Comparison Studies of HCLPF Capacities Determined by CDFM and Fragililty Analysis Methods

Robert C. Murray
Lawrence Livermore National Laboratory, Livermore, CA USA

INTRODUCTION

Seismic margin reviews of nuclear power plants require that the High Confidence of Low Probability of Failure (HCLPF) capacity be calculated for certain components. The candidate methods for calculating the HCLPF capacity are the Conservative Deterministic Failure Margin (CDFM) method and the Fragility Analysis (FA) method. The present study evaluated these two methods using some representative components in order to provide further guidance in conducting seismic margin reviews. It is concluded that either of the two methods could be used for calculating HCLPF capacities. Results of this study are documented in (Kennedy et al., 1988).

BACKGROUND ON SEISMIC MARGIN METHODOLOGY

In recent years there has been increasing interest in assessing the capability of nuclear power plants in the United States to withstand earthquakes beyond their original design bases. This interest has developed because of the following concerns: (1) the perception of seismic hazard in the plant vicinity has changed and in most cases increased since the design of the plant, and (2) the seismic design criteria have been revised substantially.

To resolve these concerns, a seismic margin study can be performed to estimate the seismic capacity of the plant. Seismic margin study methodology has evolved over the years, beginning with the Systematic Evaluation Program (SEP). More recently, the NRC formed an expert panel to develop a seismic margin review methodology and guidelines for application (Budnitz et al., 1985, Prassinos et al., 1986). A parallel effort was initiated by the Electric Power Research Institute (EPRI, 1987).

A seismic margin review studies the question of whether the capacity of the plant exceeds target earthquake input selected for review. The objectives are then to show that the plant can withstand the effects of this review earthquake level with high confidence and to identify seismic vulnerabilities. This is accomplished using the results and insights obtained from past seismic Probabilistic Risk Assessments (PRA), data on actual performance of structures and equipment in recorded earthquakes, and analytical qualification and test data.

Although a seismic PRA would provide answers regarding the seismic capacities of components, systems, and the plant, the large uncertainties in the seismic hazard curves make decisions regarding seismic adequacy difficult. The large number of systems and components to be considered in a PRA limit the attention paid to the more critical components and systems in the plant. The seismic margin review focuses on the few components and systems in the plant whose failure would lead to severe core damage. The output of a seismic margin review is an estimate of the plant seismic capacity expressed as a function of peak ground acceleration and thereby identifying seismic vulnerabilities, whereas the seismic PRA provides estimates of seismic risk of core damage and adverse public health effects.

DEFINITION OF SEISMIC MARGIN

The concept of a high confidence of low probability of failure (HCLPF) capacity is used in the seismic margin reviews to quantify the seismic margin of a nuclear power plant. This is a conservative capacity, and in simple terms it corresponds to the earthquake level at which, with high confidence, it is extremely unlikely that failure of the component, system, or plant will occur. The concept of HCLPF capacities of components is used in the seismic margin studies in (1) screening out certain components as having capacities generically higher than the review earthquake level and (2) evaluating the capacities of certain critical components in order to assess the seismic capacity of the plant.

Estimating the HCLPF capacity of a component requires estimating the response of the component, conditional on the occurrence of the seismic margin earthquake, and estimating the capacity of the component. Two candidate methods for calculating the HCLPF capacities for components have been recommended (Kennedy, 1984; Prassinos et al., 1986): the Conservative Deterministic Failure Margin (CDFM) method and the Fragility Analysis (FA) method. The fragility analysis method was used in the Maine Yankee seismic margin study (Ravindra et al., 1987). The CDFM method prescribes the parameter values and procedures to be used in calculating the HCLPF capacities and requires less subjective judgment than the FA method. The details of the CDFM method are given in Chapter 2 of (EPRI, 1987).

OBJECTIVE AND ORGANIZATION OF THE STUDY

The objectives of this study were to (1) perform a comparison of the HCLPF capacities obtained by using the CDFM and FA methods to study a representative set of components; and (2) provide additional guidance for use in seismic margin reviews.

A five-member Study Group was assembled to perform this study. Members of the Group were:

R. P. Kennedy (Chairman)	RPK/Structural Mechanics Consulting
R. C. Murray	Lawrence Livermore National Laboratory
M. K. Ravindra	EQE Engineering Inc.
J. W. Reed	Jack R. Benjamin and Associates, Inc.
J. D. Stevenson	Stevenson & Associates

The Study Group laid out the approach followed in this study and performed the capacity evaluation.

