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NRC PIPING DESIGN RESEARCH

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Introduction

In recent years, the NRC Office of Nuclear Regulatory Research has sponsored and completed several research projects to evaluate nuclear plant piping design procedures for dynamic loads. This research is largely in response to the recommendations of the NRC Piping Review Committee, specified in NUREG 1061 Volumes 2, 4, and 5 (References 1-3). The Committee concluded that the piping dynamic load design criteria and practices (as they existed in the mid-1980's) were overly-conservative. It recommended almost twenty regulatory and research actions that were intended to lead to improved dynamic load design. This paper will summarize the NRC-sponsored research activities. For more information on the issues behind this research and its planning, the reader should refer to the NRC Piping Research Program Plan (Reference 4).

Pipe Damping

At the time of the Piping Review Committee's evaluation (1983-1985), improvements to dynamic response calculations seemed to provide the best alternatives for reducing unnecessary conservatisms in the piping design process. Thus a variety of standards and research activities addressing analytical response estimation techniques were made. Those involving the use of higher damping values have been shown to be the most influential, both in a technical sense (Reference 5) and in a regulatory sense. While several restrictions have been added, the endorsement of ASME Code Case N-411 through Revisions 24 and 25 of Regulatory Guide 1.84 is the Committee's only recommended regulatory action affecting the seismic design of piping that has been implemented generically.

Until recently, the NRC-sponsored Pipe Damping Study Project at Idaho National Engineering Laboratory (INEL) has been the major research contributor in the area of pipe damping. INEL studies (References 6 through 10) supported both the development of the PVRC pipe damping criteria (References 11 and 12) and its acceptance by the NRC.

In addition, INEL evaluated high frequency pipe damping data (Reference 13) and proposed a new damping curve that in effect raises the PVRC's curve to 3% damping in the high frequency regime and extends its range up to 100 Hz. The PVRC Technical and Steering Committees on Piping Systems endorsed this proposed criteria and recommended that it be considered in the ASME's revision of Appendix N (discussed below).

In other tasks, INEL has provided statistical descriptions of pipe damping (Reference [illegible]) for use in probabilistic studies, and has evaluated pipe damping in the high strain regime (Reference 15). The latter study helps justifying the premise that low estimates of pipe damping are self-correcting. That is, although a particular piping system's damping might be lower than some generic value used for design load levels, very high damping will be produced before failure levels are approached. INEL continues to collect and evaluate damping data from new high level dynamic tests of piping systems.

The ASME Task Group on Damping now is revising the pipe damping criteria given in Appendix N of Section III of the ASME Boiler and Pressure Vessel Code. This change will supersede Code Case N-411. A recent EPRI/Bechtel evaluation of the existing pipe damping data base (Reference 16) was made to support this effort. It is hoped that eventually Regulatory Guide 1.61 can be revised to reference this new pipe damping criteria. The NRC staff and INEL are following and contributing to the ASME effort.

Independent Support Motion Method

The Independent Support Motion (ISM) method is used to estimate dynamic response for cases where the in-plant response spectra differ for the various groups of supports in a piping system. It is supposed to yield more accurate results than conventional envelope spectra methods, and it is hoped that the increased analytical rigor involved would be rewarded by lesser required response margins.

A specific ISM procedure was recommended in Volume 4 of NUREG 1061. However there since have been unresolved questions about its use in conjunction with Code Case N-411 and suggestions that the square-root-of-the-sum-of-the-squares (SRSS) procedure be used in place of the absolute sum (ABS) procedure for combining support group responses. These ISM issues have been resolved for specific licensing cases, but not on a generic basis.

Brookhaven National Laboratory (BNL) was funded to revisit their previous ISM study (Reference 17) and evaluate the effects of Code Case N-411 damping, plus to look more comprehensively at the SRSS versus ABS group summation issue. The new BNL study (Reference 18) concluded that the ISM method used in conjunction with Code Case N-411 damping produces <u>relative</u> response margin trends similar to those seen previously, and that, surprisingly, the ISM/SRSS procedure gives results comparable to the conventional enveloped spectra method.

The PVRC Task Group on ISM was chartered to provide industry guidance and has reviewed the two BNL studies along with other research studies (References 19 and 20) and licensing cases. An important conclusion of the task group is that how support groups are defined is as significant as what group summation procedures are used. In hindsight, it has been found that BNL's grouping procedures were inappropriate and this caused atypical results. However, parts of References 17 and 18 are being used to support the task group's recommendations, now under development.

