Load Combination Research Program at the Lawrence Livermore National Laboratory

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SUMMARY

This paper presents an overview of the Load Combination Research Program at the Lawrence Livermore National Laboratory sponsored by the U. S. Nuclear Regulatory Commission (USNRC).

General design criterion 2, "Design Bases for Protection Against Natural Phenomena," of Appendix A, 10CFR50, requires that structures, systems, and components important to the safety of nuclear power plants be designed to withstand combinations of effects of natural phenomena and the effects of normal and accident conditions.

Historically, the USNRC has required that the structural/mechanical responses due to various postulated accident loads and loads caused by natural phenomena be combined in the analysis of structures, systems, and components important to safety. This requirement appears in the various regulatory documents such as regulatory guides, regulation revisions, and branch technical positions, as well as in the standard review plan.

The postulated accident loads and loads caused by natural phenomena such as earthquakes are random events. Amplitude, duration, frequency content, time of occurrence, and time-phase relationship are random and stochastic in nature. Without a systematic probability assessment, it is difficult to come up with a rationale for appropriately combining events.

Requirements to consider dynamic events action concurrently have therefore been based on judgment tending towards conservatism, because no comprehensive probabilistic study and unified philosophy exists on which to base better-founded decisions. Consequently, safety margins between various systems and from plant to plant vary widely. Trying to follow the inconsistent and fragmented load combination requirements is frustrating to the nuclear industry.

A unified approach to load combination is needed by the NRC as well as the nuclear industry. This approach must evolve from a rational procedure to address the following basic issues:

1. How shall we postulate pipe break locations?
2. What loads need to be combined?
3. If certain loads must be combined, what is the appropriate methodology to combine them?
4. What factors should be applied to load effects or responses?
5. What are appropriate service levels, load categories, and stress limits?

The Load Combination Program, a multi-million dollar, long-term research program undertaken by the Lawrence Livermore Laboratory represents a milestone effort funded by the USNRC to resolve these difficult and important issues. The first phase effort completed at the end of summer 1980 has two major objectives accomplished: (1) to determine the probability of a large LOCA (Loss of Coolant Accident) induced by a range of earthquakes; (2) to develop a methodology for combining generic dynamic loads for nuclear power plant design.

This paper presents an overview of the Load Combination Program. Technical details and results of Phase I activities are presented in 10 separate papers in SMiRT-6 Conference.

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Introduction

The Code of Federal Regulations requires that structures, systems, and components important to the safety of nuclear power plants in the United States be designed to withstand appropriate combinations of effects of natural phenomena and the effects of normal and accident conditions. Historically, the U.S. Nuclear Regulatory Commission (NRC) -- through Regulatory Guides, regulations, branch technical positions, and the Standard Review Plan--has required that the responses to various accident loads and loads caused by natural phenomena be combined in the analysis of safety-related structures, systems, and components.

The loadings to be taken into account in designing a nuclear component are governed by the ASME Boiler and Pressure Vessel Code. However, the code provides no specific criteria for combining various dynamic events. Rather, the code requires utility owners and their designated architect engineers to develop a design specification as part of the Safety Analysis Report (SAR). The postulated accident loads and loads caused by natural phenomena such as Loss-of-Coolant-Accident (LOCA) and Safe Shutdown Earthquake (SSE) are random events having much lower probabilities of occurrence than normal or operating loads. The amplitude, duration, frequency content, time of occurrence, and time-phase relationship for those dynamic events are random and stochastic in nature. Without a systematic probability assessment, it is difficult to come up with a rationale for appropriately combining random events. Requirements to consider dynamic events and their responses acting concurrently have therefore been based on judgment tending towards conservatism, since no comprehensive probabilistic study or unified philosophy exists on which to base better-founded decisions. Consequently, identical components or systems designed for different loading combinations by different license applicants have safety margins that vary widely between systems and from plant to plant.

