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CONF-850670--18

N 24 1985

BNL-NUREG--36487

TI85 012189

The Assessment of Alternate Procedures for the Seismic Analysis of Multiply Supported Piping Systems

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ABSTRACT

When response spectrum methods are used in the seismic analysis of piping systems the response due to inertial action, the dynamic response, and the response due to the time varying differential motions of the support points (the pseudo-static response) must be determined. In this study the adequacy and the degree of conservatism associated with the uniform response spectrum method, the center of mass response spectrum method and fourteen variants of the independent response spectrum method to compute the dynamic response and five different methods to compute the pseudo-static response were evaluated. For this purpose a sample of six piping systems, two of which were subjected to thirty-three earthquakes, were studied. For each system and seismic excitation a multiple in- 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 response parameter over the thirty-three responses are obtained to allow an assessment of the adequacy and degree of exceedance associated with each method.

The evaluation of the dynamic component of response follows the standard modal approach adopted for a general second order differential equation in matrix form. Both the uniform and independent support motion response spectrum methods were applied. In addition to the results for the uniform response spectrum method (URS), results correspondi-g to fourteen different combination sequence options were developed for the independent support motions (ISM). In addition a var-

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When response spectrum methods are used in the seismic analysis of piping systems the response due to inertial action, the dynamic response, and the response due to the time varying differential motions of the support points (the pseudo-static response) must be determined. In this study the adequacy and the degree of conservatism associated with the uniform response spectrum method, the center of mass response spectrum method and fourteen variants of the independent response spectrum method to compute the dynamic response and five different methods to compute the pseudo-static response were evaluated. For this purpose a sample of six piping systems, two of which were subjected to thirty-three earthquakes, were studied. For each system and seismic excitation a multiple independent support excitation time history analysis was developed and used to provide a best estimate of true response and to form the basis for comparison. A combination procedure to calculate the total responses is considered as well. Results are presented and compared to the corresponding responses evaluated using the current uniform response spectrum method and the center of mass response spectra approach. Based on the results, recommendations concerning the use of the methods were developed.

INTRODUCTION

When multiple independent excitations [1,2] 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 response components are difficult to define. Therefore, a sample of six piping models, two of which are 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 [3].

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The evaluation of the dynamic component of response follows the standard modal approach adopted for a general second order differential equation in matrix form. Both the uniform and independent support motion response spectrum methods were applied. In addition to the results for the uniform response spectrum method (URS), results corresponding to fourteen different combination sequence options were developed for the independent support motions (ISM). In addition a variation of the URS method and the CMS method was also considered.

In the CMS method the spatial location of the center of mass of the piping system is determined. Spectra are then developed for this location using linear interpolation from the piping system boundary points. These space averaged spectra are then used in place of the envelope spectra in the computations.

DESCRIPTION OF CANDIDATE METHODS

The current guidelines for predicting the seismic response of piping systems are well described in the Standard Review Plan [4], Regulatory Guides [5,6], ASME Code Section III, and other related documents. The dynamic analysis options are either time history or response spectrum methods. In these procedures it is usually assumed that all the support points are excited with identical inputs which may be obtained by enveloping all the support excitations. There is virtually no specific guidance as to how to obtain the pseudo-static component of response. Many organizations have developed their own procedure and consider that their results represent the most conservative one could obtain. According to the SRP [4], the dynamic and pseudo-static components should be combined by the absolute sum method.

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The intent of this study is to develop certain alternate methodologies for evaluating these response components so that:

a) the results reflect the actual system response without endangering the safety of the design,
b) the methods are simple enough to be adopted by the industry without major deviations from their current procedures,
c) the formulations can be programmed into the existing computer codes, and
d) the additional cost involved in the new procedures are overcome by the benefit observed in the final design.