The PVRC Task Group on ISM has raised another point not fully understood when the Piping Review Committee made its evaluation. That is, the ISM method should be used for only a very limited amount of piping analysis problems, only those having very significant differences in support group input spectra. The PVRC task group should provide guidance on the ISM method in 1989. It is hoped that this guidance will be acceptable to the NRC and eventually could be referenced in Section 3.9.2 of the Standard Review Plan.

Closely-Spaced and High-Frequency Modes

To address research recommended in Volume 4 of NUREG 1061, BNL has been evaluating proposed response spectra techniques to better account for closely-spaced modes and high-frequency modes. A response margins study similar to those performed in References 17 and 18 is being performed, but using only the envelope spectra method. This project has undergone both administrative and technical setbacks, but it now appears that it will be completed in 1989.

Uncertainties and Conservatisms in Input Response Spectra

The Piping Review Committee recommended that research tasks be performed to assess the uncertainty range of design spectra and to develop a simple spectra broadening procedure based on equivalent energy input. While the second task is no longer in the NRC's research plans (there is at least one industry project in that area), the assessment of spectra uncertainty may soon have a large impact on piping design.

First, the Lawrence Livermore National Laboratory (LLNL) performed a limited study (Reference 21) and concluded ± 30% broadening of spectra would be more appropriate than the ± 15% value now specified in Regulatory Guide 1.122. Now, the Category I Structures Program is near completion and its results support the design consideration of a lower lower-bound input spectra frequency due to loss-of stiffness effects in rectangular concrete nuclear plant buildings. Upcoming actions by the ASCE (Reference 22) and the NRC staff could introduce changes that would significantly affect future piping system design. Assessments of both the regulatory and risk significance of lower shear wall stiffness are now being made (Reference 23).

To place the conservatisms in piping analysis into perspective, a response margins study (Reference 24) was made which looked at the whole earthquake design process and compared the results of various piping design calculations to realistic best-estimate response predictions. It was shown that considerable margin is introduced into piping seismic design from areas not explicitly addressed in piping analysis. The results of this study will undoubtedly be referenced in future attempts to revise piping analysis procedures.

Inelastic Piping Response Prediction

The Piping Review Committee recommended that research be conducted to develop simple estimation methods for inelastic piping response. In addition to industry efforts and a few smaller NRC-sponsored projects, the Westinghouse Hanford Company performed an extensive evaluation (Reference 25) of candidate nonlinear response prediction methods. While this has provided valuable background information, it is not clear at this point how these methods could be introduced into the design process.

High Level Dynamic Piping Tests

The Piping Review Committee recognized the potential benefit that could come from improving ASME Code piping design criteria for dynamic loads, but unfortunately insufficient dynamic piping failure data existed during the time of their evaluation. The NRC's support of the dynamic testing associate with the EPRI/NRC Piping and Fitting Dynamic Reliability Program (References 26) is a direct result of the Committee's recommendation to conduct such research.

All testing was completed in 1988. Forty-one piping component failure tests were completed by ANCO Engineers. In addition to an earlier pipe system fragility test (Reference 27), the Energy Technology Engineering Center ruptured two piping systems using high seismic-like loads, and one of these systems was retested. The Materials Characterization Laboratory finished testing over 140 fatigue ratchetting specimens. Also, waterhammer pipe systems tests were performed by ANCO Engineers. The test results consistently showed very high resistance to dynamic inertial loads; failure was produced by dynamic loads scaled 15 to 30 times higher than typical design values. The failure mechanisms were different than what was assumed when the current ASME Code piping design rules were developed. That is, piping rupture was due to ratchetting and fatigue effects and cross-sectional collapse did not occur.

General Electric is now developing a final proposal for revising the piping dynamic load stress criteria given in Section III of the ASME Boiler and Pressure Vessel Code. New concepts for piping design rules have been discussed with standards groups and the NRC staff. A proposed Code revision should be introduced formally to the ASME in the fall of 1989. All final reports for the Piping and Fitting Dynamic Reliability Program should be published by EPRI in 1989.

The NRC has also contributed to the high level piping test at the HDR facility (Reference 28). While the piping itself was not ruptured, it was shown that seismic loads at least eight times greater than design (Level D) values could be sustained.

Piping Earthquake Experience Data

There is an extensive and growing data base of earthquake experience for piping in heavy industrial facilities (References 29 and 30). The remarkable success rate for above-ground welded steel piping has been factored into the development of new seismic evaluation procedures (i.e., seismic PRA's, seismic margins reviews - Reference 31, and USI A-46 - Reference 32), and has been used qualitatively to support actions intended to relax piping seismic design criteria. However, this data is yet to be used directly in the nuclear piping design process.

