# Determination of HCLPF Value For Seismic Margins Study

**Howard H. M. Hwang**
*Memphis State University, Memphis, TN USA*

## ABSTRACT

For seismic margins studies of nuclear power plant facilities in the United States, the high confidence of low probability of failure (HCLPF) capacity is used to represent the capacity of structures and equipment. The HCLPF value is defined as an earthquake level corresponding approximately to a 95 percent confidence that the probability of failure is less than 5 percent. This paper presents an alternative definition for the HCLPF value and describes an analytical method to evaluate HCLPF values for structures.

## INTRODUCTION

In recent years, advances in seismology have led to the perception that the potential earthquake in the eastern United States may be higher than originally assumed. Hence, there is a need to develop a method to assess the actual seismic capacity of nuclear power plant facilities especially those located in the eastern United States. Because of the conservatism built in the design process, well-designed nuclear power plant structures and safety-related systems, in general, are capable of withstanding earthquakes larger than the original design basis such as the Safe-Shutdown Earthquake (SSE). A general definition of seismic margin is expressed in terms of the earthquake peak ground acceleration (PGA) that compromises plant safety, specifically leading to melting of the reactor core. A single reference earthquake which may be called seismic margin earthquake (SME) is selected for the seismic margins review. For example, an earthquake with a PGA = 0.3g may be selected as a criterion. Then, the purpose of the seismic margin study is to determine whether the nuclear power plant has the capability to withstand this selected 0.3g earthquake.

In a seismic margins study, value with a high confidence of a low probability of failure (HCLPF) is used to represent the fragility of a component (structure or equipment). However, as demonstrated by Ellingwood (1988), the component fragility modeling may have a significant impact on the determination of the HCLPF value. This might affect the result of a seismic margins study and subsequently the decision making by the utility owner or the regulatory agency. Thus, it is important to examine the procedure for evaluating the HCLPF value and to suggest an alternative procedure if necessary.

## EVALUATION OF HCLPF VALUE

In the current seismic margin studies, as shown in Fig. 1, the HCLPF value of a component is defined as the PGA value with a 95 percent confidence that the probability of failure is less than 5 percent given a family of fragility curves for a component. The usual method for determining the fragility of a component is using a lognormal model with three parameters: median capacity $A_m$; logarithmic standard deviation $\beta_R$ denoting inherent randomness; and logarithmic standard deviation $\beta_U$ denoting modeling uncertainty in estimating median capacity (Kennedy and Ravindra, 1984). With this lognormal fragility model, the HCLPF value can be expressed as

$$\text{HCLPF} = A_m \exp\left[-1.645\ (\beta_R + \beta_U)\right] \qquad (1)$$

The median capacity $A_m$ is estimated by using a multiplication scheme with subjective inputs. It has been pointed out by Hwang (1985) that the subjective inputs and multiplication scheme do not appear to be a good combination. As a result, the fragility curve is very sensitive to the subjective inputs. This also has a tremondous effect on the estimation of HCLPF value. In addition, the notion of separating variability into inherent randomness and modeling uncertainty is an idealized concept. In practice, the distinction of randomness and uncertainty usually becomes blurry. Furthermore, it is expensive to perform the necessary analyses to obtain $\beta_R$ and $\beta_U$ if an analytical model using time history analysis technique is employed (Bohn et al., 1984).

Following the lognormal fragility model, the fragility of a component can be easily expressed by two parameters; i.e., median capacity $A_m$ and logarithmic standard deviation $\beta_C$, which describes the total variability from both inherent randomness and modeling uncertainty. The parameter $\beta_C$ has the following expression:

$$\beta_C = (\beta_R^2 + \beta_U^2)^{1/2} \qquad (2)$$

The fragility curve determined from the two-parameter fragility model is called the composite fragility curve. Given such a curve the task to determine the HCLPF value can be much simplified if an equivalent HCLPF value can be defined. Mathematically, it is to find the probability of failure $P_f$ from the composite fragility curve given the HCLPF value determined from three-parameter lognormal fragility model as illustrated in Fig. 1. From the two-parameter lognormal fragility model, $P_f$ can be determined as follows:

$$P_f = \Phi\left(\frac{\ln \text{HCLPF} - \ln A_m}{\beta_C}\right) \qquad (3)$$

where $\Phi(.)$ is the standard normal distribution. As shown in Table 1, for the practical range of $\beta_R$ and $\beta_U$, the value of $P_f$ is approximately 0.01. Thus, the HCLPF value can be defined alternatively as the PGA value corresponding to failure probability of one percent on the basis of the composite fragility curve of a component.

