

## Combination of the Primary and Secondary Stress Components for Piping Systems

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Most piping systems are supported at many points from either a single structure or from several separate structures. The motion of each of the support points for the primary structure or structures when subjected to a single earthquake ground input motion may be quite different. In such cases, the piping system must be designed to withstand loads due to both the inertial effect and due to the relative displacements at the support points.

The current US NRC Standard Review Plan (SRP), Section 3.7.3, requires two separate analysis which represent a conservative and acceptable approach. For the purpose of piping design in the nuclear power plant industry using the ASME code, the stresses produced by the inertia of masses are considered as primary, the stresses produced by the relative support displacement are considered secondary. An upper bound envelope of all the individual response spectra for all the support locations is used to calculate the maximum inertia responses. In addition, the relative displacements at the support points are used in a static analysis to predict the maximum pseudo-static stress responses. The present guideline requires that the support displacements must be imposed on the supported item in the most unfavorable combination. Although the ASME code piping design criteria uses these two components separately in calculating limits to primary and secondary stresses, a recent anticipated change considers both of these effects in the primary category. Hence, the SRP requires combination of these two stress components by the absolute sum method.

The present study considers several typical piping models subjected to distinct support motions. The independent time history analysis yields both primary stresses due to inertia and secondary stresses due to relative support motions. In addition, this analysis predicts the total response due to both effects. These results presumably are the best estimate of the actual response of a piping system subjected to a real earthquake because the analysis involves solving the system equations at every time step and the phasing during the process of solution is not lost.

The piping models were then analyzed using the response spectrum method to obtain the maximum primary stresses. The secondary stresses were next calculated by performing a set of static analysis which result in the most unfavorable combination. These two results are combined by both SRSS and absolute sum methods and the results are compared with the time history solutions. It was found that the SRSS combination of the primary and secondary stress components yield acceptable results provided the latter component is calculated in its most unfavorable combination.

## 1. Introduction

The design of piping systems in nuclear power plants requires the consideration of moment responses caused by postulated earthquake loadings at the structure foundation. The seismic loads are transmitted to the piping through the pipe support connections and structure supporting the system. Thus, potentially each support point excites the piping system with a different time dependent input loading. One way of estimating the pipe response is to perform a time history analysis with a model that includes the piping system together with the structure and all components. The cost of such an analysis is prohibitive. An alternate procedure is to decouple the piping from the structure and to input loading functions for the piping defined from the responses of the structure at the support points. This requires a time history analysis of the piping system, which predicts the piping response without taking into account the effect of the pipe-structure interactions.

The later analysis [1] yields two components of response if the support point loadings are different. One is due to the inertia effect of pipe mass and the other is due to the differential input motion of the support points. The former component is the dynamic response and is categorized as producing primary stresses whereas the later component is known as the pseudo-static component and produces secondary stresses. In the older versions of the ASME code [2], the primary stresses were combined with other stresses caused by sustained loads and pressure to satisfy the code requirements. The secondary stress became a part of the thermal stresses or stresses caused by terminal movements.

In the 1980 version of the ASME Section III requirements, the above two kinds of stress can be combined with other dynamic and sustained load responses. In the present requirement of the Standard Review Plan (SRP) [3], these two components must be combined by absolute sum if their time dependent magnitudes are not known, which is the case if they are calculated by other than Time History Methods. This poses a question of the level of conservatism introduced by adopting such a combination method. This paper identifies examples of the level of conservatism inherent in various combination procedures.

The combination is carried out between the dynamic responses (i.e., primary) obtained by a response spectrum analysis and the pseudo-static responses (i.e., secondary) derived from the Seismic Anchor Movement (SAM) analysis. Since the above two methods predict response in a conservative way, they do not represent the actual responses of a piping system. Time history analysis with independent input accelerations is considered to yield the most realistic responses. The percentage of conservatism associated with any combination between the primary and secondary stresses can be estimated by comparison to the time history solution.

## 2. Technical Procedure

In present industry practice the dynamic component of piping response is obtained by using the Response Spectrum Method. The input spectra for this kind of analysis represents the envelope of all the support spectra developed from the time history results from the earthquake analysis of the supporting structure or building. The envelope spectra are applied to all support points simultaneously. These spectra are broadened as per the Regulatory Guide 1.122 [4], before analysis. The modal and spatial combinations are chosen as recommended in the Regulatory Guide 1.92 [5]. The predicted moment response thus calculated is supposed to represent the maximum dynamic or inertial response of the piping system.

