# Reliability Analysis for Stiff Versus Flexible Piping Systems

S.C. Lu, C.K. Chou
*University of California, Lawrence Livermore National Laboratory, P.O. Box 808, L-90, Livermore, California 94550, U.S.A.*

SUMMARY

This paper describes the program plan and progress to date on a research program entitled, "Reliability Analysis for Stiff Versus Flexible Piping Systems." This two and one-half year program was undertaken by the Lawrence Livermore National Laboratory (LLNL) for the U.S. Nuclear Regulatory Commission (NRC) to develop improved requirements for nuclear piping system design. These improvements may involve NRC requirements, industry practice, as well as ASME code specifications.

The overall approach to this problem is probabilistic, wherein the reliability of a piping system is evaluated, subject to daily events, transient loads, and postulated seismic events. The reliability model is capable of computing the failure probability of a complete piping system including piping, on-line components, and support devices.

The total program is divided into three steps: the first step is to confirm safety concerns introduced by the stiff piping system design; the second step is to develop optimum, or near optimum, piping designs; and the third step is to perform a value impact study and propose changes.

*This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

## INTRODUCTION

Nuclear power plant piping systems are required to be designed to withstand effects due to natural phenomena and postulated accidents in addition to the normal plant operation. Events associated with natural phenomena and postulated accidents are random in nature and often accompanied by great uncertainties. In order to accommodate these uncertainties, conservative design procedures have been adopted for nuclear piping systems and usually resulted in stiff piping designs with excessive use of support devices such as rigid supports, snubbers, and pipe whip restraints.

Use of piping support devices, however, has created certain safety concerns. For instance, addition of rigid supports usually introduce higher thermal stresses during daily plant operation, which may then reduce the overall reliability of piping systems. On the other hand, use of snubbers tends to introduce unexpected seismic stresses because snubbers may lose their function during a seismic event. Actual test data on snubbers has clearly indicated that reliability for these devices is low enough to warrant safety concern. As for pipe whip restraints, pipe may be in contact with a restraint device due to imperfect installation creating stresses not originally computed in the design analysis.

In order to assess the aforementioned problems with current nuclear power plant piping design, a steering committee was established by the Pressure Vessel Research Council (PVRC) with joint participation of the NRC, the American Society of Mechanical Engineers (ASME), and representatives from the nuclear industry in the United States. The PVRC Steering Committee is aimed to overlook these problems and to identify courses of actions to be voluntarily adopted by the various parties.

As a parallel effort, a research program sponsored by the NRC was initiated at LLNL to supplement PVRC committee activities. The objective of this research program is to develop modifications of design requirements and criteria which will improve the reliability of piping systems. The research work is devided into two phases. In Phase I, reliability analyses for stiff versus flexible piping systems will be performed. This phase will result in the evaluation of the effects of current design practices and design criteria to piping problems. In Phase II, we will incorporate new technical data generated by the PVRC technical committee into current design considerations. Thus, the proper design criteria will be developed for issuance by the NRC for future plant design, as well as for guidance on existing plant modifications. This paper presents an overview of the ongoing Phase I activities. Some interium results will be reported during the actual presentation of this paper.

## CONFIRMATION STUDY

In order to demonstrate the advantage of flexible piping design over stiff design based on reliability, actual piping system designs from existing nuclear power plants, or plants under construction, will be considered. For each piping system the reliabilities will be assessed and compared among three iteration designs, namely, the initial design, the intermediate design, and the final design.

The initial design refers to a piping system with necessary supports only to accommodate plant normal operation loads, such as pressure, gravity, and thermal effects. The final design is the existing pipe design which has additional supports and snubbers added to the initial design to make the piping system meet ASME Code requirements. The intermediate design is a fictitious design which has certain seismic support removed from the final design. This piping design may be over-stressed at a number of locations in accordance with ASME Code requirements.

The confirmation study will address the reliability of the piping portion of the piping system at this time. We realize that a complete evaluation ought to include possible failure of on-line support devices and components. We will incorporate support and component failure at a later stage. However, for confirmation purpose, we believe that it is sufficient to consider only piping reliability.

Piping systems under evaluation will be selected from both the power generating group, such as the main stream, main feedwater, etc., and the accident mitigation group, such as the ECCS, RHR, etc. The difference in characteristics of piping systems from the two groups may have pronounced influence on the applicability of conclusions resulting from our confirmation study.

In the ongoing piping reliability study, leak and rupture probabilities will be assessed. The computer code used in the assessment is capable of predicting probability of pipe failure, i.e., leak or rupture, due to either fatigue crack growth or stress corrosion cracking at pipe weld joints.

