Equivalent Static Coefficients for Simplified Seismic Analysis of Piping Systems

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SUMMARY

It is found that when a single span concentrated load static model is used to compute design piping stresses and support reactions, an equivalent static coefficient of 1.0 will suffice. On the other hand, if a piping analysis is to be conducted on an equivalent static basis using the lumped mass approach, the equivalent static coefficient need not be more than 1.10. Hence, a conservative factor of 1.20 can be recommended.

INTRODUCTION

Equivalent static coefficients have been used in simplified seismic analysis for small diameter piping, tubing, electrical conduits, and simple electrical and mechanical components. These coefficients used in the past have ranged from 0.67 to 1.5. For instance, Paragraph II.1 of Section 3.7.2 of the revised Standard Review Plan (Reference 1) stated that:

> "To obtain an equivalent static load of a structure, equipment or component which can be represented by a simple model, a factor of 1.5 is applied to the peak acceleration of the applicable floor response spectrum. A factor of less than 1.5 may be used if adequate justification is provided."

On the other hand, Regulatory Guide 1.100 (Reference 2) also stated that:

> "There is no adequate evidence presented in Section 5.3 to substantiate the validity of a static coefficient of 1.5, or one greater or less than 1.5 in its application to equipment analysis."

The basis of using a factor of 1.5 can be traced to References 3 and 4, where equivalent static coefficients have been obtained based on one to four span simply-supported and cantilever beam models. Although the largest equivalent static coefficient in these two studies reached 1.47, it occurred only in one case and only for one support reaction load. However, the use of the factor 1.5 prevailed for the reason of conservatism, which culminated in the recommendation in the Standard Review Plan.

With the publication of 1.100, further justification became a necessity even when using the very conservative factor of 1.5 in the equipment qualification. To fill such a need, Reference 5 presented close form solutions for rigid equipment, flexible equipment with one predominate mode and flexible equipment with multiple modes. In Reference 5, it is recommended that both for rigid equipment and flexible equipment with one predominate mode, a factor of 1.0 will suffice. Whereas for flexible equipment, the factor of 1.5 may be a more appropriate upper bound value. Subsequently, Reference 6 provided additional data based on analysis of a large number of mechanical components. In this study, the static coefficients have been shown to be less than 1.2, and it is less than 1.0 for the majority of the components studied. However, the data has not been organized according to equipment dynamic characterisitcs, as presented in Reference 5. Hence, a direct substantiation of the recommendation by Reference 5 remains to be acoomplished.

In this paper, the studies reported in References 3 and 4 will be re-evaluated together with some new information obtained using similar approaches.

It is found that when a single span concentrated load static model is used to compute design piping stresses and support reactions, an equivalent static coefficient of 1.0 will suffice. On the other hand, if a piping analysis is to be conducted on an equivalent static basis using the lumped mass approach, the equivalent static coefficient need not be more than 1.10. Hence, a conservative factor of 1.20 can be recommended.

PIPE GEOMETRY AND INPUT

A number of simple pipe support configurations have been used in the studies reported in References 3 and 4. For instance, Reference 3 used five particular cases. They are: 1) cantilever, 2) simply supported beam, 3) fixed end beam, 4) two-span simply supported beam, and 5) four-span simply supported beam. In all five cases, five mass points between each set of supports were considered in the rigorous dynamic analysis. The input used for all cases is a constant 1 g acceleration response spectrum. This input is very conservative since all modes compiled by dynamic analysis will be subjected to the same spectral acceleration. Whereas, in reality, only modes close to a response spectra peak should see the peak acceleration value. For instance, using the one-span simply-supported beam as an example, a five-mass model would produce five modes with only the modes 1, 3, and 5 contributing to responses. Assuming the first mode is at the response spectrum peak, the third and fifth modes would most likely be at the zero period acceleration (ZPA) of the response spectrum. In the meantime, the participation factors for the third and fifth modes would only be 1/3 and 1/5 of the first mode, respectively. Assuming that ZPA is only 1/6 of the peak acceleration value (a reasonable assumption for most piping systems), the total contribution from the third and fifth modes is about 9 percent of the fundamental mode. The percentage of contribution would be larger if a higher mode (instead of the fundamental mode) is at the spectrum peak. For a larger model, such as a four span beam model, the total number of modes contributing becomes greater. Therefore, the conservatism of applying the same spectrum acceleration to all the modes simply increases with the number of modes considered (although it may reach an asymptote fairly rapidly). Hence, one may conclude that an overconservatism of at least 9 percent exists for the data reported in Reference 3.