There exist no standard procedure for calculating the pseudo-static response of the piping system due to seismic loading. Current standards require that this component be

obtained in such a manner that it represents the most severe condition. In order to calculate this, the magnitudes of the maximum support displacements as well as the phasing between these support movements are required. The Standard Review Plan [3] suggests the support displacements can be calculated either from the structure time history analysis or from the support point response spectra. The former method requires a selection of the maximum displacements from the structural analysis. The later method uses the formula, displacement =  $S_a g / \omega^2$ , where  $S_a$  is the floor response spectra ZPA amplitude representing the floor motion,  $g$  is the acceleration due to gravity, and  $\omega$  is the first fundamental frequency of the structure supporting the piping system. This method is purported to predict the upper bound of the actual displacement of the support point.

Once these components are obtained, the phasing between the support points must be defined. Since there is no established procedure for determining the worst phasing for a piping system with more than two different support movements, a particular method currently available in the existing piping code PSAFE2 [6] is being used for this study. It has the capability of considering each spatial direction individually, the analyst specifying the displacement phasing at all the supports for all supports on input, and then combining the spatial direction results in either of three combination methods. They are the algebraic, square root of the sum of the squares (SRSS) and absolute sum methods.

It should be noted that an intuitive approach is used to predict the worst phasing between support points in any spatial direction. Thus, the prediction of the static response at any point of the piping system becomes dependent on the choice of the phasing used by the analyst. To illustrate a simple case, when there are two support points (or groups) with two distinct movements, the worst static responses will be produced when they are subjected to out of phase motion. Thus, there exists only one possible choice of phasing in each spatial direction to produce the most unfavorable stress condition. For a system with three distinct support groups three distinct combinations of phasing in each spatial direction must be considered to determine the most severe stress condition at a point in the piping system.

For each case of phase distribution considered in a particular piping system, the same phasing is used in all three spatial directions. Then the results are combined by either the algebraic, SRSS or the absolute sum method. The algebraic method must be used with care since the moment responses at any point can be cancelled if the moment caused by different spatial directional movements have opposite signs. On the other hand, the SRSS and absolute sum methods can predict the worst possible cases. In the present study all three combinations between the spatial effects are considered for each phase consideration. Thus, for the case of two support groups there are three possible solutions corresponding to each combination method for pseudo-static response calculations.

As mentioned earlier, the time history analysis with different support inputs yields the actual dynamic and pseudo-static responses at each point of the piping system. It should be noted that this analysis uses time history inputs at the support points which are consistent with the response spectra used in the response spectrum solutions. In other words, the response spectra used in this study are derived from the time histories predicted in the time dependent solutions. The damping values used are also the same in both analyses. In the present study a critical damping value of 1% was used.

The time history results with independent support movements yields both the dynamic and pseudo-static responses as well as the total responses at each time point for the piping

system. Since the phasing is retained between the dynamic and pseudo-static components in this computation the total response should represent the actual response of the piping system. This result is later compared with the different combinations of the individual components (i.e., primary and secondary) obtained from the response spectrum and seismic anchor movement analysis methods.

The moment results at each end of each pipe element are obtained from the separate dynamic and pseudo-static calculations for each problem. Once the three moment components at any point are calculated by any of the combination procedures identified earlier, the resultant moment is determined using vector summation. This moment is used as the parameter to study the conservatism in the combination method between the primary and secondary stress components.

The two combination procedures between two moment resultants considered in this study are the SRSS and absolute sum methods. The results corresponding to each combination method are compared with the total responses as predicted from the time history solution. A percentage of deviation from this actual response is then included for comparison purposes.

### 3. Analysis and Results

Four piping systems were chosen for this study. These represent typical three-dimensional piping problems suitable for nuclear power plants. The entire sampling of piping systems includes one 4-group, one 3-group and two 2-group problems. The 4-group problem has four distinct support groups which are excited with different earthquake motions at the support points. Similarly, the 3-group problem has three distinct inputs and the 2-group problems have two different support movements. Sketches of two of the piping systems are presented in Figs. 1 and 2.