Dynamic (or Inertia) Responses

It is commonly believed that the uniform response spectrum method always yields a conservative estimate of response because the input envelope spectra represent the largest excitation any support can experience. It should, however, be noted that the excitation level alone does not govern the dynamic response. The frequency content in the loading function, the dynamic characteristics of the system itself (i.e., natural frequencies and mode shapes), and the independent effect of each support, can influence the overall response of the piping model. In the uniform response spectrum method, the modal responses are calculated by multiplying the spectrum magnitude with the corresponding modal participation factors at the modal frequency. The modal participation factors for this analysis reflect the modal contributions when all supports are excited simultaneously with the identical input. The modal contributions thus calculated could either underpredict or overpredict true response depending on the exact phasing between the individual supports in the system.

In order to overcome this, the independent support motion method has been chosen for this study. This method derives the modal participation factors for each individual support (or group of supports) in each direction of excitation. The effect of each support excitation is obtained by multiplying the participation factors with the corresponding response spec-

Description of the different combinations considered in the dynamic analysis:

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)

Case No.	Combination Sequences
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)

The first two cases correspond to algebraic group combination, the next six cases to SRSS group combination. In the first category, algebraic summation, the missing four cases involve changes in the sequence of groups with the mode and direction combinations and have no meaning since the signs of each component are lost during the process.

In additions, each piping system is also analyzed using a set of envelope spectra and a set of uniform spectra corresponding to the piping center of mass developed from the individual support spectra. The results are calculated using the guidelines presently adopted in the nuclear industry. These responses, designated as the 'URS' and the 'CMS' case, are also compared with the independent time history solutions to obtain a measure of the conservatism inherent in these methods.

Pseudo-Static (SAM) Responses

As mentioned earlier, the pseudo-static component of seismic response of piping systems is due to the differential motion of the support points. This is known as the pseudo-static component because it is reindependent effect of each support, [illegible] overall response of the piping model. In the uniform response spectrum method, the modal responses are calculated by multiplying the spectrum magnitude with the corresponding modal participation factors at the modal frequency. The modal participation factors for this analysis reflect the modal contributions when all supports are excited simultaneously with the identical input. The modal contributions thus calculated could either underpredict or overpredict true response depending on the exact phasing between the individual supports in the system.

In order to overcome this, the independent support motion method has been chosen for this study. This method derives the modal participation factors for each individual support (or group of supports) in each direction of excitation. The effect of each support excitation is obtained by multiplying the participation factors with the corresponding response spectra, thus representing a better estimate of the true response of the system. One of the questions raised in applying this analysis procedure is how to combine the group effects, along with the modal and direction of excitation effects, to predict the dynamic response of the system.

In the present study, the dynamic analysis involves an evaluation of the methods of response combination between modes, directions, and support points (or groups) and the sequence of their combinations. Some consideration of different combination methods was made by Lin and Loceff [8]. The combination methods used between modes and directions are those specified in the US NRC Regulatory Guide 1.92 [6]. Accordingly, the combinations between modes is by SRSS with clustering between closely spaced modes considered, a cluster factor of 0.1, and the directional combination is SRSS. Since the support group combination method is yet to be established, algebraic (ALG), SRSS and absolute summation (ABS) between groups are considered. Considering all variations and sequences of these procedures, fourteen distinct combination methods could be used to predict the dynamic response of a piping system and were considered. These are:

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Pseudo-Static (SAM) Responses

As mentioned earlier, the pseudo-static component of seismic response of piping systems is due to the differential motion of the support points. This is known as the pseudo-static component because it is related to the static load-response behavior of the system. Sometimes it is termed the Seismic Anchor Movement (SAM) response due to its relationship to anchor movements and is also termed the pseudo-static component of response due to its time-dependence without, however, dynamic amplification. The present guidelines require that the support displacements be imposed on the supported system in the most unfavorable combination. The analysis is performed using conventional static analysis procedures.