A basic assumption made in the development of current load combination criteria is that additional conservatism will introduce additional reliability. This assumption may not always be justified. For example, designing for a conservatively defined seismic load requires an increase in the number of pipe supports and hangers or an increase in pipe stiffness or both. This assumption may result in higher thermal stresses under operating conditions, which would decrease reliability during operation. In addition, ductility and damping are not fully utilized in a stiff structure that relies heavily on strength to achieve seismic resistance. Because of its energy absorbing capability a flexible structure has a greater safety margin against failure than does a stiff structure.

Finally, a higher safety factor for a particular component or system does not necessarily lead to higher reliability for the entire plant since a stiff pipe will impart higher moments to the structure or equipment to which it is connected than a flexible pipe.

It is clear that a unified approach to load combination issues is needed. This approach must evolve from a rational procedure to provide consistency in design requirements that assure adequate safety margins or reliability in design. To achieve this goal a few basic issues must be addressed:

1. How shall we postulate pipe break locations and define the loads due to each postulated accident?
2. What loads need to be combined?
3. What is the appropriate method for combining loads?
4. What are the appropriate design limits for each load combination case?

Current design practice in postulating pipe break locations, are guided by Mechanical Engineering Branch technical position MEB-3T and Regulatory Guide 1.46, "Protection Against Pipe Whip Inside Containment". These guidances are also commonly used by the nuclear industry in system design outside containment. In implementing Regulatory Guide 1.46, 11 breaks will have to be postulated for each primary coolant loop for a typical 4-loop Westinghouse PWR plant. The penalty for postulating these breaks is that asymmetric blowdown phenomena, jet impingement forces and pipe whip impact loads are introduced which cause great difficulty in the design and construction of piping and support systems. This strongly suggests that a more rational basis is needed to improve the method of specifying pipe break locations.

Current design practice in determining what loads need to be combined is established on the basis of conservatism. Low probability loads, such as the most severe LOCA and SSE, are required to be combined in the design of nuclear power plants to provide additional safety margins. This combination requirement has been implemented by the nuclear industry for more than ten years. It was not controversial until recent years when the postulated LOCA and SSE loads were both increased by a factor of two or more to account for such phenomena as asymmetric blowdown in PWRs and techniques to better define the loading were developed. As a result of this change, the combination requirement became more difficult to implement, particularly in the design of reactor pressure vessel internal and support system. For future plants, the change on loading definition brought with it the prospect of increased construction costs. But for existing plants to meet the revised loading definition and also satisfy the combination requirement, modification is almost unavoidable. Certain plants can be feasibly modified, but other plants are not feasible to modify, and they present a difficult problem to the NRC. This strongly suggests that a technical basis is needed to reassess whether certain low probability loads need to be combined.

With regard to the appropriate method for combining responses, current design practice uses the so-called absolute summation (ABS) method of simply adding the absolute value of the peak structural response due to the individual dynamic loads. The ABS approach may lead to overly conservative design requirements for new plants and to design requirements that may require unnecessary modifications for operating plants when considering the newly identified loads. An alternate approach, recommended by the nuclear industry yields a combined response equal to the square root of the sum of the squares (SRSS) of the peak responses due to the individual dynamic loads. In order for NRC to determine the proper acceptable method for combining dynamic responses, a technical basis needs to be established.

For the basic issue relating to appropriate design limits for each response combination case, current design practice is governed by the ASME Boiler and Pressure

Vessel Code. The philosophy of the ASME Code is to place limits on stress which the combined responses must not exceed. These stress limits vary in accordance with the service level assigned to a particular load combination. But the actual load combinations are not specified by the code explicitly. Therefore, lacking a unified philosophy or rational basis the service level for each combination case must be determined by judgment. This also presents a difficult problem for NRC when reviewing license applications. It would be advantageous if all the basic issues were to be addressed rationally at the same time within one frame work. The load Combination Program undertaken by the Lawrence Livermore National Laboratory funded by U.S.NRC represents a milestone effort in resolving these difficult and important issues.

