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SEISMIC RESPONSE DISTRIBUTIONS OF ISOLATED NUCLEAR POWER PLANTS BY USING STOCHASTIC RESPONSE DATABASE

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ABSTRACT

A seismic isolation system protects structures from earthquakes by isolating the structure and the ground. When the isolation system is installed to the structure, the natural period of the structure will be adjusted and seismic responses will be change. The seismic safety of isolated nuclear power plants should consider the effect of the seismic isolation system. The seismic response distribution are required for evaluating the seismic safety of isolated nuclear power plants. A large number of numerical analyses is required to obtain the seismic response distributions of an isolated nuclear power plant. However, the computational cost of seismic response analysis is high due to the nonlinear characteristic of the seismic isolation system. The stochastic response database is developed to estimate the seismic response distribution of the isolated structure without seismic response analyses. In this study, the maximum seismic response distributions according to seismic intensity of an isolated nuclear power plant are calculated by using the stochastic response database. The seismic isolation system is designed for a nuclear power plant and it is installed. The seismic response distributions of the isolated nuclear power plant are obtained by the stochastic response database with tremendously reduction of computational costs. Finally, the maximum displacements of seismic response distribution have been investigated with various seismic intensities.

INTRODUCTION

The seismic isolation systems are one of the solution to protect the structures from earthquake events. It is widely used in the civil engineering field due to the simplicity and economical reasons (Eem *et al.*, 2013). The performance of seismic isolation systems was validated from the “Northridge earthquake 1994” and the “Kobe earthquake 1995” (Jun, 2010). The studies are ongoing to apply seismic isolation systems to nuclear power plants for these reasons. When the isolation system is applied to the structure, the natural period of the structure will be adjusted. Therefore, if a seismic isolation system is applied to the nuclear power plant, seismic safety should be reevaluated considering the effect of the seismic isolation system.

The seismic safety assessment of a nuclear power plant usually performs a seismic probabilistic safety assessment. The seismic response distribution due to earthquakes is caused by the randomness of the earthquakes and the uncertainty of the structures (Galambos *et al.*, 1983). The seismic response distributions should be calculated to evaluate the seismic safety of isolated nuclear power plants. Typically, the method of calculating the seismic response distribution is the Monte Carlo Simulation. It should be calculated through nonlinear dynamic analysis since the nonlinearity behaviors are shown in seismic isolation system. In other words, it is necessary to perform a lot of nonlinear seismic response analyses to obtain the seismic response distributions. It means that it will cost a huge amount of computational effort to calculate the seismic response distributions of an isolated nuclear power plant.

The stochastic response database was developed to obtain the seismic response distribution of isolated structure without any of seismic response analyses. It estimates the seismic response distribution of the isolated structure due to the randomness of the earthquakes. It provides parameters that determine the shape of the seismic response distribution with the structural characteristics as input. It can reduce the computational cost tremendously because it provides a seismic response distribution without seismic response analyses. In this study, seismic response distributions of an isolated nuclear power plant was investigated using the stochastic response database. The Korean standard nuclear power plant is considered which is called APR1400. The seismic isolation system applied to the nuclear power plant was designed according to ASCE code. The maximum seismic response distributions with various seismic intensities was obtained from the stochastic response database.

STOCHASTIC RESPONSE DATABASE

The stochastic response database is a device that can estimate the maximum seismic response distributions of isolated structures without seismic response analyses. The stochastic response database is constructed with a collection of seismic response analysis results of isolated structures. Therefore, when the structural parameters are known, it can provide the maximum seismic response distribution of isolated structures instantaneously. The detail information on stochastic response database and the equivalent model of isolated structure can refer to “Seismic response distribution estimation for isolated structures using stochastic response database” which is written by the author (Eem *et al.*, 2015). Figure 1 illustrates the concept of the SRD.

