Evaluation of seismic forces due to anchor movement and inertial effects in multiply supported piping systems

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1. INTRODUCTION

To calculate seismic forces in multiply supported secondary systems such as piping, decoupled analyses are most commonly used. This assumes that the secondary system is relatively light such that its dynamic interaction with the primary structure is negligible. For most practical situations this assumption is justified. This enables us to specify the support motion inputs independent of the secondary system.

In practice, these inputs are obtained in terms of the support motion time histories or floor response spectra by performing a dynamic analysis of the primary structure. The time histories retain the correct phase relationship of the support motions. Thus a time history analysis of a secondary system will provide the most accurate response, but then it will only be correct for the ground motion time history used in the analysis of the primary structure. Response obtained from such an analysis cannot be used in a design evaluation, unless a large ensemble of time histories are used as the input for calculating the design response. Use of several time histories in an analysis can be a costly proposition.

Since a response spectrum analysis is inexpensive, the characterization of the support motions in terms of floor response spectra and using these spectra as input in the analysis is a better and practical alternative to the time history approach. Currently, it is most common to define the support motions by pseudo acceleration floor response spectra. It has, however, been shown that this definition of support inputs for multiply supported secondary systems is very inadequate, primarily because it does not give any information about the cross correlation of various floor motions. The research by the writers (Burdisso and Singh, 1987a) has shown that for a complete description of the support motions for a multiply supported secondary system we require: (1) auto floor response spectra for the pseudo acceleration and relative velocity responses of the oscillator, (2) cross floor response spectra to define cross correlation between the accelerations of various interconnected floors, (3) maximum displacement response of various supports and their correlations, and (4) maximum relative velocity response of the floors and their correlations. The cross floor response spectra can be defined in terms of the three-dimensional response spectrum surfaces as done by Asfura and Der Kiureghian (1986), or in terms of the two-dimensional response spectra curves as done by the writers (1987b). The methods for direct generation of the two-dimensional generalized floor response spectra from the ground response spectra are given by Singh and Burdisso, 1987b. These inputs can also be modified to incorporate the effect of the dynamic interaction between the primary and secondary systems (Burdisso and Singh, 1987c).

2. RESPONSE OF SECONDARY SYSTEMS

An approach for utilization of the generalized floor inputs for calculating the multiply supported secondary system response is described by the writers (1987a). In this approach, the response of a secondary system is divided into (1) dynamic and (2) pseudo static parts. The dynamic part is due to the acceleration motions of the supports and thus represents the inertial effects. The pseudo static part, on the other hand, is due to the relative displacements between the supports. In the calculation of the dynamic part, it is also necessary to consider the effect of the cross correlation between the accelerations of the support. In the approach proposed by the writers, this effect is included through the cross floor response spectra. Likewise, it is also necessary to consider the correlation between the floor displacements in the calculation of the pseudo static response part. Furthermore, it is equally important to consider properly the correlations between the dynamic and pseudo static responses. This is included in the approach through a term called the cross response term. Thus the total response is obtained according to the following equation:

$$R^2 = R_{dd}^2 + R_{pp}^2 + R_{dp} \tag{1}$$

where R = total response, R_{dd} = dynamic part, R_{pp} = pseudo static part and R_{dp} = cross response term representing the contribution of the correlation of the dynamic and pseudo static parts.

The details for calculating these response terms in terms of the generalized floor response spectra and the floor displacements are velocities are given by the writers (1987a). The approach is based on random vibration principles, and accounts for the modal correlation and the floor motion correlations properly. In this paper, therefore, the results obtained by this approach are considered as the bench mark results for comparison with many other proposals that have been suggested for combination of these response quantities.

3. SOME CURRENT RESPONSE COMBINATION PROCEDURES

The division of the total response into dynamic and pseudo static is also used in several currently used response spectrum procedures in the industry. To incorporate the effect of the correlation between the motion of the supports two approximate procedures are used: (1) envelope response spectrum approach and (2) multiple response spectrum approach. In the envelope spectrum approach, a common seismic input defined in terms of the floor response spectra which envelopes all the support point spectra is used with the fixed base model of secondary system. The envelope spectrum is then applied as the base input at all the supports. The response of the secondary system is obtained by the square-root-of-the-sum-of-the-squares (SRSS) or modified SRSS approach. Since the envelope of all the spectra is used as the input, it is believed that this approach will provide a conservative estimate of the dynamic response, thus compensating the inadequacy of the approach to consider the cross correlations between the motions of the supports. This assumption is numerically evaluated for a multiply supported secondary system. In the numerical calculations, the dynamic response obtained by this approach is identified as DE, where the letter D means the dynamic response and the letter E means that it has been calculated with the envelope spectra as the input.

