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The Effect of PVRC Damping with Independent Support Motion Response Spectrum Analysis of Piping Systems

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ABSTRACT

The Technical Committee for Piping Systems of the Pressure Vessel Research Committee (PVRC) has recommended new damping values to be used in the seismic analyses of piping systems in nuclear power plants. To evaluate the effect of coupling these recommendations with the use of independent support motion analyses methods, two sets of seismic analyses have been carried out for several piping systems. One set based on the use of uniform damping as specified in Regulatory Guide 1.61, the other based on the PVRC recommendations. In each set the analyses were performed using independent support motion time history and response spectrum methods as well as the envelope spectrum method. In the independent response spectrum analyses, 14 response estimates were in fact obtained by considering different combination procedures between the support group contributions and all sequences of combinations between support groups, modes and directions. For each analysis set, the response spectrum results were compared with time history estimates of those results. Comparison tables were then prepared depicting the percentage by which the response spectrum estimates exceeded the time history estimates.

By comparing the result tables between both analysis sets, the impact of PVRC damping can be observed. Preliminary results show that the degree of exceedance of the response spectrum estimates based on PVRC damping is less than that based on uniform damping for the same piping problem. Expressed differently the results obtained if ISM methods are coupled with PVRC damping are not as conservative as those obtained using uniform damping.

INTRODUCTION

Response spectrum methods are most commonly used to evaluate the seismic response of nuclear piping systems. The U.S. Nuclear Regulatory Commission (NRC) has clear guidelines [1] delineating the procedures an applicant can follow in using these methods. In particular the currently acceptable procedure involves a response spectrum evaluation based on uniform, envelope excitation of all supports coupled with the use of uniform system damping. Alternate response spectrum analysis procedures based on the consideration and use of separate, independent inputs for each support, or support group, have been advanced [2-4]. Further the damping assumptions have been addressed and an alternate definition of the system damping, involving a variation of damping with response frequency, has been advanced by the Steering Committee on Piping Systems of the Pressure Vessel Research Committee (PVRC) [5]. It is current industry opinion that analysis based on a coupling of independent support motion (ISM) response spectrum analysis methods and the PVRC recommendations for system damping will be beneficial, providing safe piping designs while eliminating the large degree of conservatism considered to be associated with current seismic design practice. In an earlier study [6] ISM methods coupled with uniform system damping were considered and recommendations advanced. In a new study the pertinent evaluations of the earlier study were repeated using the PVRC recommendations for system damping. Herein a preliminary reporting of the results of the new study will be provided.

Study Description

In the earlier study the total seismic response of six different piping systems were evaluated using ISM methods with uniform damping and considering fourteen different combination procedures to compute the dynamic component of response, five different methods to compute the pseudo-static component of response and two combination procedures to compute the total response. In the current study the dynamic component of response was again determined for the same problem set and all fourteen combination procedures, but in this case, the ISM response spectrum and time history evaluations being coupled with the PVRC recommendations for damping. In each study the degree of conservatism associated with a response spectrum estimate was assessed by comparison to a time history estimate of the same response quantity developed considering independent inputs and a definition of damping consistent with the response spectrum evaluations.

Using different combination procedures fourteen response spectrum estimates were developed for each problem using the ISM methods. The fourteen combination procedures investigated vary in the method used to combine responses between support group contributions, algebraic, absolute and SRSS being considered, and in the sequence of performing the response combination between groups, modes and directions. A summary of the combination procedures and their associated case number identifiers are:

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

In all cases the combination between modes is SRSS with clustering and the combination over directional contributions is SRSS.

To complete the data set two additional solutions were developed for each problem. In one, the uniform response spectrum method with envelope spectra was used to develop a solution which corresponds to current practice as modified by PVRC damping. In the second, independent support motion, time history methods, incorporating the PVRC damping recommendations, were used to formulate a best estimate of true response. For each problem then the dynamic component of response was determined using fifteen variations of the response spectrum method and one time history evaluation.

