Review of Containment Fragility Curves in Use

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1. Introduction

The containment structure in a nuclear power plant is to prevent the release of radioactivity which may be present as the result of an accident because a failure of this containment incurs serious problems from safety point of view. Thus predicting the probability of containment failure has been a key issue in the risk assessment of nuclear power plants for a long time.

US NRC was the first to adopt an expert elicitation methodology to predict the failure mode and probability during the assessment of five US nuclear power plants[1]. The experts proposed probability distributions for containment failure pressure and mode in the presence of a slow pressure rise and plant specific probability function was developed aggregating the proposed distributions[2].

On the other hand, since development of a leak does not arrest a fast pressure rise, the determination of the failure mode becomes more complicated for a pressure rise due to deflagration or vessel failure. Thus Helton et al. [3] has developed a mathematical theory for a probability of containment failure mode for fast pressure rise. The conclusion of this theory was that the distributions for containment failure mode for both the slow and fast pressure rise cases are the same.

Also since NRC has recommended a deterministic criteria for steel containment when subjected to a severe accident condition as stated in the safety goals in SECY-90-016 [4], there was a study to develop equivalent criteria for both reinforced and prestressed concrete containment [5]. In the study, deterministic analysis first and then a Monte Carlo analysis were performed to get probabilistic curves for each of the surrogate containments.

In this paper we have reviewed the above-mentioned three methodologies used in developping containment fragility curves. Then the fragility curve of KSNP was reviewed also for its engineering applicability.

2. Evaluation of Fragility Curves in Use

2.1 Fragility Curve of NUREG-1150 [2]

The expert elicitation method was applied to determine the distribution that characterizes the failure pressure for static loadings of the Surry containment and also the conditional probabilities for each failure mode for each pressure. Three experts among four members proposed cumulative failure probability based on their engineering judgement and one expert proposed failure probability density function. The proposed functions were handled through aggregation and the probabilities like Fig. 1 were finally determined and the curves were actually used in the risk assessment of NUREG-1150. It is clear that the expert judgement should not be considered equivalent to accepted calculations or models based on physical and chemical laws or on extensive experimental or observational data. But to apply the results to safety issues, we should judge the appropriateness of the results. Taking into account the fact that the pressure band of Fig.1 curve should come from the uncertainties of inputs, the cumulative failure probability is somewhat out of date for present engineering knowledge. Also the failure density function of Fig. 1 contradicts a physical phenomenon. For example, the failure probability should increase as the pressure increases but Surry failure density does not show this behaviour. The proposed density function is actually a conditional density function which means that the failure does not occur below the certain P and the failure occurs between P and P+dP. So we judge the failure probability is not consistent from engineering point of view and it's better not to use it for risk assessment.

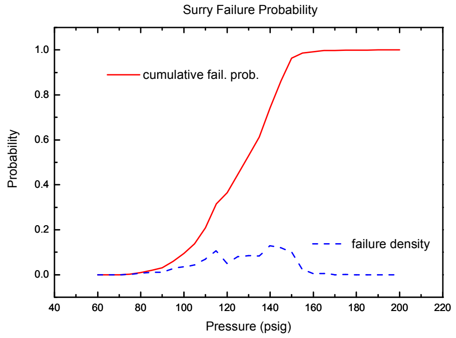

Fig. 1 Failure Probabilities of Surry Plant

2.2 Mathematical Theory of Helton et al. [3]

Helton et al. proposed a mathematical theory showing that the distributions for containment failure mode for both the slow and fast pressure rise cases are the same. We have reviewed carefully the mathematical theory. For the theory to be correct, it is critical that two assumptions between the cumulative function F and the failure density function f and the failure mode m_i should be satisfied, that is,

$$dF_i(P)/dP = f_i(P), F_i(0) = 0, F_i(\infty) = 1$$

and

$$G(m_i \; |P) f(P) = f_i(P)(1 - F_j(P))(1 - F_k(P))$$

The functions F , f , m_i are all functions defined in the NUREG-1150. By reviewing the original functions proposed in the NUREG-1150, we found first that these functions do not satisfy the proposed assumptions and also that such functions do exist from physical and engineering point of view. So we should not credit anymore the Helton et al.'s theory and this means that we do not have failure probability for fast pressure rise case.

