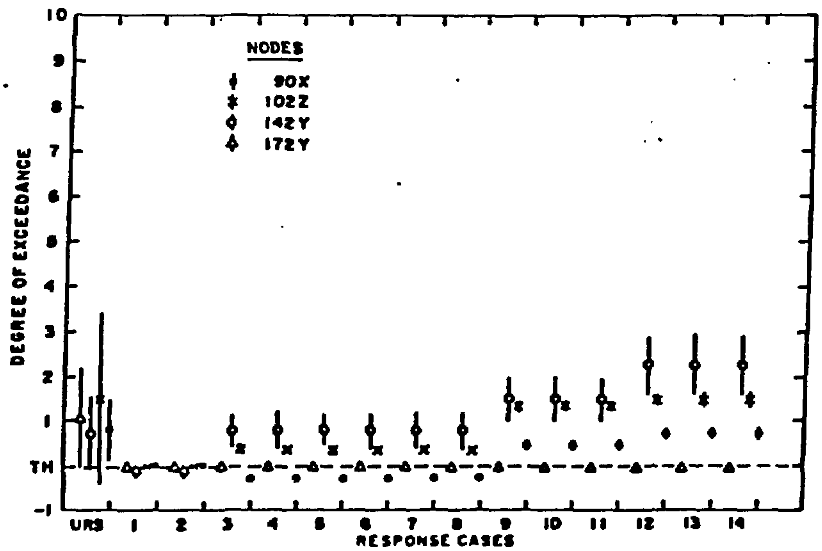

Fig. 4 - Static Acceleration Responses for AFW Model

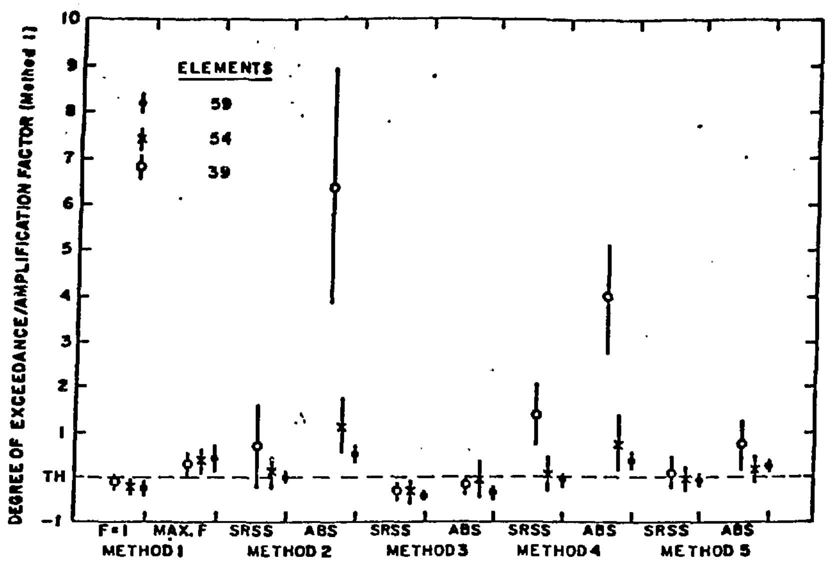

Fig. 5 - Static Pipe Resultant Moment Responses for RHR Model

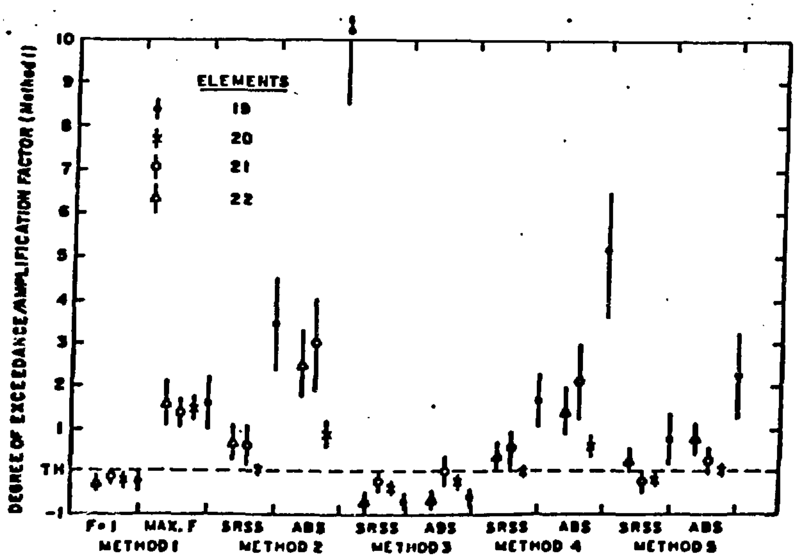

Fig. 6 - Static Support Force Responses for RHR Model

Abstract

The seismic design of secondary systems such as piping requires knowledge of the motions at various locations of the primary structures. When the structure or buildings are subjected to earthquake-like excitations at the ground level, the responses at different floor levels may be quite different from each other. This difference depends on the building and soil frequency characteristics, the characteristics of the input signals, the damping levels and soil-structure interaction effects. Hence the secondary systems, supported from the primary structures, may be subjected to independent excitations at each support point. Besides piping, large components such as steam generators and reactor coolant pumps also experience independent seismic excitation.

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 is unique and the input earthquake motions are random in nature, deterministic methods to calculate the above response components are difficult to define. To address this problem, a sample of six piping systems, two of which were subjected to thirty-three earthquakes, were studied to develop a statistical assessment of different methods of predicting the dynamic, pseudo-static and combined response. Both uniform and independent support motion methods were considered.

In addition to the current SRP method using envelope spectra, fourteen different cases, based on the independent support motion method, were considered to establish the combination sequence and procedure between modes, directions and support groups, for the dynamic component of the response. For the static component of response, five different methods constituting nine different cases were evaluated. Finally, the combined response, calculated by combining the time history estimates of the static response with all fourteen dynamic response estimates, were obtained considering both SRSS and absolute combination between the response components.