As mentioned, the problem set consisted of six piping systems. These ranged from a simple, planar three anchor system to two problems, the AFW and RHR models, corresponding to actual piping from a nuclear power plant. For these two problems the evaluations were in fact performed considering 33 separate seismic events. For the other four problems only one seismic event each was considered. The solutions for the two realistic problems form a statistical data base which is considered below.

In all cases the relative adequacy of response spectrum estimates of displacement, acceleration, pipe support force and pipe internal moment were computed. This was done by comparing each response spectrum estimate to the corresponding time history estimate of the same quantity. These comparisons were expressed as the degree-of-exceedance given by DOE = (Response - TH)/TH where Response is the response spectrum estimate and TH is the corresponding time history estimate of a response quantity. For the AFW and RHR models, where 33 seismic events were involved, the mean and standard deviation of this data was computed and is considered below.

Summary of Results

The complete results of this study are far too extensive to allow their presentation herein. Instead what will be done is to compare some sample results from this study to those developed in the earlier study for uniform damping. Through this comparison some insight into the impact of coupling the PVRC recommendations for damping with the ISM methods will be gained.

The sample results are shown in Figures 1 through 8. On each of these figures two data sets are depicted, the solid circles correspond to results from the earlier study (uniform damping) and the open circles correspond to results from the current study (PVRC damping). Of the eight figures, four depict displacement, acceleration, force and moment results for the RHR model while the other four depict those results for the AFW model. On each figure all the data presented correspond to a single point or element in either the AFW or RHR model (i.e., the RHR displacements are the displacements of node 57 in the Z direction). The results presented are in fact the degree-of-exceedance computed for the envelope spectrum case (labeled URS) and the fourteen combination options for the ISM method. The dashed line with a DOE of zero is the time history result. Any negative entries indicate that the response spectrum result underestimated the time history result. For each data set (i.e, URS or case 1-14) the symbol represents the mean value of that response component over the thirty-three seismic events while the line extends plus or minus one standard deviation about that mean.

Although a large quantity of data was developed for each problem, only the response estimates for a single response component are depicted on the figures. The data depicted were selected because they defined the vicinity of the lower bound of the degree-of-exceedance for all responses of that type (i.e., the displacement of node 57 in the Z direction of the RHR model exhibited the lowest DOE for all displacements in the RHR model) for all cases.

Reviewing all the figures the basic trend of the lower bound results for both studies can be seen. With the exception of the acceleration data for the RHR model, the mean values of the data corresponding to PVRC damping (open circles) are below the mean values corresponding to uniform damping (solid circles). Further the lower bound of all results (line extent) is also typically set by the PVRC damping cases. Importantly this trend is evident for both the URS case as well as the ISM cases. Whether the same trend exists for the mean or average of all results remains to be determined.

Although no results from the evaluations of the other four problems have been presented the trend noted above was clearly evident in each of those evaluations. In fact, in those cases the trend was much stronger, the estimates based on PVRC damping exhibiting a degree-of-exceedance 30 to 150% lower than those computed considering uniform damping. The comparison in those problems, however, may be inappropriate as the earlier results were based on a uniform damping level of 1% versus the 2 to 5% levels embodied in the PVRC recommendations. For the AFW and RHR models the uniform damping level used in the earlier study was 2% which makes direct comparison more reasonable.

Conclusions

Although the processing of the study results are still in a preliminary phase, a distinct trend seems to be emerging. For reasons that have not been established, a response spectrum estimate based on the PVRC damping recommendations exhibits a lower degree-of-conservatism than an estimate based on uniform damping. That is, a response spectrum estimate based on PVRC damping more closely approaches a time history estimate based on PVRC damping than a response spectrum estimate based on uniform damping approaches a time history estimate based on uniform damping. This trend was strong in the single case solutions and observable in the statistical results for the problems evaluated for multiple seismic events. Further the trend was evident in the uniform response spectrum solutions as well as in the ISM response spectrum solutions. This indicates that the effect is associated with the damping assumption rather than with the mode of computation. Finally regarding the coupling of ISM response spectrum methods and PVRC damping, since either used separately provides results which exhibit a lower level of conservatism, the coupled analysis will exhibit an even lower factor of safety and, if used, care should be taken to assure an adequate margin of safety.