2.3 Fragility Curve of NUREG/CR-6433

The study of NUREG/CR-6433 provides another methodology to determine the failure distribution curve. The approach is first based on the structure analysis of the containment. As is shown in Fig. 2 , the structure strain was analysed as a function of containment pressure. The containment is supposed to fail at strain of 2% . On average the strain reaches 2% at a pressure of 130 psig but because of the uncertainties in the material properties and also in the modeling , the strain could be 2% at pressure 140 psig. Next using this strain curve and a Monte Carlo method, a fragility curve like in Fig.3 could be derived. A failure density function in this case is defined as a function of uncertainty distribution.

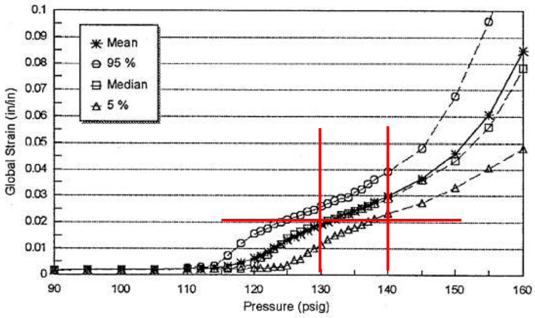

Fig. 2. Containment Pressure and Strain Curve

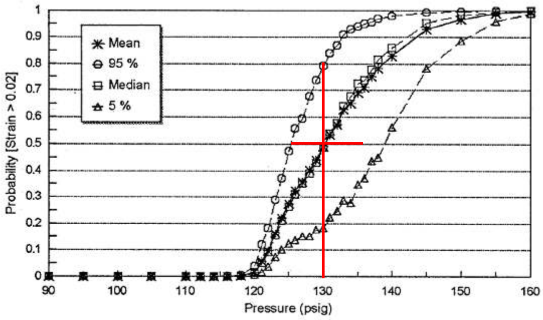

Fig. 3. Containment Fragility Curve derived from Fig.2

We conclude that the the functions proposed in this method have firm physical backgrounds and we recommend this fragility curve should used in the risk assessment of nuclear power plant

2.3 Fragility Curve of KSNP

The fragility curve used in the Level 2 PSA of YGN56 is given in Fig.4 below. Comparing with the Fig.1 curve, we can see that the curves are developed referencing the NUREG-1150 methodology. As is clear from our discussion so far, the fragility curve of NUREG/CR-6433 has more firm physical background and this methodology should be referenced in developing the domestic fragility curves.

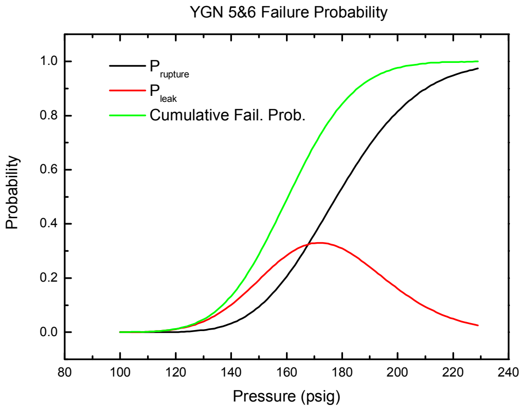

Fig. 4. YGN56 Fragility Curve

3. Conclusion

Three methodologies available for developing the containment fragility curve are reviewed and we found that the only acceptable one is that of NUREG/CR-6433. The fragility curves for KSNP is developed referencing the physically unclear NUREG-1150 curve and thus we recommend that the fragility curves for domestic plants should be revised. The new curve will affect much the results of PSA for domestic plants.

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