Objectives

The Load Combination Program is a multi-million dollar long-term research program. Current planning is that the program will continue through 1985. The long-term overall objectives are:

1. Define each individual load
   a. Develop a methodology to estimate the reliability of typical piping systems, both inside and outside the containment structure, and provide the NRC with a sound technical basis for defining criteria for postulating pipe breaks.

   b. Assist the NRC in defining individual dynamic load magnitudes and event occurrence rates.

   c. Develop a methodology for estimating the dependency between events, as, for example, the probability of a LOCA or water-hammer induced by earthquakes.

2. Develop a methodology to establish load combination criteria for nuclear power plant design. This methodology should be capable of addressing basic issues with regard to which loads need to be combined, how they are to be combined, and what ASME service level is applicable.

General Approach

A systematic, probabilistic approach is used to determine the dependency of one event upon another and to develop load combination design criteria. Major steps involved in this development are:

1. Identify load combination issues;
2. Develop the methodology and resolve as many issues as possible;
3. Demonstrate the feasibility, applicability and practicality of the methodology with regard to its intended purpose;

4. Validate the methodology against experimental data or justify the methodology by calibration with existing design codes;
5. Apply the methodology to generate results upon which design requirement modification could be based.
6. Recommend changes in design requirements. These modifications should provide assurance of plant safety at specified levels and provide more consistent safety margins from component to component and from plant to plant.

Phase I Activity Summary

The first phase of the Load Combination Program started March, 1979 and was completed at the end of the summer of 1980. The following objectives were addressed relating to two major issues:

(1) Estimate the probability of a large LOCA induced by earthquakes for a selected PWR plant and develop a probabilistic fracture mechanics model that can be used to estimate piping reliability in general.

(2) Develop a methodology for combining generic dynamic loads for nuclear power plant design.

The first objective, namely, the determination of the probability of a large LOCA induced by earthquakes, requires the development of a deterministic fracture mechanics model for fatigue crack growth. This model incorporated with stochastic inputs of initial crack size distribution, material properties, stress histories, and leak detection probability is used to calculate the probability of pipe leak and break when subjected to the various loading conditions including seismic. The "best estimate" model and approach were used in the computation. The probability results together with their uncertainties are used to determine whether low probability events such as a large LOCA and SSE should be combined for the design of nuclear structures and components. Results indicate that the probability of a double-ended guillotine break, either with or without an earthquake, is very small (on the order of 10^{-12}). The probability of a leak was found to be several orders of magnitude greater than that of a complete pipe rupture. A detailed description of the fracture mechanics model, simulation scheme, stress calculations and discussion of results will be presented in Division J No. 6/6, Division M Nos. 12/2, 12/3, 12/4 and Division F No. 7/3 in SMiRT-6.

The second objective, the development of a methodology for combining generic dynamic loads, involves the computation of component reliability to derive the appropriate load combination requirements for nuclear power plant design. This methodology, by considering event probability, nature of these events, structural properties, response characteristics, and other random phenomena, will achieve greater consistency in component design than can be achieved with current practice. With this methodology, the NRC can evaluate component reliability implied by current design. The methodology can also be used to compare the component reliability implied by the use of SRSS and ABS

problem. Two piping designs were used for illustration. The first example deals with an Essential Service Water (ESW) line in a PWR plant subjected to seismic and hydraulic transient loads, in addition to self-weight, thermal expansion and internal pressure. The second example deals with a Steam Relief Valve (SRV) line from a typical BWR Mark II plant subjected to normal, seismic, weight, thermal expansion, thermal transient, SRV building response, SRV steam hammer, SRV discharge, SRV drag, condensation oscillation, and chugging loading conditions. The proper load combination equations were developedfor the two systems based on component reliability criteria. A comparison between SRSS and ABS response combinations were also studied. the appropriate service level associated with each load combination case was discussed. Detail descriptions in methodology development, illustration and applications will be presented separately in Division J nos. 6/1, 6/2, 6/7, 6/8 and 6/9 in SMiRT-6 conference.