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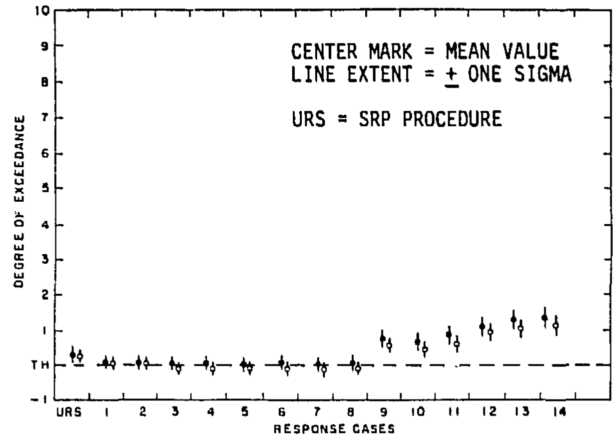

Fig. 1 RHR Displacement Results

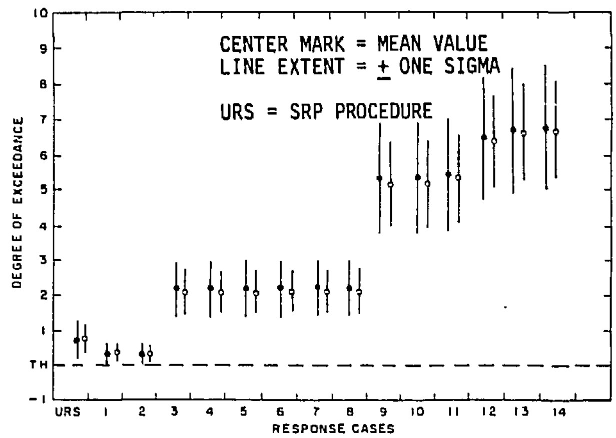

Fig. 2 RHR Acceleration Results

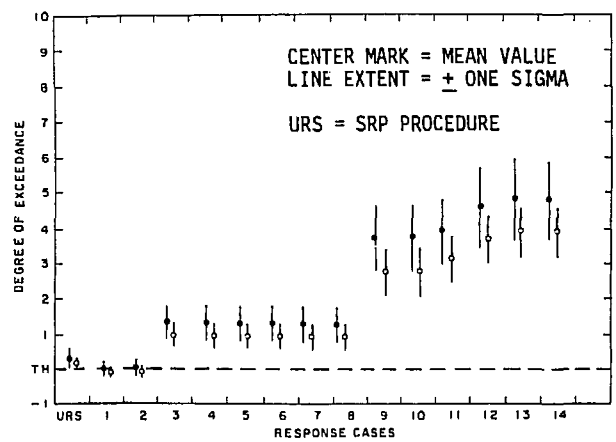

Fig. 3 RHR Force Results

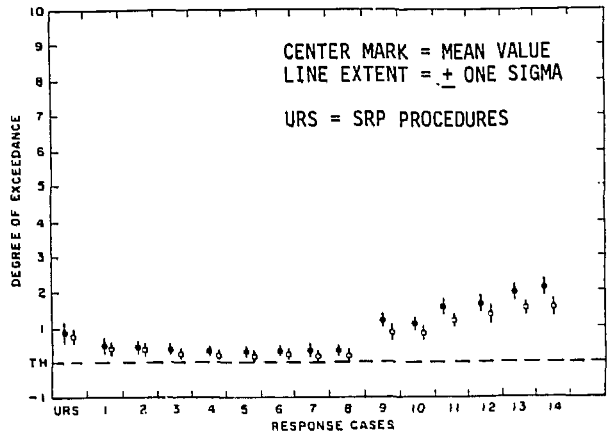

Fig. 4 RHR Moment Results