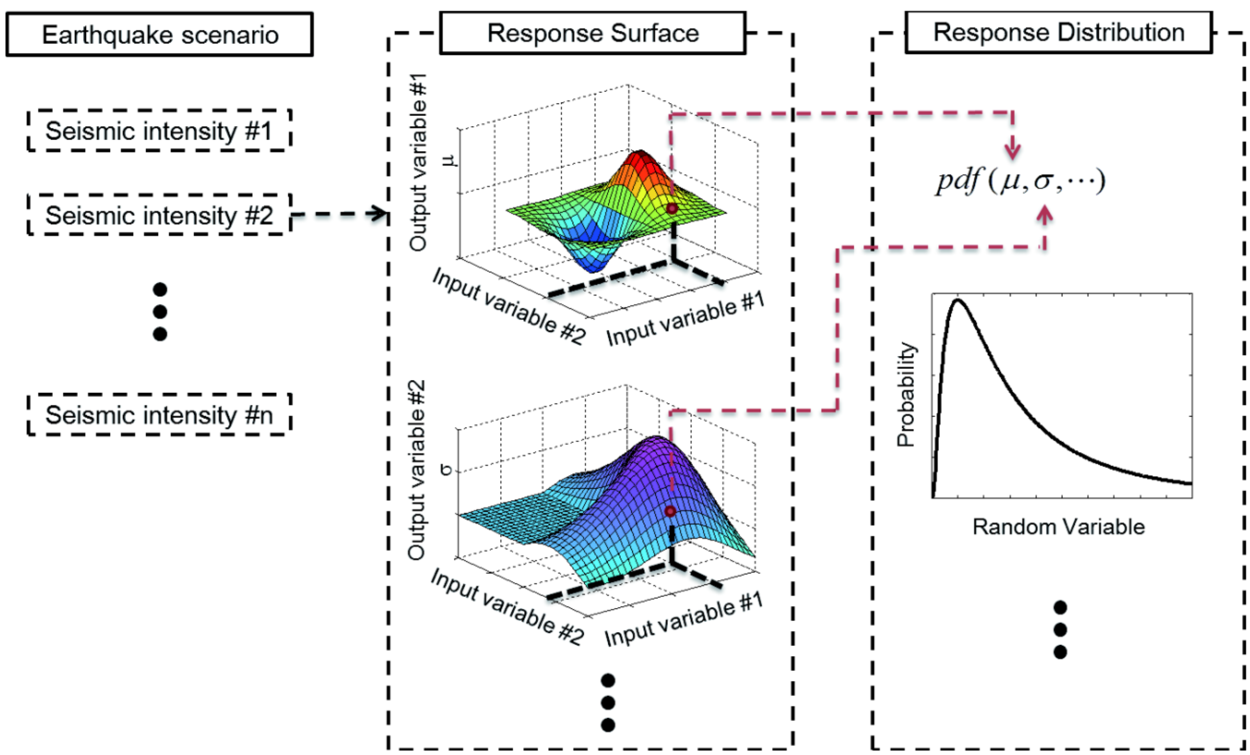


Figure 1. Concept of the stochastic response database (Eem *et al.*, 2015)

As shown in figure 1, a seismic intensity and structural parameters are input for the stochastic response database and the parameters of probabilistic model for maximum response distribution of the isolated structure are output of stochastic response database. The stochastic response database is constructed with various parameters of isolated structures. The input parameters for the stochastic response database are T_d, Q_p, α, R_p, and e_r. T_d is the period calculated by second stiffness of isolation system, Q_p is the ratio between characteristic strength (Q_d) and weight (W) of the isolated structure, α is the ratio between initial stiffness and second stiffness of isolated structure. R_p is the ratio between radius of gyration (R_m) and radius of disposition (R_k). e_r is the ratio between eccentricity (e) of and radius of gyration (R_m). And the seismic intensity of stochastic response database is PGA (Peak Ground Acceleration), and the seismic intensities of 0.3 g, 0.5 g, 0.75 g, 0.835 g, 1 g, 1.5 g, 2.0 g and 3.0 g are established for estimation.

However, when the structural parameters are out of range of stochastic response database, the stochastic response database cannot provide the seismic response distribution of isolated structures. The equivalent isolated structure model is developed to improve the applicability of the stochastic response distribution. An equivalent isolated structure model is model that can behave same as original isolated structure with different structural parameter. It means that even though the structural parameters of a target isolated structure are different with the structural parameters that constructed the stochastic response distribution, it can use the stochastic response database to gain the maximum seismic response distribution with the stochastics response distribution. Figure 2 shows the dynamic model of the equivalent isolated structure model. In the figure, K is the stiffness of the isolator, e_r is the eccentricity between the center of mass and the center of rigidity, and UG_x and UG_y are the displacements of the center of mass.