In Reference 4, eight typical pipe support configurations have been studied. These include 1) cantilever, 2) simply-supported (SS), 3) fixed-fixed (FF), 4) simply-supported-fixed (SF) with no overhang, 5) simply-supported-fixed with 16 percent overhang, 6) simply-supported-fixed with 33 percent overhang, and 7) simply-supported-fixed with 50 percent overhang. Again, as in the case of Reference 3, all models are lumped with five masses between end points and subjected to a 1 g constant response spectrum input. Consequently, the data reported in Reference 4 is also quite conservative, at least by 9 percent. It should be noted that Reference 4 has reported results for several equipment models using actual response spectra as input. In these cases, the worst results occur at the unsymmetrical double (flexible) cantilever on a flexible base. The last model is only present for a flexible equipment supported by a flexible base. This is a rare design even for equipment. Consequently, data corresponding to this model is not realistic and is not used in the present study. All other equipment cases in Reference 4 have shown rather low ratio for dynamic response versus static concentrated loads using peak response spectrum value.

While data reported in Reference 4 is mainly from one to two span beams, the study of Reference 3 covers 1 to 4 span beams. However, in a real piping system, a straight pipe run could have more than four spans. Thus, there is the need of evaluating pipe runs with more than just 4 spans. As a result, a study of 13 different pipe spans has been conducted. The study includes up to 24 spans, with five lumped masses within each span and using a constant 1 g response spectrum as input. Again, the 1 g constant response spectrum input is very conservative which may have contributed to the increase in dynamic response loads for beams with greater number of spans.

The use of up to 24 spans is judged to be sufficient for trend setting. Any more spans included in the model would simply increase the inaccuracy of the data due to the constant acceleration input used.

NUMERICAL EXAMPLES

Presented in Tables 1, 2 and 3 are the numerical results obtained in References 3 and 4, respectively. It should be pointed out that Tables 1, 2 and 3 merely present the pertinent data from References 3 and 4. Since References 3 and 4 include comparisons of dynamic analysis, uniform load analysis and constant static load (at the fundamental frequency) analysis, the conclusions are strongly influenced by the conservative approach such as the uniform load approach. Consequently, it is felt that by extracting only data on dynamic analysis and concentrated load analysis (based on peak spectral acceleration), Tables 1, 2 and 3 would provide a much more accurate and yet conservative comparison of these two approaches.

Table 1 is a comparison of the dynamic analysis and the single span concentrated load analysis. It shows that the single span static analysis is always more conservative than the dynamic analysis, more so for bending moments than for support reactions. However, even for supports, the maximum dynamic response is only 0.94 of the static reaction. Therefore, Table 1 shows that a factor of 1 will suffice if the piping is to be evaluated based on the single span concentrated load with peak spectral acceleration as the input.

In Table 2, the same result from the dynamic analysis is compared with the static analysis with concentrated peak acceleration applied at the mid-span. Table 2 shows again that the static analysis is more conservative than the dynamic analysis except for one support. For this support (from the 4 span beam model), the static analysis is exceeded by the dynamic analysis by about 5 percent. However, since the constant response spectrum input is at least 9 percent too conservative when applied to the dynamic analysis model, Table 2 shows that a factor of 1 for the static analysis will still be conservative.

Table 3 compares the dynamic analysis results with the static concentrated load analysis to different end conditions. It shows that beams with cantilever type of arrangements generally produce higher dynamic response. However, in no case has the dynamic analysis been exceeded by the static analysis. This shows, again, that a factor of 1 should be used as the multiplier for the static analysis.

Finally, Table 4 presents a comparison of dynamic analysis results for different number of spans. All numbers in this table have been normalized to single span results. As has been seen in Tables 1 and 2, the governing factor is in the support loads. While multiple-span results are higher than the single span results for support loads, pipe deflection, pipe stress and bending moments are all highest for the single span. Also, even with the total spans increased to 24, the responses remain fairly constant. For pipe stress and moments, the two-span results are actually the highest. It is important to note that because of the constant 1 g response spectrum, the results will not be quickly converged to an asymptote. This is probably the reason that the support loads are still increasing very slowly. The gradual increase in support loads to the highest in 24 spans (up to a factor of 1.18), indicates that the analysis is still picking up contribution from the higher modes. Also, by examining Table 1, one can see that the highest support loads are actually shifting to central most span of the model. Because of the conservatism in the constant 1 g spectrum and the sufficiently large number of spans (24) used, it is concluded that the factor of 1.18 should be very conservative. And, if the minimum conservatism of 9 percent discussed earlier is used to reduce the factors in Table 4, Table 4 shows that all factors should be less than 1.10. However, for reason of conservatism a factor of 1.20 can be recommended.