The results are obtained in tabular form. The mean and standard deviation for the two piping systems subjected to thirty-three earthquakes were obtained to allow an assessment of the adequacy and level of conservatism associated with each method. These results are also displayed in graphical form for selected, critical locations in the piping systems. The limitations of each method and recommendations are discussed.

1. Introduction

The recent increased interest to minimize the the number of pipe supports in the nuclear industry has prompted researchers to investigate alternate design methods. Unlike earlier practice, it is current design practice to consider a large portion of piping isolated by terminal anchors in one model. The design [1] of the piping, as well as the supports, are then heavily dependent on the results obtained from finite element analyses developed using general purpose computer codes. The present study addresses the dynamic analysis of piping systems which are subjected to seismic excitations. Hydrodynamic loadings caused by SRV discharge and suppression pool swell, in the case of BWR Systems, could also be included. These loads can produce unidentical responses at various locations in the structure(s) supporting the piping systems. The piping then is excited by multiple independent inputs at each support location. Because of the excitations, the piping response is considered to be composed of an inertial or dynamic component, due to the dynamics of the pipe masses, and a static or pseudo-static component due to the potentially different movement of each support point.

In current practice, the philosophy to piping design is based on a pipe break type of failure which is controlled by the ASME primary stresses. This, together with the inherent large uncertainties existing in the seismic analysis, mandated the use of very conservative design procedures and resulted in very stiff systems. Based on experience gained in the past two decades, it has been found that pipe failures, when they occur, are governed by thermal ratchetting and fatigue which are associated with the ASME secondary stresses and are a direct result of the system stiffness.