In the multiple response spectrum approach, the secondary system response is calculated for each support input separately with the other supports assumed fixed. These response for individual spectra are then combined by either the SRSS or by the absolute sum approach. These two estimates of the dynamic response are designated by DS and DA, respectively. Here the letters S and A signify the SRSS and the absolute sum approaches. Later in the paper, these three estimates of the dynamic response — that is, DE, DS and DA -- are compared with the corresponding dynamic response value calculated by the approach proposed by the writers (1987a).

To calculate the pseudo static response, each support is moved by its own maximum displacement, keeping the other supports fixed. The responses calculated for each support displacements are then combined either by the SRSS or by the absolute sum approach to calculate the total pseudo static response. We will designate these results by PS and PA, respectively. These response values are also compared with the values calculated by the approach proposed by the writers (1987a).

It is well recognized that the dynamic and pseudo static parts are correlated. However, in absence of any better approach to account for this correlation, it has been a common practice to combine the two by either the SRSS or by the absolute sum approach. Since there were three different estimates of the dynamic response and two for the pseudo static response, these when combined with the SRSS and absolute sum will give a total of 12 different estimates of the total response. These 12 estimates are compared with the value calculated by the writers' approach (1987a) and evaluated in the next section.

4. NUMERICAL RESULTS

The numerical results are obtained for the primary-secondary system shown in Fig. 1 for the ground motion defined by a set of response spectrum curves. For this structure: K = 1.075 E+8 k/ft, M = .335 E+5 slugs, k = .31 E+6 k/ft, m = .335 E+3 slugs, and k_c = .23 E+6 k/ft. The modal damping ratios for the primary and secondary systems were taken to be .05 and .02, respectively. Member forces calculated with the approach proposed by the writers (1987a) are presented in

Table 1. The table shows the dynamic, pseudo static, and cross response components and the total response for various members of the secondary system. The relative contribution of each of the components to the total response is also shown. It is noted that neither of the response components can be assumed to be insignificant compared to the others in all situations. It depends upon the type of structural properties, their configuration and the seismic input characteristics. The correlation between the dynamic and pseudo static parts can also be positive or negative. It is, therefore, necessary that this correlation be included properly in the calculation of response.

Table 2 compares various estimates of the dynamic response (DE, DS and DA) and the pseudo static response (PS and PA) with their counterparts obtained by the approach proposed by the writers (1987a). The results are shown in the ratio form. That is, the estimated values are divided by the bench-mark values. Thus a ratio value less than 1.0 means that the estimated value is a unconservative, whereas a value higher than 1.0 means it is conservative. The values clearly show that the envelope spectrum approach need not give a conservative estimate all the time. The same statement is true for DS. The absolute sum combination, however, ensures a conservative estimate, which sometime can be ultra-conservative. The pseudo static response, on the other hand, seemed to be over-estimated even by the SRSS combination. The absolute sum combination, of course, provides an ultra-conservative estimate of the pseudo static response. These over-estimations are seen to vary from member to member.

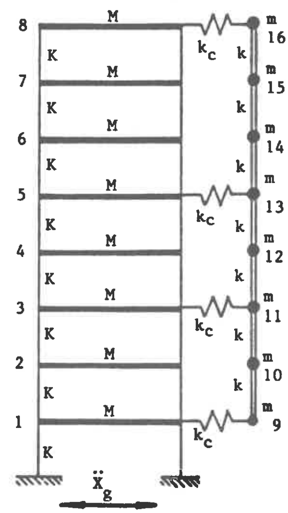

Fig. 1 A Primary-Secondary System.