CONCLUDING REMARKS

The following conclusions can be made from the data presented:

1. The large multiplier reported in Reference 3 pertains only to the static analysis using a uniform load approach. In an engineering problem where lumped (concentrated) mass approach is used, the multiplier should be substantially less. For the approach of using a simplified, single span beam concentrated load, static analysis, peak response spectral acceleration value can be used directly as the input acceleration. That is, a multiplier of 1.0 will suffice.
2. When static analysis is performed on the actual piping model using a lumped mass approach, the equivalent static coefficient need not be more than 1.10. Hence, to be conservative, a factor of 1.20 can be recommended.

REFERENCES

[1] Standard Review Plan, NUREG-0800, July 1981.

[2] U.S. NRC Regulatory Guide 1.100, "Seismic Qualification of Electric Equipment for Nuclear Power Plants," March 1976.

[3] Stevenson, J. D., and W. S. LaPay, "Amplification Factors to be Used in Simplified Seismic Dynamic Analysis of Piping Systems," ASME Paper 74-NE-6.

[4] Gwinn, J. M., and N. A. Goldstein, "Equivalent Static Load from Amplified Response Curves," ASME Paper 74-NE-6.

[5] Lin, C.-W., "A Justification of the Static Coefficient of 1.5 for Equipment Seismic Qualification," in American Nuclear Society/European Nuclear Society Topical Meeting on Thermal Reactor Safety, April 6-9, 1980, pp. 773-780, CONF-800403 (Vol. 2).

[6] Hyde, S. J., and J. Pandya, "Seismic Analysis of Auxiliary Mechanical Equipment in Nuclear Plants," in Dynamic and Seismic Analysis of Systems and Components, ASME-PVP-65, American Society of Mechanical Engineers, Orlando, Florida, 1982.

TABLE 1

COMPARISON OF DYNAMIC ANALYSIS AND
SINGLE SPAN CONCENTRATED LOAD ANALYSIS

Model Type	Location	Type of Analysis: Single Span Concentrated*	Type of Analysis: Dynamic	Ratio Dynamic/ Static
1 Span	R_{21}	600	254	0.42
	M_{21}	9000	4888	0.54
	R_{41}	600	192	0.54
2 Span	R_{42}	600	540	0.32
	M_{41}	9000	4065	0.45
	R_{51}	600	150	0.25
	R_{52}	600	443	0.74
4 Span	R_{53}	600	564	0.94
	M_{51}	9000	2670	0.30
	M_{52}	9000	3778	0.42

* Support reaction has been doubled to include effects from the adjacent span.

TABLE 2

COMPARISON OF CONCENTRATED LOAD (WITH
PEAK ACCELERATION AND CONCENTRATED
AT MID-SPAN) AND DYNAMIC ANALYSIS

Model Type	Location	Type of Analysis: Concentrated Mid-Span	Type of Analysis: Dynamic	Ratio Dynamic/ Static
1 Span	R_{21}	300	254	0.88
	M_{21}	9000	4888	0.54
	R_{41}	187	218	0.73
2 Span	R_{42}	825	2684	0.60
	M_{41}	6750	1809	0.41
	R_{51}	204	150	0.74
	R_{52}	728	443	0.61
4 Span	R_{53}	536	564	1.05
	M_{51}	5790	2670	0.47
	M_{52}	3858	3778	0.98

TABLE 3

COMPARISON OF THE DYNAMIC ANALYSIS AND
THE STATIC CONCENTRATED LOAD ANALYSIS

Beam Model	Ratio Dynamic/Concentrated Static
Cantilever	0.89
SS	0.51
FF	0.59
SF - no overhang	0.58
SF - 16 percent overhang	0.51
SF - 33 percent overhang	0.76
SF - 50 percent overhang	0.87

TABLE 4

COMPARISON OF DYNAMIC ANALYSIS RESULTS
FOR MULTIPLE-SPAN BEAMS WITH SINGLE-SPAN

No. of Spans	Maximum One Side Support Load	Maximum Total Support Load	Maximum Deflection	Maximum Pipe Stress	Maximum Moment
1	1	1	1	1	1
2	0.97	0.97	0.41	0.77	0.84
3	1.09	0.82	0.51	0.60	0.66
3.4	0.95	0.87	0.38	0.62	0.68
4	0.98	0.98	0.39	0.71	0.78
5	1.09	0.92	0.44	0.64	0.70
6	1.01	1.01	0.33	0.71	0.78
7	1.08	0.96	0.41	0.66	0.73
8	1.02	1.03	0.31	0.71	0.78
10	1.03	1.04	0.30	0.71	0.78
12	1.04	1.04	0.30	0.71	0.78
14	1.07	1.07	0.30	0.72	0.80
24	1.18	1.18	0.33	0.79	0.87