The computer code PSAFE2 was used to perform all the analyses in this study. This code is an all purpose piping analysis code developed at BNL. Independent support motion analysis algorithms [1] have been implemented into the code for both the response spectrum and the time history analysis modes. The code has been used in other NRC programs to perform confirmatory analyses of piping systems for plants seeking operating license and in the development of Piping Benchmark Problems.

The source for input support excitations data was the CALTECH earthquake records which include all components (acceleration, velocity and displacement) for each earthquake record. These records represent ground motion records for different sites rather than the support point time histories for some nuclear structure. Also, each earthquake record has different frequency content and is uncorrelated with others. For the purpose of this study these records were used as inputs for the support groups, introducing randomness in the study results.

In order to represent realistic systems, this study also included an analyses using floor time history solutions of a nuclear structure. In this case, the building structure filters all the frequencies representing the dynamic characteristic of the building itself. Because of the massiveness and high strength of nuclear power plant structures, each floor is assumed to exhibit in-phase motion and the floor motions contain similar frequency contents. The results from this analysis are used to support the conclusions presented herein.

After selecting the piping systems and the loading functions, each piping problem was subjected to a set of analyses as described in the previous section. It includes an independent time history analysis, a response spectrum analysis using envelope spectra and a

number of static analyses for seismic anchor movement results depending on the number of groups and the intuitive selection of the most unfavorable phasing between these groups.

For comparison purposes, the resultant moment at each end of each element in a piping problem was calculated for all load cases. These results are presented in the report [7] in tabular form for each estimate of seismic anchor movement component in its worst stress condition within each problem. It is not possible to include all the input load function data and the tabulated results for each problem in this paper. Tables 1 and 2 presented in this paper, however, correspond to the piping system shown in Figs. 1 and 2 respectively.

In order to estimate the lower bound for the SAM analysis results, the moments predicted by the independent time history analysis for the pseudo-static component were in fact used as predicted static component (see column 4 in tables). Consequentially the variable of phasing choice has been eliminated from the included results. This component is then combined with the predicted dynamic component (see column 3 in tables) obtained from the response spectrum analysis. The combined results are tabulated in columns 5 and 6 corresponding to the SRSS and absolute combination method. The last two columns in these tables represent the percentage of conservatism associated with each of these combination methods when compared against the actual piping response included in column 2.

#### 4. Conclusions

It can be concluded that absolute sum combination between the primary and secondary stresses will always yield the worst possible stress condition for a given choice of support phasing. The use of SRSS combination also provides reasonably conservative results. The most important parameter affecting conservatism was found to be in fact the choice of phasing between the support groups. This particular issue was not addressed in the tables presented in this paper since the actual static component was considered in these results. Lastly, with a few exceptions, the SRSS combination predicts conservative results for most points in the piping system. The few exceptions can be considered to be within the uncertainties and conservatism inherent in the seismic analysis of piping systems.

Several other studies using more realistic input loadings were made which are not included in this paper. As mentioned earlier, the earthquake input for the presented studies were chosen from the real ground motion earthquake records available in the CALTECH publications. A number of analyses were performed with a set of real floor time history and response spectra records from an actual nuclear structure. A general trend observed in this extended study is described below.

Most Category I nuclear structures are designed on the basis of radiation shielding which governs the concrete wall thickness. These structures are consequentially very rigid. Such structures, when subjected to an earthquake excitation, exhibit floor responses which are both in-phase and highly correlated. For a piping system supported within this type of structure all support excitations would be in-phase. If the simplified SAM analysis considered them out of phase, then the computed SAM stress component would presumably be overly conservative as compared to the independent time history solutions. This observation is also true, for a significant portion of piping systems are supported from more than one building. Only the intermediate section between the buildings would experience larger SAM stresses than would be predicted for in-phase response. With this in mind, it should be obvious that the level of conservatism inherent in real nuclear plant designs will usually be large regardless of which combination procedure is used between the primary and

secondary stress components if any phasing other than in-phase motions is considered in the SAM analysis.

In summary, the SRSS combination between the primary and secondary stress components of a piping system subjected to seismic loading provides a reasonable level of conservatism in estimating the stress condition. It is not as conservative as that provided by the absolute sum procedure. It should, however, be noted that the estimation of the static component (i.e., secondary stress) should be made in a proper and conservative way as it has a significant effect on the results.