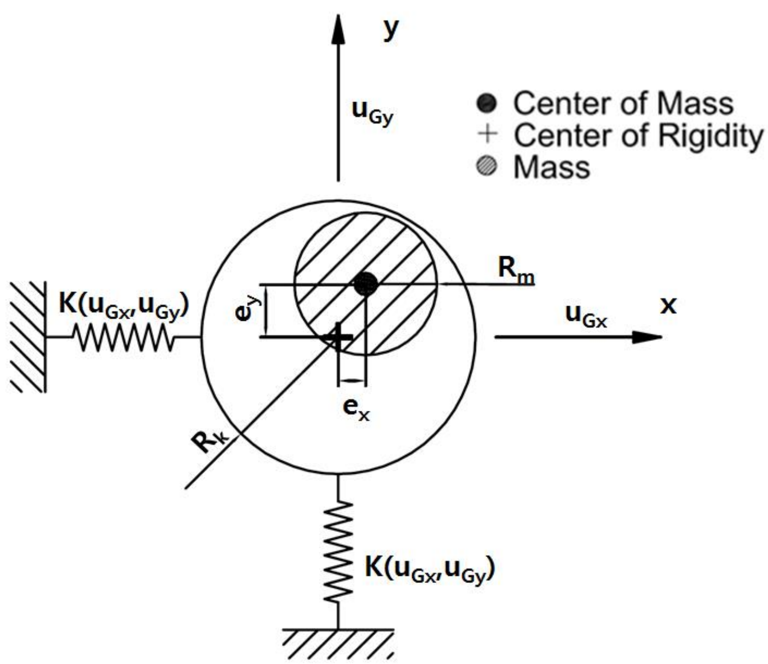


Figure 2. Equivalent isolated structure model for stochastic response database

The parameters for the equivalent isolated structure model are listed in table 1, when assuming the mass and radius of gyration as ‘1’.

Table 1: Parameters for the equivalent isolated structure model

	Isolated structure model	Equivalent isolated structure model

Stiffness	K	K/M
Center of mass	(CM_x, CM_y)	$(e_x/(R_m^2+e_r^2),\ e_y/(R_m^2+e_r^2))$
Radius disposition of isolators	R_k	$\sqrt{R_k^2/(R_m^2+e_r^2)}$

SEISMIC RESPONSE DISTRIBUTION OF ISOLATED NUCLEAR POWER PLANTS

The maximum seismic response distributions of isolated nuclear power plants are investigated with the stochastic response database. The selected isolated structure is the Korean Standard Nuclear Power Plant (Advanced Power Reactor 1400). The Advanced Power Reactor 1400 (APR1400) is a standard evolutionary advanced light water reactor developed in Korea in 2002, capable of producing 1400 *MWe* (KEPCO E&C 2012). The nuclear island are consists of the reactor containment building, containment internal structures, and an auxiliary building. The nuclear island structures share one common basemat and only the nuclear island part is isolated by the seismic isolation system, as shown in figure 3. The mass of the upper part of nuclear island is 464,500 *tons* and its size is 140 *m* × 103 *m*.

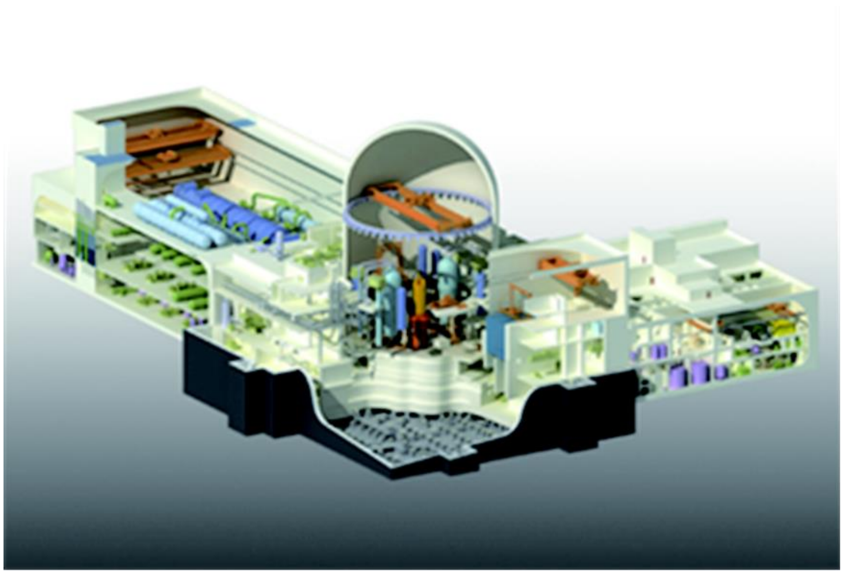
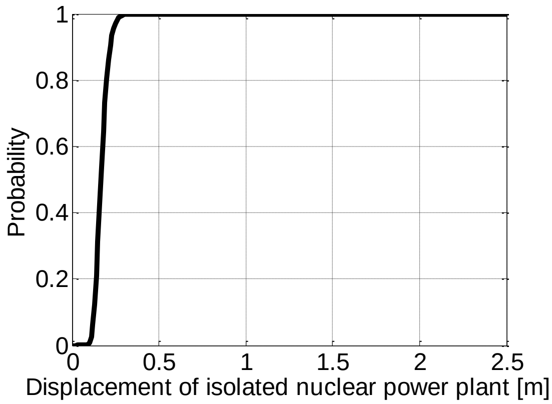