The Oak Ridge National Laboratory (ORNL) and its contractors are currently investigating the possible use of USI A-46 type bounding spectra for piping design, documenting the design procedures used for the piping in the data base, and quantifying similarities and differences between non-nuclear and nuclear plant piping. This study will be completed in 1989 and may lead to a significant departure from current analytically-based design practices.

Nozzle and Branch Connection Design

The Piping Review Committee recommended that research to develop improved design guidance on nozzle stress limits and flexibility. ORNL has completed three related studies (References 33-35), and is now finishing new guidance on nozzle flexibility estimation. The latter should help improve the design of piping systems that are connected to tanks and thin-walled pressure vessels.

Discussion and Conclusions

As a result of the NRC Piping Review Committee's concerns and recommendations, the Office of Nuclear Regulatory Research has sponsored several projects to evaluate and improve the dynamic load design of nuclear power plant piping. The majority of these research projects have been completed, or will be completed in 1989.

While the new research results have raised technical issues, most importantly that fatigue or fatigue-ratchetting (not collapse) is the bounding failure mechanism for most dynamic load cases, they fortunately also have demonstrated very large margins-to-failure for piping subjected to dynamic inertia loads. New high level tests and the review of earthquake experience data have done much in the last four years to improve our appreciation of the inherent robustness of welded steel piping. This knowledge has been used in the development of new seismic evaluation procedures (e.g., seismic margins reviews) to justify not wasting resources on piping analyses. But ironically, with the exception of the endorsement of higher damping and some relaxation of pipe rupture criteria, the piping design regulatory changes recommended by the Piping Review Committee have not been made. And the research discussed above is yet to have an impact on piping design.

Why have we been so slow to accept changes to piping design procedures? For one reason, there has been a regulatory tradition of relying on analysis rather than test or experience data to ensure protection against piping dynamic loads, and there are no established criteria goals for setting margins-to-failure for piping dynamic loads. Even for the more narrow area of response prediction techniques, there is no firm guidance for accepting new methods. (For example, what should be an acceptable degree of nonexceedance when the results from a new method are compared to best-estimate predictions?) And there have been so many proposed changes to analytical methods that it is difficult to account for all possible combined effects.

Probabilistic and reliability arguments have had only limited success in improving overall piping design. This is partly because it is difficult to characterize all possible piping configurations, and partly because it is recognized that the loads and conditions that have damaged nuclear piping systems are difficult to predict and generally are not considered in the design process.

But perhaps the greatest hindrance to piping design change has been the perception, globally made, that the safety significance is small. After all, recent research has not uncovered any new threats to current piping designs, even though it is recognized that their reliability is not optimized. Since the motivation for change appears to be chiefly for economic rather than safety reasons, it is best that industry take the lead in future related research activities.

References

1. USNRC Piping Review Committee (April 1985). Summary - Piping Review Committee Conclusions and Recommendations, NUREG 1061, Volume 5
2. USNRC Piping Review Committee (April 1985). Evaluation of Seismic Designs - A Review of Seismic Design Requirements for Nuclear Plant Piping, NUREG 1061, Volume 2
3. USNRC Piping Review Committee (December 1984). Evaluation of Other Dynamic Loads and Load Combinations, NUREG 1061, Volume 4
4. USNRC (September 1988). Piping Research Program Plan, NUREG-1222
5. Munson, D. (July 1986). Guidelines for Reducing Snubbers on Nuclear Piping Systems, EPRI-NSAC-104
6. Ware, A. G. (November 1981). A Survey of Experimentally Determined Damping Values in Nuclear Power Plants, NUREG/CR-2406
7. Ware, A. G. (November 1982). Parameters That Influence Damping in Nuclear Power Plant Piping Systems, NUREG/CR-3022
8. Ware, A. G. and Thinnes, G. L. (April 1984). Damping Test Results for Straight Sections of 3-inch and 8-inch Unpressurized Pipes, NUREG/CR-3722
9. Arendts, J. G. and Ware, A. G. (September 1984). Tests to Determine How Support Type and Excitation Influence Pipe Damping, NUREG/CR-3942
10. Ware, A. G. and Arendts, J. G. (June 1986). Pipe Damping - Experimental Results From Laboratory Tests in the Seismic Frequency Range, NUREG/CR-4529
11. Welding Research Council (December 1984). Technical Position on Damping Values for Piping - Interim Summary Report, Bulletin 300
12. Pressure Vessel Research Committee (January, 1987), Damping Values - Piping Systems, Technical Position and Justification, PVRC Monograph