#### References

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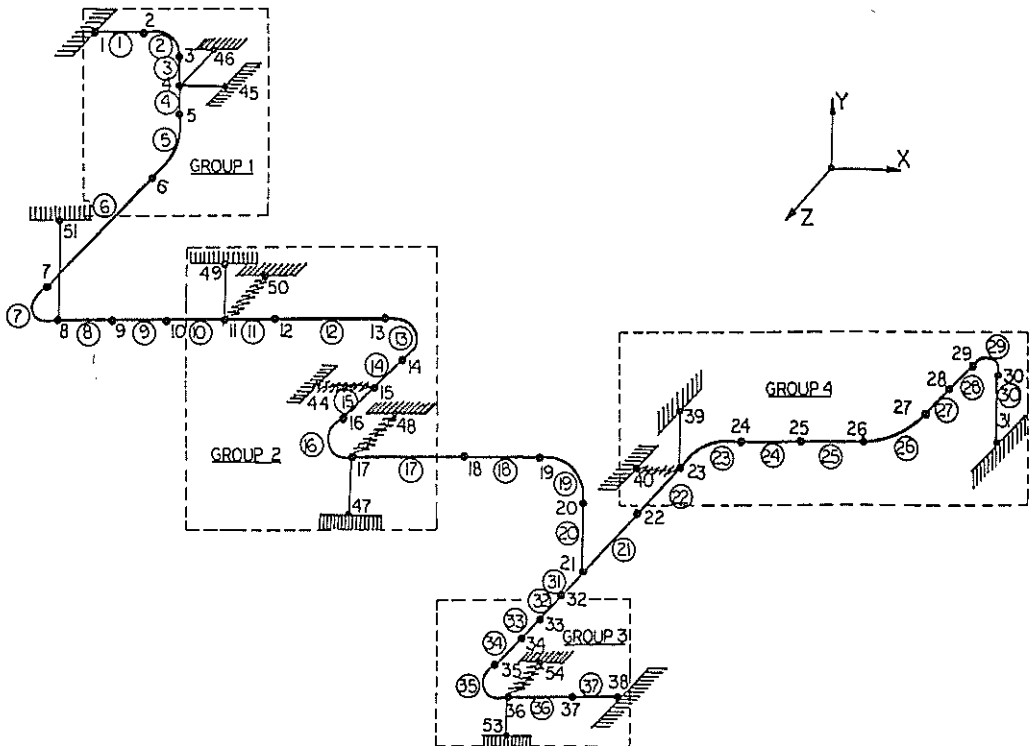


Figure 1 - Piping System 1

Table 1. Resultant Moment Responses in Kip-In for Piping System 1

NODE	T.H. (1)	R.S. (2)	STATIC (3)	SRSS (2,3)	ABS (2,3)	SRSS (PER)	ABS (PER)
1	10	3	10	10	13	2	26
2	10	2	10	10	12	3	20
3	10	2	10	10	11	2	18
4	10	5	13	14	19	6	38
5	10	4	10	11	14	6	36
6	23	8	9	10	13	10	48
7	28	28	28	29	36	3	28
8	19	14	17	23	32	20	70
9	10	11	8	13	18	28	78
10	4	16	19	25	35	18	66
11	12	9	10	13	18	7	50
12	19	9	15	19	25	8	37
13	19	8	17	24	32	6	47
14	25	15	23	26	39	6	47
15	25	2	25	33	47	1	28
16	29	4	29	30	38	2	29
17	13	3	15	19	27	9	54
18	13	3	15	19	23	3	33
19	15	5	15	21	31	3	34
20	15	36	54	65	90	17	62
21	15	10	16	19	26	16	61
22	17	10	17	19	26	11	52
23	17	9	16	19	25	11	51
24	13	8	12	14	20	12	55
25	16	6	16	17	22	5	37
26	16	6	16	17	22	4	35
27	13	5	12	13	18	6	38
28	11	5	10	11	15	2	35
29	10	5	9	10	13	2	38
30	66	40	61	73	101	11	53
31	65	46	59	75	105	16	62
32	64	50	58	77	108	20	69
33	61	53	55	76	108	25	77
34	70	13	68	69	60	-8	16
35	1	18	69	71	87	-1	22
36	36	17	34	38	51	6	43
37	45	21	43	48	64	6	41