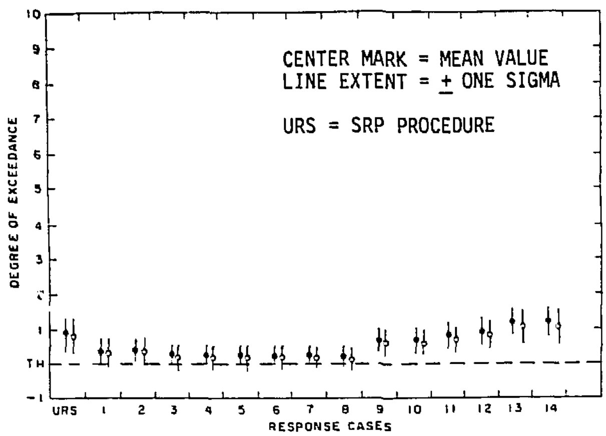

Fig. 5 AFW Displacement Results

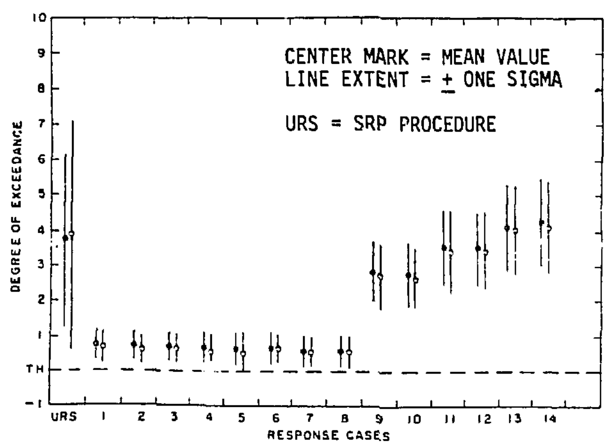

Fig. 6 AFW Acceleration Results

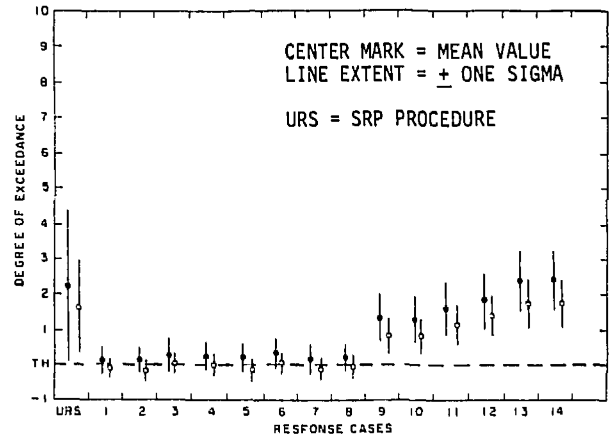

Fig. 7 AFW Force Results

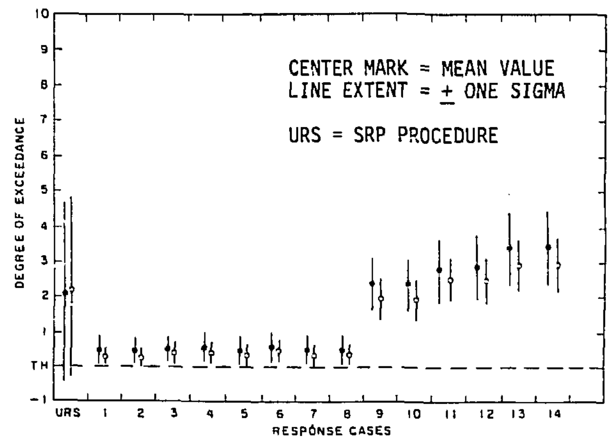

Fig. 8 AFW Moment Results

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