The current state-of-the-art for the seismic design or analysis of piping systems in nuclear power plants is described in the US NRC Standard Review Plan [2] (SRP), Section 3.9.2. The dynamic component of the response can be obtained using either a time history method or the Uniform Response Spectrum (URS) method. Because of the prohibitive analysis cost in performing time history analysis, the uniform response spectrum approach is most commonly used in piping design. In the uniform response spectrum method it is assumed that all supports are excited simultaneously with a single set of prescribed envelope input motions. Also all peaks in the input spectrum are broadened as specified in Regulatory Guide 1.122 [3] and an envelope of input spectra is used. Ths analytical approach adopts a modal analysis of a finite element model of the piping system. The modal responses are combined following the procedures given in Regulatory Guide 1.92 [4]. Each modal response is calculated by multiplying the appropriate modal participation factor with the response spectrum of an inertial or dynamic component, due to the dynamics of the pipe masses, and a static or pseudo-static component due to the potentially different movement of each support point.

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The pseudo-static component of response is obtained by conventional static analysis procedures. This component can be very significant if the motions of the support points are quite different. If all supports of a typical piping system have identical excitation, then this component of the seismic response does not exist at all. According to the SRP, Section 3.9.2, for multiply-supported components with distinct inputs, support displacements obtained either from the structural response calculations or from the floor response spectra are imposed on the piping system in the "most unfavorable combination". If the spectra are used, the maximum displacement of each support is predicted using $S_d = S_a g/\omega^2$, where S_a is the structural acceleration g's at the high frequency end of the spectrum curve, g is the gravitational constant, and ω is the fundamental frequency of the primary support structure, in radians per second. The displacement values thus obtained are generally very conservative since the spectrum curves represent the absolute acceleration of floors including ground motion effects. The most unfavorable combination is conservatively recommended because the phasing between support points is assumed to be unknown.

Regarding the combination of the two response components, it is suggested in the SRP that they be added by the absolute sum method. Alternate approaches to predict the total seismic response of the system, such as time history methods, are also acceptable.

The present study focuses primarily in developing procedures to predict both the dynamic as well as the pseudo-static components of the response, and to develop a method for evaluating the total response of piping systems subjected to multiple support excitations [5-8]. The responses are obtained using finite element formulations and considering multiple independent support excitations. This procedure allows the calculation of the response quantities due to the excitation of each support in each spatial direction of motion and has the advantage of predicting each component of response in a form suitable for use in the current design practice.

2. 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:

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

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, stiffness matrix K and the boundary stiffness matrix K_B of the secondary system. The solution to eq. (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 metod (URS), the following fourteen different combinations are carried out for each response quantity. These are:

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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:

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

where $(X_s)_{nj}^{(k)}$ 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. Five different methods to compute the static response are considered in this study. The first method considers the time-history input at the support points whereas the other four methods only the peak support displacements which are 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. All response quantities, such as accelerations, moments and forces, are calculated from the solutions of eq. (1) and (2).

3. Results and Conclusions

The results of the entire study are included in a report reference [9]. Herein only selected statistical results for the two systems subjected to 33 earthquake events are presented. Specifically figures 1 to 3 show some of the results for the dynamic component of response while figures 4 to 6 show results for the static component of response. In each of these figures the abscissae represents the different cases for the dynamic or the different methods of evaluation for the static response. The ordinate represents the degree of exceedance associated with each of the candidate procedures where the degree of exceedance is defined as DE = Predicted - TH/TH, TH = time history estimate. The dashed horizontal line

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A review of all the results indicated that the independent support motion response spectrum method provides acceptable estimates of the dynamic component of response. If this method is used the supports should be segregated into groups having similar excitations and SRSS combination between support group contributions should be adopted. For this procedure the sequence of combinations is unimportant. For the computation of the static component of response, grouping by elevation (method 4) is appropriate for preliminary design while grouping by attachment point (method 5) provides the best estimate of response and should be used in final design. Lastly SRSS combination between the dynamic and static components provides an acceptable estimate of total response.

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NOTICE

This work was performed under the auspices of the U.S. Nuclear Regulatory Commission, Washington, DC. The findings and opinions expressed in this paper are those of the authors, and do not necessarily reflect the views of the United States Nuclear Regulatory Commission or organizations of authors.