The calculation of support displacements are obtained either from a time history analysis of the buildings while developing the floor response spectra or from the SRP, recommended procedure, Section 3.9.2, using the floor response spectra. Often times these displacements are available to the pipe stress engineers for each floor level as well as at all terminal points such as nozzles, penetrations and so on. The application of these displacements at the support points are often left to the intuitive judgement of the stress engineer. Sometimes the stress engineers neglect this analysis entirely if no information is available or if they can justify that the displacements are of negligible magnitude.

Five different approximate methods to predict the pseudo-static component of the response were considered in this study. In this first method, a sample of the time history input at the support points is used retaining the true phasing and magnitude between these points. In the remaining four methods only peak support displacements are used and the phasing information is lost. In each of these methods a different support grouping procedure is used to simulate the support phasing. Within a group all supports are assumed to move in phase and their affects are combined algeoraically.

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 group contributions were considered.

Total Seismic Response (Dynamic Plus Static)

The current SRP recommendation (Section 3.9.2) requires that the response due to the inertia effect and that due to relative displacements should be combined by the absolute sum method. The present study was extended to consider both the SRSS and absolute sum procedures in combining these components. A similar study was also reported by the authors under the load combination program. The independent time history analysis provides a prediction of the total respose as well as the two response components. Thus, the total response obtained by combining peak pipe responses calculated using the procedures described in the previous sections, can be compared with the true responses and the level of exceedance determined for each response parameter.

Sample Results

Figures 1-3 and 4-6 shows samples of the results developed for the dynamic and pseudo-static response quantities respectively predicted by the various methods considered. On each of these figures is summarized the results for a specific response parameter over the 33 seismic events and for all methods considered. The results depicted is the degrees of exceed-

DISCUSSION OF RESULTS

Dynamic Response Component

Based on an overall review of all the results for the dynamic component of response, the following observations were made:

- The sequence of combination between the modes, groups and directions of excitation is relatively unimportant.

- The conservatism associated with the group combination methods was

  - algebraic combination: nonconservative at times
  - SRSS combination : nonconservative at times, more conservative than ALG
  - ABS combination : always conservative

- Uniform Response Spectrum (URS) method results vary from very conservative to nonconservative, but within an acceptable range

- All methods are conservative if the piping system is contained in a single structure

- The degree of exceedance (conservatism) for displacements, pipe moments and support forces is markedly reduced at the interface between structures

- The dynamic accelerations are not significantly affected by structural interfaces

- The degree of exceedance varies inversely with the overall rigidity of the piping system

- The degree of exceedance varies directly with the degree of correlation of the inputs

- The degree of exceedance becomes smaller for large response quantities

- The center of mass approach could underpredict dynamic responses.

Pseudo-Static Response Component

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Sample Results

Figures 1-3 and 4-6 shows samples of the results developed for the dynamic and pseudo-static response quantities respectively predicted by the various methods considered. On each of these figures is summarized the results for a specific response parameter over the 33 seismic events and for all methods considered. The results depicted is the degrees of exceedance defined as TH-predicted/TH where TH is the independent support motion time history estimate and predicted is the *response spectrum estimate* of the parameter. On each figure the symbol indicates the mean degree of exceedance while the vertical line extends ± one standard deviation for this parameter Further, on the figures the results are only shown for those points for a specific problem which establish the lower bound of that result for all points in the problem. The dashed line on each figure indicates the TH estimate. All points below this indicate underestimates of the response quantity. Referring to figure 1, the mean degree of exceedance for the acceleration of point 36 in the Y direction for the RHR model, as estimated with the independent support mtion response spectrum method with algebraic combination between groups followed by combination over directions followed by combination over modes, dynamic case 1, is 1.5. A complete compilation of all results are provided n reference 3.

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- The dynamic accelerations are not significantly affected by structural interfaces

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- The degree of exceedance varies directly with the degree of correlation of the inputs

- The degree of exceedance becomes smaller for large response quantities

- The center of mass approach could underpredict dynamic responses.

Pseudo-Static Response Component

Based on a review of the results for the pseudo-static component of response, the following observations were noted:

For Pseudo-Static Acceleration

- The results are very sensitive to the spectral ZPA values.