Table 1. Comparison of $P_f$ values

| $\beta_R$ | $\beta_U$ | $\beta_C$ | $P_f$ |
|---|---|---|---|
| $\beta$ | $\beta$ | $1.414\beta$ | 0.01 |
| $2\beta$ | $\beta$ | $2.236\beta$ | 0.014 |
| $\beta$ | $2\beta$ | $2.236\beta$ | 0.014 |

## EVALUATION OF COMPOSITE FRAGILITY CURVE

As mentioned, the current method for estimating fragility curves is very sensitive to the subjective inputs and thus the resulting fragility curves may not be reliable. Recently, Jaw and Hwang (1988) have proposed an analytical method to generate composite fragility curves for structures. In this method variability including inherent randomness and modeling uncertainty in earthquake and structure are quantified by evaluating uncertainties in pertinent parameters which define earthquake-structure system. The uncertainty in each parameter is characterized by several representative values and then Latin hypercube sampling technique is utilized to combine these values to construct samples for nonlinear time history analysis. The modified Takeda hysteretic model is utilized to describe the nonlinear structural behavior. An ensemble of structural responses, obtained from the nonlinear seismic analyses, are statistically analyzed. On the other hand, five limit states representing various degrees of structural damage are defined and the statistics of the structural capacity corresponding to each limit state can be established. The fragility curve for each limit state is generated by evaluating the limit state probabilities (probabilies of failure) at different levels of peak ground acceleration. For illustration, the fragility curves for a five-story shear wall building are shown in Fig. 2 (Jaw and Hwang, 1988). The HCLPF values for various degrees of damage can be evaluated as the PGA values corresponding to one percent probability of failure. For example, the HCLPF value for moderate structural damage is about 0.09g while the HCLPF value for collapse is about 0.17g.

## CONCLUSIONS

This paper presents an alternative definition of the HCLPF value for the seismic margins studies of nuclear power plant facilities. As can be seen from equation 1, the HCLPF value is not sensitive to individual values of $\beta_R$ and $\beta_U$, but to the sum of uncertainty. Thus, it is appropriate to use the composite fragility curve to define HCLPF value. The new definition of

HCLPF value is the PGA value corresponding to the failure probability of one percent based on a composite fragility curve. It has been shown that the HCLPF value obtained under this new definition is equivalent to the current value determined based on the 95 percent confidence that the failure probability is less than 5 percent given a family of fragility curves. The HCLPF value on the basis of the new definition is much easier to evaluate by using an analytical method to generate the composite fragility curve.

A new fragility analysis method is also described in this paper. In this method, uncertainty in earthquake motion and structure is quantified by evaluating uncertainties in pertinent parameters which define the earthquake-structure system. In addition, the nonlinear behavior of structure is explicitly taken into account. The fragility curve and the HCLPF value are much more reliable by using this method

## REFERENCES

Bohn, M.P. et al. (1984) Application of the SSMRP Methodology to the Seismic Risk at the Zion Nuclear Power Plant. NUREG/CR-3428, U.S. Nuclear Regulatory Commission, Washington, D.C.

Ellingwood, B. (1988) Validation Studies of Seismic PRAs. Second Symposium on Current Issues Related to Nuclear Power Plant Structures, Equipment and Piping, Orlando, Florida.

Hwang, H. (1985) Fragility Assessment for Seismic PRA Studies. Proceedings of SMiRT-8 Conference, Paper No. M1 6/2.

Jaw, J.-W. and Hwang, H. (1988) Seismic Fragility Analyses of Shear Wall Structures. NCEER-88-0009, National Center for Earthquake Engineering Research, SUNY, Buffalo, New York.

Kennedy, R.P. and Ravindra, M.K. (1984) Seismic Fragilities for Nuclear Power Plant Risk Studies. Nuclear Engineering and Design, Vol. 79, pp. 47-68.