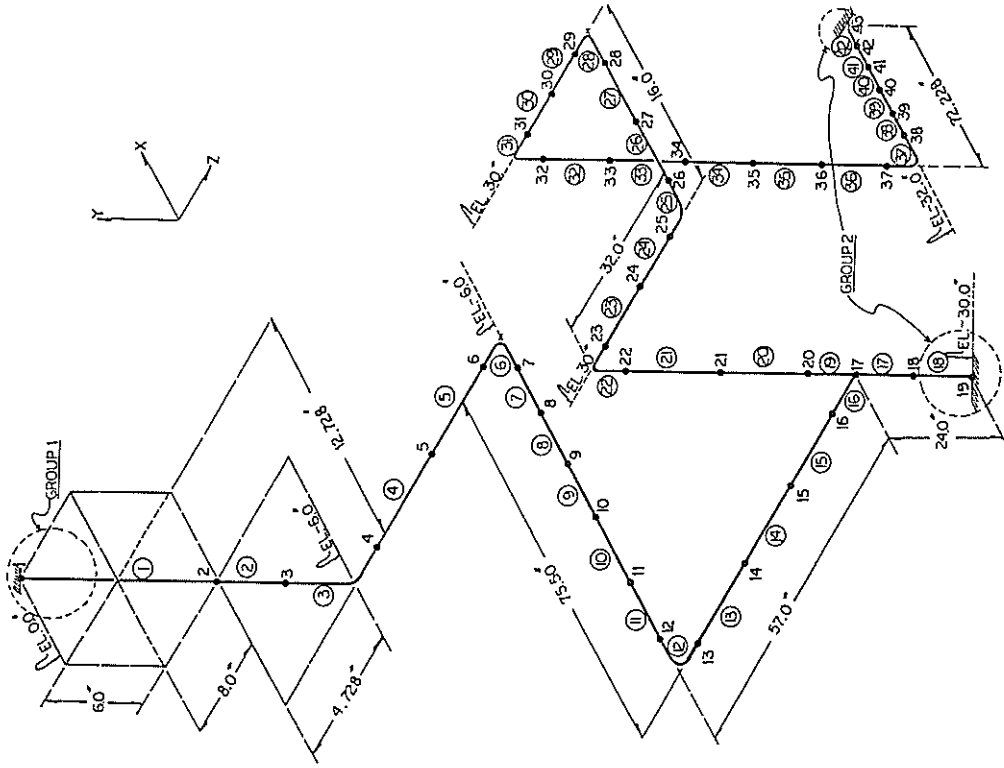


Figure 2 - Piping System 2

Table II. Resultant Moment Responses in Kip-in for Piping System 2

NODE	T.H. (1)	R.S. (2)	STATIC (3)	SRSS (2,3)	ABS (2,3)	SRSS (PER)	ABS (PER)
1	49	68	38	78	106	60	117
2	46	69	34	77	103	68	126
3	43	63	32	71	95	67	124
4	41	56	33	65	89	58	116
5	40	54	33	63	86	55	113
6	45	62	33	70	95	58	113
7	42	58	29	65	87	55	108
8	32	38	22	44	61	37	88
9	25	31	16	35	47	37	84
10	26	44	11	46	56	76	113
11	34	65	11	66	76	95	126
12	40	78	14	79	91	99	130
13	41	81	16	83	97	100	134
14	36	71	15	72	85	103	139
15	31	63	13	64	76	107	145
16	32	61	12	63	74	99	134
17	38	85	14	86	99	126	159
18	31	77	7	77	84	149	172
19	29	74	15	76	89	165	211
20	23	42	14	45	57	91	142
21	21	32	14	35	46	64	117
22	22	27	14	30	41	40	90
23	21	26	14	29	40	37	86
24	20	28	15	31	42	57	112
25	21	35	15	38	50	80	136
26	23	41	15	44	56	88	141
27	25	43	15	45	58	81	131
28	27	45	15	47	60	75	120
29	24	38	15	40	52	71	121
30	23	31	14	34	45	49	97
31	26	37	13	39	50	52	94
32	27	42	13	44	55	61	102
33	26	42	13	45	56	70	113
34	28	47	14	49	60	76	119
35	32	54	14	55	67	76	114
36	36	62	14	64	76	75	109
37	42	72	14	73	86	75	105
38	43	73	14	75	87	74	104
39	37	62	13	64	75	74	106
40	32	52	13	54	65	71	107
41	28	45	13	46	57	68	107
42	26	41	12	43	54	66	107
43	25	40	12	42	52	65	106