13. Ware, A. G. (July 1986). Pipe Damping-Results of Vibration Tests in the 33 to 100 Hertz Frequency Range, NUREG/CR-4562
14. Ware, A. G. (October, 1986). Statistical Evaluation of Light Water Reactor Piping Damping Data Representative of Seismic and Hydrodynamic Events, INEL Informal Report EGG-EA-7260
15. Ware, A. G. (August 1987). An Evaluation of Damping in Piping Systems at High Strain Levels, INEL Informal Report EGG-EA-7380
16. Hadjian, A. H. (October, 1988). Piping System Damping Evaluation, EPRI Report NP-6035
17. Subudhi, M., et al. (August 1984). Alternate Procedures for Seismic Analysis of Multiply Supported Piping Systems, NUREG/CR-3811
18. Bezler, P., Wang, Y. K. and Reich, M. (March 1988). Response Margins Investigation of Piping Dynamic Analyses Using the Independent Support Motion Method and PVRC Damping, NUREG/CR-5105
19. Francis, G., et al. (July 1988). Comparison of Dynamic Analysis Methods for Nuclear Plant Piping, NSAC-124
20. Liu, T. H., Nelson, S. R., and Lin, C. W. (March 1989). Seismic Analysis of Multiply Supported Piping Systems, EPRI Report NP-6153
21. Lu, S. C. and Tsai, N. C. (March 1986). Assessment and Improvement of Spectrum-Broadening Procedure in Piping Design - Phase I Final Report, UCID 20710
22. Bennett, J. G. and Farrar, C. R. (March 1989). ASME Working Group Activities on Stiffness of Concrete Shear Wall Structures, NUREG/CP-0097, Volume 3, pp. 279-292
23. Bohn, M. P. and Klamerus, E. C. (March 1989). Assessment of Effects of Structural Response on Plant Risk and Margin, NUREG/CP-0097, Volume 3, pp. 293-298
24. Johnson, J. J. and Bende, B. J. (February 1988). Quantification of Margins in Piping System Seismic Response: Methodologies and Damping, NUREG/CR-5073
25. Severud, L. K., et al. (January 1988). High-Level Seismic Response and Failure Prediction Methods for Piping, NUREG/CR-5023
26. Guzy, D. J., et al. (March 1989). Piping and Fitting Dynamic Reliability Program, NUREG/CP-0097, Volume 3, pp. 247-264
27. Chen, W. P., Onesto, A. T., and DeVita, V. (February 1987). Seismic Fragility Test of a 6-Inch Diameter Pipe System, NUREG/CR-4859
28. Kot, C. A., et al. (March 1989). SHAM: High Level Seismic Tests of Piping at the HDR, NUREG/CP-0097, Volume 3, pp. 339-362
29. Stevenson, J. D. (April 1985). Summary and Evaluation of Historical Strong-Motion Earthquake Seismic Response and Damage to Aboveground Industrial Piping, NUREG 1061, Volume 2 Addendum
30. Silver, M. M., et al. (January 1988). Recommended Piping Seismic-Adequacy Criteria Based on Performance During and After Earthquakes, EPRI Report NP-5617
31. Budnitz, R. J., et al. (August 1985), An Approach to the Quantification of Seismic Margins in Nuclear Power Plants, NUREG/CR-4334, pp. 5-6 & 5-7
32. Chang, T.Y. and Anderson, N. R. (February 1987). Regulatory Analsis for Resolution of Unresolved Safety Issue A-46, Seismic Qualification of Equipment in Operating Plants, NUREG-1211, page 5
33. Moore, S. E., et al. (December 1987). Review and Evaluation of Design Analysis Methods for Calculating Flexibility of Nozzles and Branch Connections, NUREG/CR-4785
34. Rodabaugh, E. C. and Moore, S. E. (to be published). Review of ASME Code Criteria for Control of Primary Loads on Nuclear Piping System Branch Connections and Recommendations for Addition Development Work, NUREG/CR-5358
35. Rodabaugh, E. C. and Moore, S. E. (to be published). Review of Elastic Stress and Fatigue-to-Failure Data for Branch Connections and Tees in Relation to ASME Design Criteria for Nuclear Power Piping Systems, NUREG/CR-5359