- The ZPA values of the envelope spectrum, as per the SRP method, typically yields conservative results

- If computed using the independent support motion procedure, absolute summatin between groups provides conservative results. Algebraic and SRSS summation can result in underpredictions.

For displacements, pipe moments and support forces:

- The SRP definition of peak input displacements, $X = S_a g/\omega^2$, is very conservative. Time history predictions of relative support point displacements would be more appropriate.

- The amplification factor to be used with the time history sampling procedure ranges from 2.0 to 4.0.

- Method 2, with absolute combination as recommended in the SRP, always yields conservative results. Either combination yields conservative results for piping within one building structure. Between structures the degree of exceedance decreases with possible underprediction for the SRSS sum.

- Method 3, 2ith absolute combination, yields reasonable results for buildings which can be simulated with a stick model. With SRSS summation, the method typically underpredicts true response.

- Method 4, with SRSS group combination, may underpredict response. Absolute combination yields good results provided the structural attachment points are properly defined.

- Method 5, with absolute combination, yields acceptable results for preliminary design. With SRSS summation, the method underpredicts true response for many points.

- The degree of exceedance increases for small response quantities.

Combined Seismic Response

Reviewing the results, it was found that the SRSS combination between the dynamic and the static component of response provides an acceptable estimate to total response for all the dynamic cases. Further the following observations were noted from all results:

- Absolute combination between the dynamic and static components, as recommended in the SRP, yields very conservative estimates of total response.

- SRSS combination provides acceptable estimates of total response with some underpredictions. However, it is felt that this the degree of underprediction will be overcome by the conservatism associated with the computation of the static component of response.

- Combined Response

  - SRSS combination between the dynamic and static components of the response should be adopted.

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<u>Combined Seismic Response</u>

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- Absolute combination between the dynamic and static components, as recommended in the SRP, yields very conservative estimates of total response.

- SRSS combination provides acceptable estimates of total response with some underpredictions. However, it is felt that this the degree of underprediction will be overcome by the conservatism associated with the computation of the static component of response.

- SRSS combination of the dynamic and pseudo-static responses coupled with absolute group combination for the dynamic response calculations (cases 9-14) alwys yield conservative results.

<u>Recommendations</u>

- Dynamic Component of Response

  - The independent support motion response spectrum method should be certified as acceptable for the evaluation of the dynamic component of response.

  - SRSS combination between support group contributions could be adopted in the independent support motion response spectrum analysis.

- Pseudo-Static Component of Response

  - Method 5 (grouping by elevations) with absolute combination between groups should be used for final design.

  - Method 4 (grouping by attachment points) with absolute combination between groups should be used for final design.

5. U.S. Nuclear Regulatory Commission. "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components", Regulatory Guide 1.122, Rev. 1 February 1978.

6. U.S. Nuclear Regulatory Commission. "Combining Model Responses and Spatial Components in Seismic Response Analysis", Regulatory Guide 1.92, Rev. 1, February 1976.

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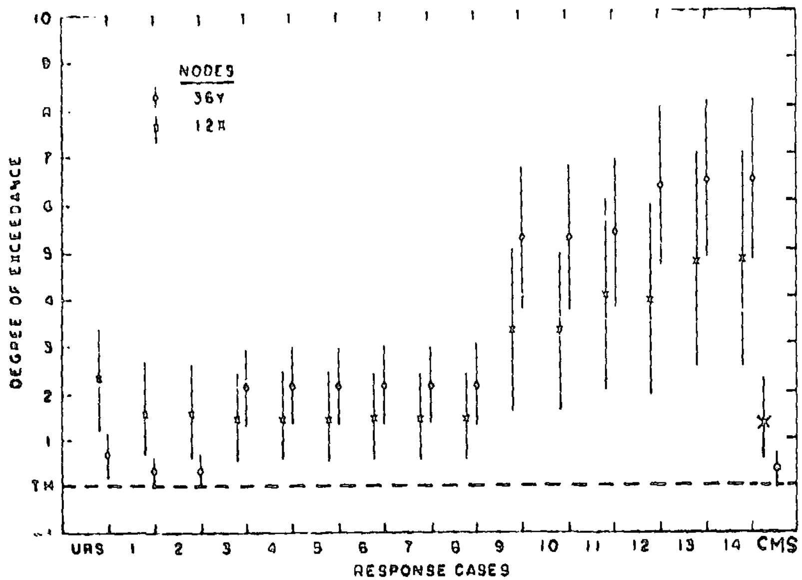