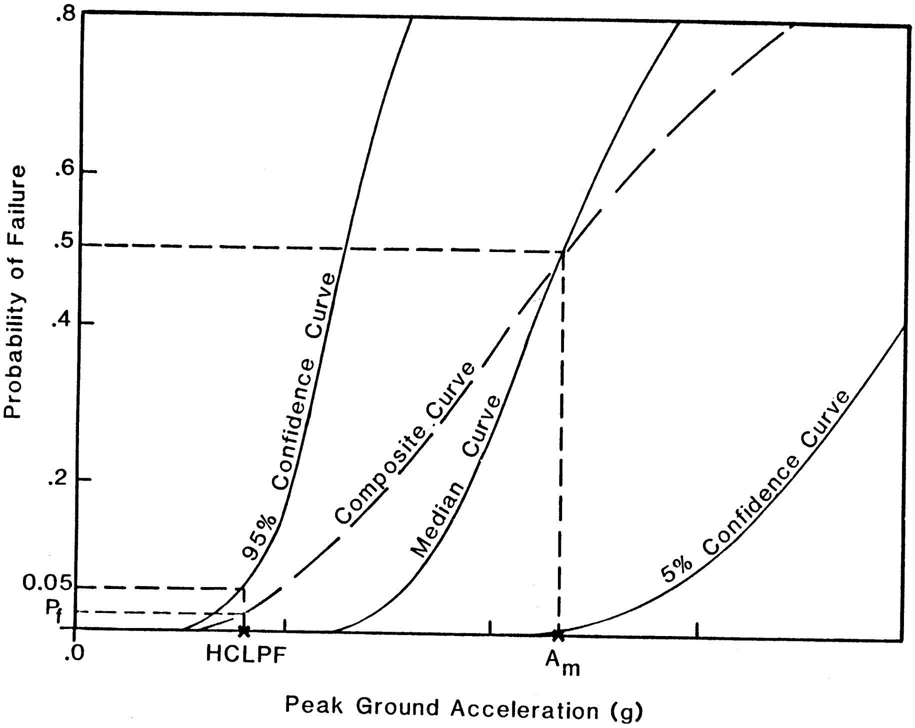

Fig. 1 Typical Fragility Curves for a Component

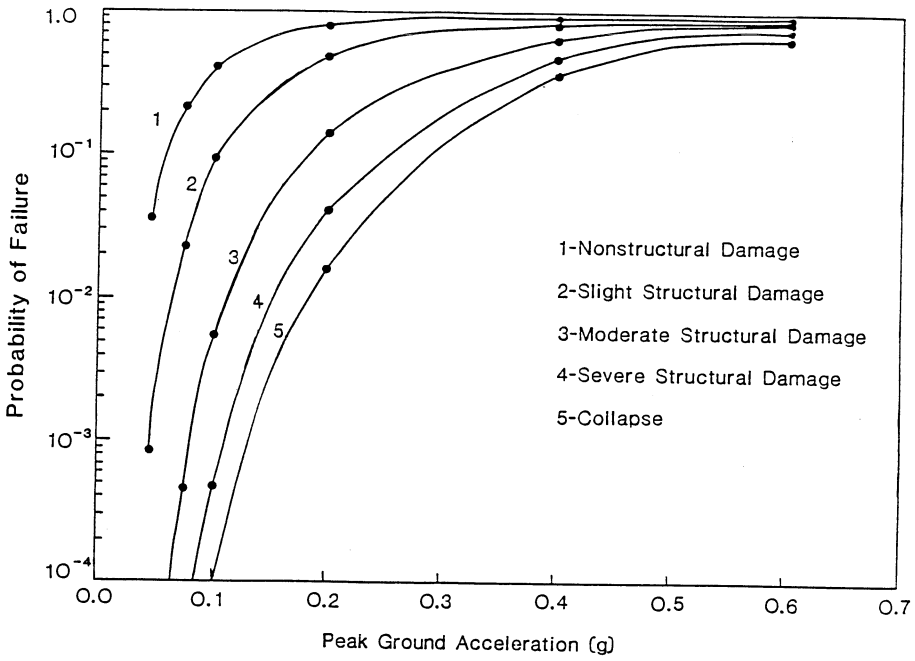

Fig. 2 Fragility Curves (Shear Wall Building)