## OPTIMUM DESIGN

Since current design criteria and design requirements of piping systems do not explicitly address reliability and functional ability, it is quite possible that the final design resulting from current design practice may not be the most desirable. Following the confirmation study, we will assess the feasibility of optimum, or near optimum, piping redesign which will satisfy current design requirements and criteria specified by ASME Code and the NRC regulations. The purpose of the redesign is to minimize the number of supports and yet to maintain a reliability level which is at least equal to that offered by the existing piping design. In searching for a piping design that produces the optimum, or near optimum, piping flexibility, we wish that we could determine how current practice affects piping reliability with regard to achieving the optimum flexibility. The optimization requires a series of redesigns which can be very costly. We will rely on the confirmation study as well as a limited sensitivity study to identify areas which can increase piping flexibility without hurting the reliability. We will also work closely with utilities and A/E's to establish guidance for accommodating space limitation, relocating supports, or utillizing alternative support design in order to achieve the maximum piping felxibility.

We plan to perform reliability analysis of the overall piping system for a number of redesigns and draw a conclusion on the piping reliability as affected by piping flexibility. Then the most effective flexible piping design can be developed.

At this stage, the overall piping system reliability will also include the reliability of on-line components and supports in addition to the pipe itself. Particular attention will be concentrated on component failure due to nozzle loads and impact on piping reliability due to snubber failure, among others. Consequently, methodologies for assessing component and support reliability will be developed.

MODIFICATION OF CURRENT DESIGN REQUIREMENTS, CRITERIA, AND PRACTICE

In the confirmation study we try to demonstrate that a flexible piping system is more desirable than a stiff one. We then try to explore the possibility of achieving alternative acceptable piping designs which offer greater flexibility and yet satisfy current design requirements and criteria used in current practice. However, current design requirements, criteria, and practice are derived from conservative considerations and usually do not lead to sufficient flexibility as desired. We believe that many elements in current design requirements, criteria, and practice may be modified in order to allow more flexibility in nuclear piping design. Several examples of possible areas of modification are discussed briefly, as follows:

(1) Loading Definition

Natural phenomena and postulated accidents are random events. Magnitude, frequency, duration, location, as well as rate of occurrence, are highly random in nature and very difficult to estimate or predict. To account for these large uncertainties, the current loading definition tends to be more conservative. One example is the broadened floor design response spectra described in the NRC Regulatory Guide 1.122. PVRC Steering Committee on Piping Systems is considering to propose a modification in the near future.

(2) Linear Elastic Analysis

A piping system, when subjected to a large dynamic load, may behave non-linearly. Current industry practice is to perform all the analyses based on linear elastic techniques. It is true that the introduction of non-linear analysis in design is not practical or cost effective. But, on the other hand, certain test programs combined with analytical research can develop the proper structural and material properties for use in the equivalent linear elastic analylsis to reflect the true non-linear capacity of structural members.

(3) Damping Value

Damping is used in the elastic analysis to account for the energy absorption capacity of the piping system. However, current damping values used in nuclear design are based on the NRC Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants." Experimental test results have suggested that the values adopted in the R.G. 1.61 are lower than those of the actual condition. Modification is considered by PVRC Steering Committee.

(4) Loading Combination Criteria and Associated Allowable Design Limits

The ASME Boiler and Pressure Vessel Code is the monitoring code for nuclear power plant component design. Section III, Division I, of the ASME code provides specific sets of design and service stress limits that apply to the pressure-retaining or structural integrity of components and supports when subjected to the individual effects or combination of effects on events due to system operating conditions, natural phenomena, postulated plant accidents, and site related hazards. However, the design and service stress limits specified by the code are developed for static loading conditions, and they do not assure, in themselves, the operability of components, including their supports, to perform the mechanical motion required to fulfill the component's safety function. More importantly, the combination of loadings, the selection of the applicable design and service stress limits appropriate to each load combination, and the proper consideration of operability are not specified by the code. Current practice calls for utility owners and their A/Es to develop a design specification. Since the specification is not developed in a consistent and rational way and because the development gives no proper consideration of operability of components, the current practices provide no assurance regarding component functionability. It is clear that in order to come up with a reliable nuclear facility design, a more rational design criterion must be developed.

In this research work, we will perform a value impact sensitivity study to assess the influence of ASME code, NRC requirement, and current design practice on piping reliability and flexibility and to study possibilities of realistically changing these requirements and criteria.