Fig. 1 - Dynamic Acceleration Response for RHR Model

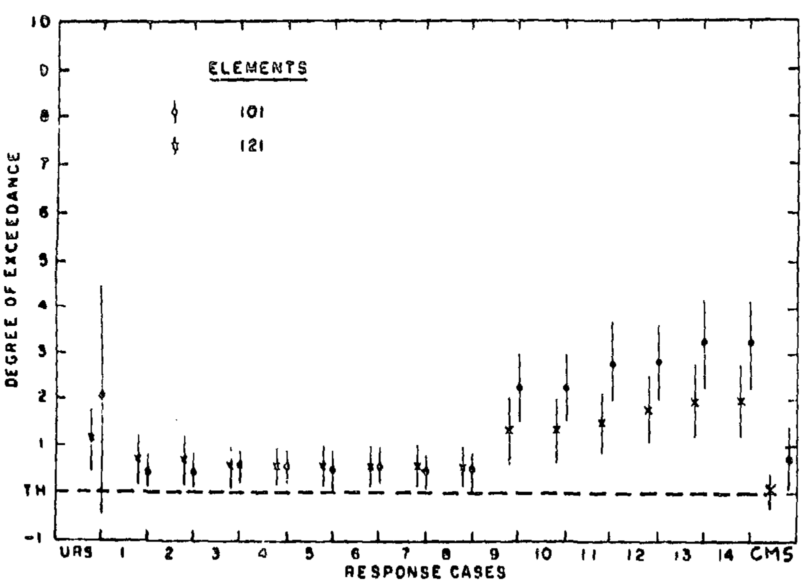


Fig. 2 - Dynamic Pipe Resultant Moment Responses for AFW Model

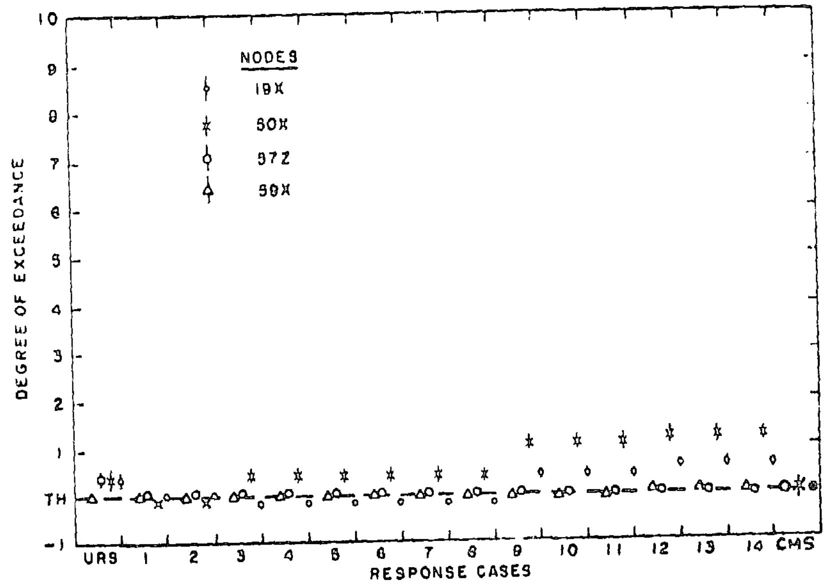


Fig. 4 - Static Acceleration Response for RHR Model