Table 3 shows the comparison of various total response estimates with the results obtained by the writers' approach (1987a). The first part of the table shows the results when the dynamic and pseudo static parts are combined by the SRSS approach whereas the second part shows the results when they are combined by the absolute sum approach. Of course, the most conservative estimate is obtained when DA and PA are combined by the absolute sum approach. Other combination procedures need not ensure a conservative estimate of the response all the time. Also the ranges of under- and over-estimations vary with member and the method of combination used. Thus nothing can be said about the superiority of any combination over another; all are ad hoc and, in fact, irrational.

Table 1: Dynamic, pseudo static and cross response components of the total response in members of Fig. 1 (lb-units).

Element (1)	Dynamic Response (2)	Ratio (2)/(8) (3)	Pseudo-Static Resp. (4)	Ratio-(4)/(8) (5)	Cross Response (6)	Ratio (6)/(8) (7)	Total Response (8)
16-15	12579.98	1.039	746.0	0.061	-3499.67	-0.289	12106.4
15-14	1111.75	0.769	746.0	0.516	543.08	0.375	1444.8
14-13	12792.30	0.961	746.0	0.056	3554.82	0.267	13298.0
13-12	1694.04	0.787	1287.59	0.598	312.93	0.145	2150.7
12-11	8939.41	0.905	1287.59	0.130	3987.10	0.403	9872.5
11-10	1281.49	0.672	1262.08	0.662	626.57	0.328	1904.6
10-9	6287.24	0.872	1262.08	0.175	3294.19	0.456	7209.3

Table 2: Comparison of various approximate estimates of the dynamic and pseudo static response with the results obtained by a more accurate approach

Element	Dynamic Response			Pseudo-Static Response	
	DE	DS	DA	PS	PA
16-15	0.785	0.623	1.039	3.565	5.236
15-14	1.821	1.484	2.639	3.565	5.236
14-13	0.791	0.655	1.072	3.565	5.236
13-12	1.742	1.077	1.863	1.805	3.045
12-11	0.791	0.642	1.081	1.805	3.045
11-10	2.016	1.073	1.937	1.036	1.842
10-9	0.814	0.608	1.085	1.036	1.842

Table 3: Comparison of total response estimated according to various approximate response combination schemes with the total response obtained by a more rational approach.

Element	(Dynamic, Pseudo Static Components)					
	(DE,PS)	(DS,PS)	(DA,PS)	(DE,PA)	(DS,PA)	(DA,PA)
	SRSS - Combination Scheme					
16-15	0.845	0.684	1.103	0.877	0.724	1.128
15-14	2.308	2.161	2.734	3.037	2.927	3.373
14-13	0.787	0.661	1.051	0.816	0.695	1.072
13-12	1.746	1.374	1.823	2.281	2.010	2.340
12-11	0.754	0.628	1.007	0.819	0.704	1.056
11-10	1.521	0.997	1.474	1.825	1.419	1.786
10-9	0.733	0.560	0.964	0.780	0.621	1.000
	Absolute Sum - Combination Scheme					
16-15	1.035	0.868	1.300	1.138	0.971	1.403
15-14	3.234	2.976	3.862	4.094	3.836	4.722
14-13	0.961	0.830	1.231	1.055	0.924	1.325
13-12	2.453	1.929	2.548	3.195	2.671	3.290
12-11	0.951	0.817	1.214	1.113	0.979	1.376
11-10	2.044	1.409	1.991	2.578	1.943	2.525
10-9	0.892	0.712	1.128	1.033	0.853	1.269

5. CONCLUSIONS

At least for the example problem, the results indicate that various ad hoc approaches used for calculating the dynamic and pseudo static responses of a multiply supported secondary system do not provide the correct estimates of the response. The approaches can under- or over-estimate the true response. Also, the contribution of the dynamic, pseudo static responses to the total response is likely to vary with the type of response, member in which the response is calculated, characteristics of the two systems and the input. No generalizations can be made about the relative contribution of these components. Furthermore, the contribution of the correlation between the dynamic and pseudo static response component to the total response can be very significant. It can not be correctly included by the currently used approximate rules for the combination of dynamic and pseudo static responses. In summary, to obtain the correct response for a multiply supported secondary system, one must use proper inputs at the support as well as employ analytically rational approach to calculate the response from the inputs.

6. ACKNOWLEDGEMENTS

This work was supported by the U.S. National Science Foundation through Grant No. CEE-8208897 with Dr. S. C. Liu as its Program Director. This support is gratefully acknowledged.

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