HCLPF CAPACITY CALCULATIONS

The basis for selection of components, description of components, and ground rules agreed upon by the Group for calculating the capacities are described. The results of the first round of calculations and the underlying reasons for differences in the capacities calculated by the investigators are discussed. The results of the second round of calculations are presented along with an analysis of the differences in the HCLPF capacities and median capacities.

Components Selected for Study

The objectives of the study are to compare the HCLPF capacity calculations performed by different analysts using either the CDFM method or the FA method. The comparison would be performed by selecting a set of representative components. Components for which HCLPF capacity estimates are likely to be made in future seismic margin reviews include: (1) block walls, (2) heat exchangers, (3) tanks, (4) active electrical equipment, and (5) HVAC fans and cooler units.

Based on a review of these components, the Study Group selected the following components for performing seismic capacity calculations.

1. **Flat-Bottom Vertical Water Storage Tank at grade**. The failure mode to be considered is the combined bolt yielding and shell buckling.

2. **Auxiliary Contactor Chatter for Motor Starter in an older Motor Control Center** (MCC). This example will focus on equipment qualified using Generic Equipment Ruggedness Spectrum (GERS). The failure mode to be investigated is the auxiliary contactor chatter. The cabinet is well anchored and

calculations were performed for cabinets mounted at grade and high up in the building. It is assumed to have an estimated frequency of 6.5 Hz. It was agreed that the seismic HCLPF capacity would be based upon the "Function-during GERS," (ANCO, 1987).

3. **Diesel Generator Room Starting Air Tank mounted high in the structure**. This is an example of a vertical skirt-mounted pressure vessel on a concrete floor high up in the building. The failure mode to be investigated is the anchorage or support failure.

4. **Component Cooling Heat Exchanger mounted high in the structure**. This is an example of a component governed by ASME rules. It is a horizontal heat exchanger fixed on one saddle support and free longitudinally at the other support. It is assumed to be bolted to a rigid support frame. The area of concern is the saddle and anchorage.

5. **Cantilevered Reinforced Block Wall located high in the structure**. This example is selected to avoid the case of a wall where arching action may be present. If arching action is present, the wall would be high capacity; therefore a cantilevered wall with rebars is chosen.

Ground Motion Aspects

For all HCLPF capacity computations, the ground motion for the largest horizontal component is given by a uniform hazard spectrum defined at the 84% non-exceedance probability (NEP) at all frequencies. Furthermore, this uniform hazard spectrum shape was defined by the NUREG/CR-0098 (Newmark and Hall, 1978) median spectrum shape for rock sites. The 84% vertical response spectrum was then defined to be equal to 2/3 of the 84% NEP largest horizontal response spectrum.

Discussion of Failure Modes

In the evaluation of seismic margin or seismic fragilities, it is important to define what is meant by failure of the component. The failure modes, as identified by the Study Group members, are discussed below for the components analyzed.

Flat Bottom Tank. Failure of the vertical storage tank is defined to be gross loss of fluid contents. Horizontal seismic load initiates uplift of the tank shell from its foundation. This uplift is resisted by the anchor bolts, the tank bottom plate, and the tank weight. The anchor bolts are permitted to yield, so long as their behavior is ductile. Shell compressive stresses progressively increase until buckling occurs.

Motor Control Centers. A functional failure mode associated with the motor control centers was assumed to be governed by chatter of auxiliary contactors for purposes of this study.

Starting Air Receiver Tank. The starting air receiver tank is a vertical, skirt-supported cylindrical tank which is anchored to the building floor by three angles welded to the tank skirt and bolted to the floor. The leg of the angle is much weaker in bending than the anchor bolts. The angle leg is very ductile in bending, and the failure mode is tearing the mounting angles. When this occurs, the air tank is assumed to fail through failure of attached piping.

Horizontal Heat Exchanger. The failure mode governing the median capacity of the horizontal heat exchanger was combined tension and shear induced failure of the anchor bolts. Tension results from overturning of the heat exchanger in the lateral direction, while shear results from inertial loads in both horizontal directions. When this anchorage failure occurs, the heat exchanger is assumed to fail through failure of the nozzles and attached piping.

Block Wall. The block wall is represented as a vertical cantilever fixed at its base. Failure is collapse or excessive lateral distortion of the wall.

Results of Calculations

The investigators independently estimated the HCLPF and median seismic capacities of the components. The differences in estimated HCLPF capacities between the investigators was much larger than the differences in results between the CDFM and FA methods, and this was due primarily to differences in the subjective judgment and personal experience of the investigators.