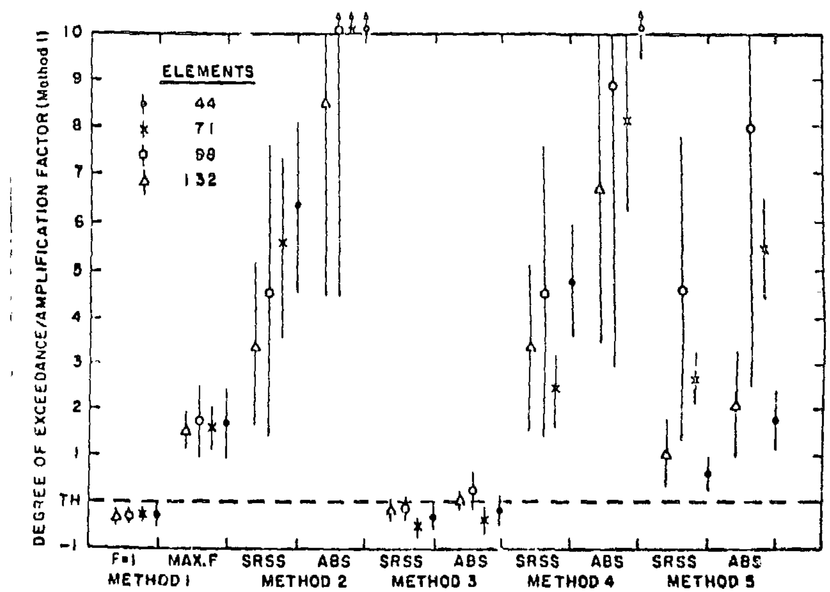
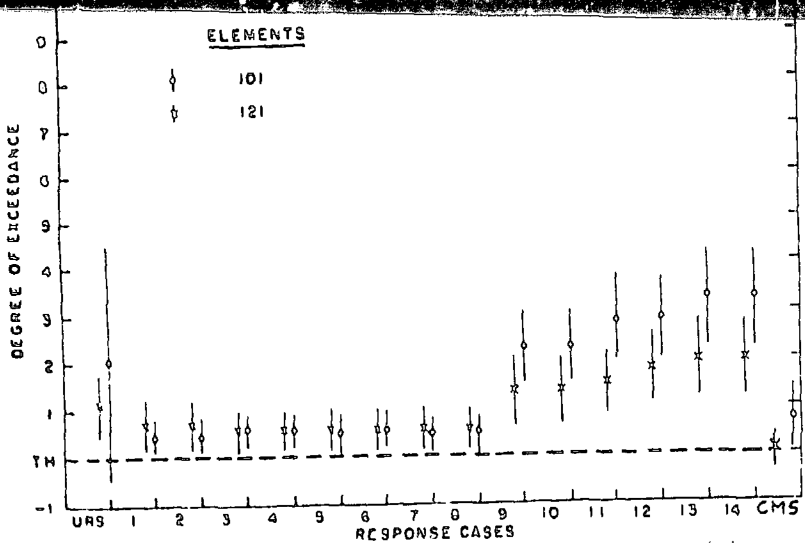


Fig. 5 - Static Pipe Resultant Moment Responses for AFW Model



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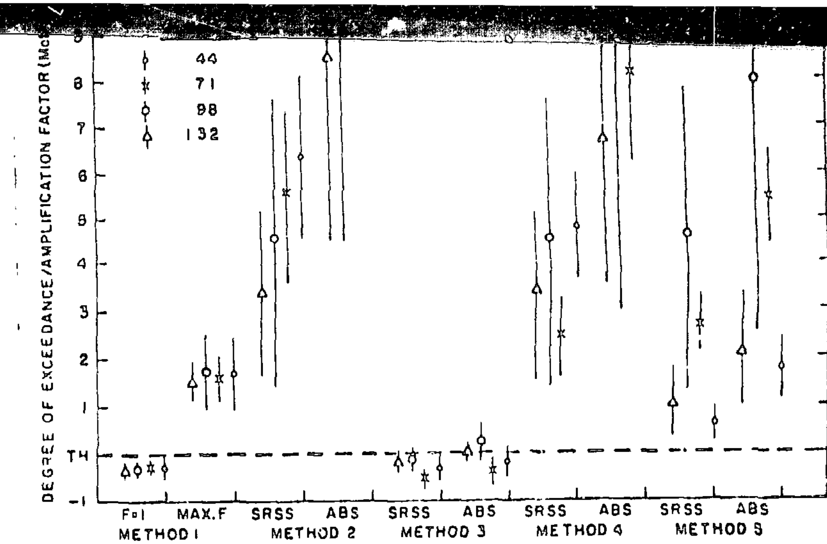

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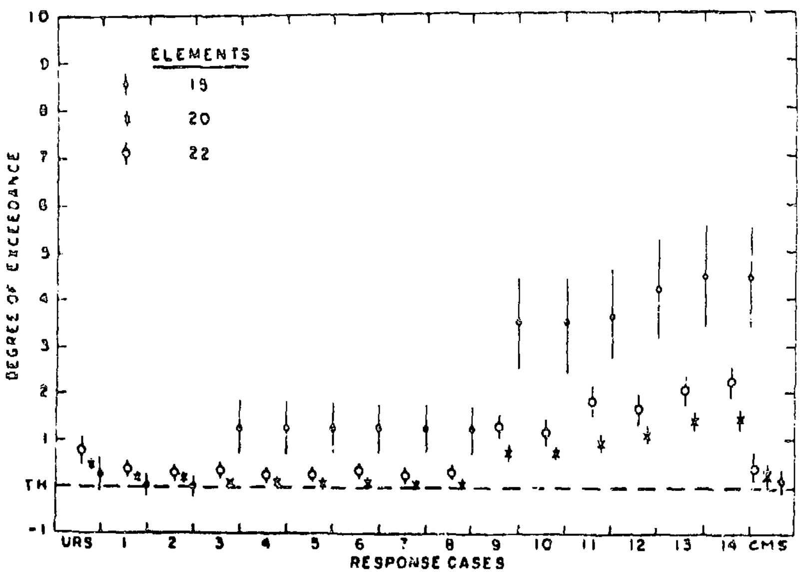

Fig. 3 - Dynamic Support Force Responses for IHR Model

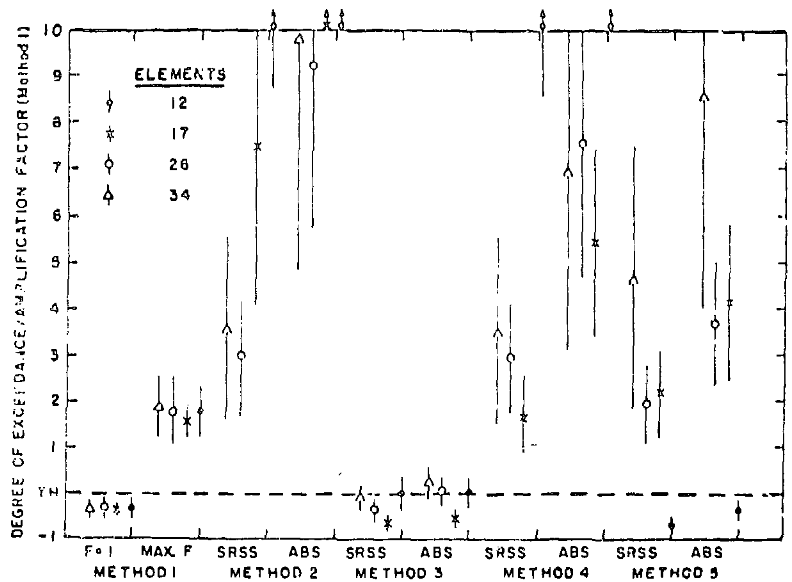

Fig. 6 - Static Support Force Responses for AFW Model