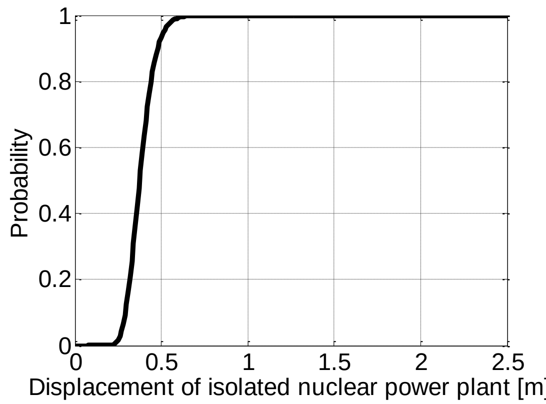
Figure 3. Advanced Power Reactor 1400 (KEPCO E&C, 2012)

The seismic isolation system is designed for the nuclear power plant by design code ASCE (ASCE, 2005). The initial stiffness of seismic isolation system is 19,675 *MN*; the α is 10; the Q_R is about 330,000,000; the radius of gyration (R_m) is 39.43 *m* and radius of disposition (R_k) is 40.60 *m*.
The figure 4 shows the maximum displacement of seismic response distribution of isolated nuclear power plants which is obtained by stochastic response database. The maximum seismic response distribution is assumed to follow a lognormal distribution. It is shown that the maximum seismic response distributions are increased when seismic intensities are increased. The dispersion (standard deviation of lognormal distribution) of seismic response distribution was decreased when seismic intensities are increased. Since the stochastic response database obtains the seismic response distribution in the database, the seismic response analyses are not necessary, and the seismic response distribution according to each seismic

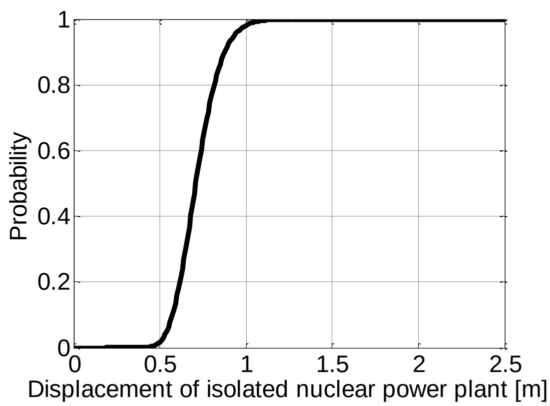
intensity is calculated immediately. The distribution of each seismic response is calculated to be less than one second, the stochastic response database can save a computational cost tremendously comparing with the methodology using the Monte Carlo Simulation methodology with seismic response analyses.



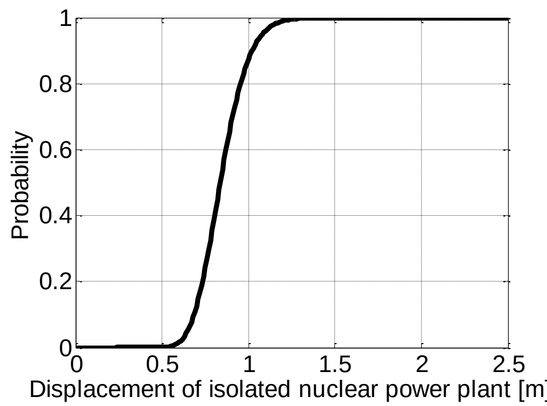
(a) Seismic response distribution with 0.3g



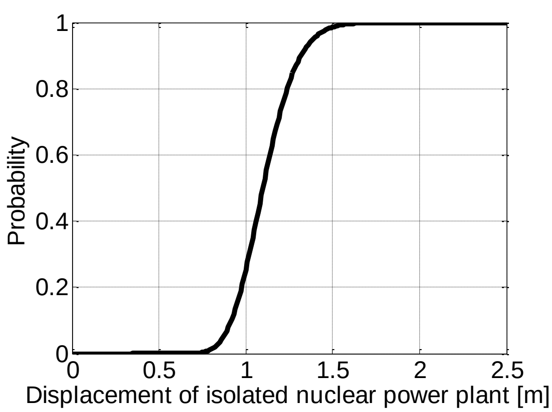
(b) Seismic response distribution with 0.5g



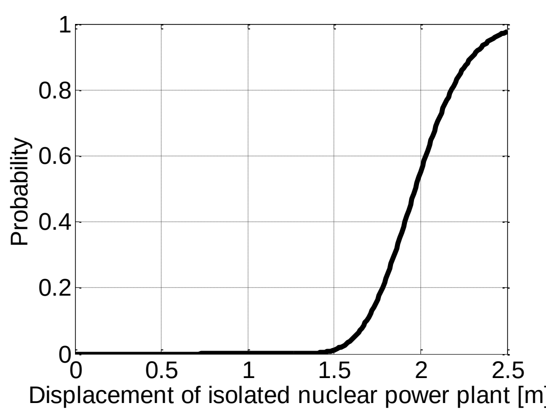
(c) Seismic response distribution with 0.75g



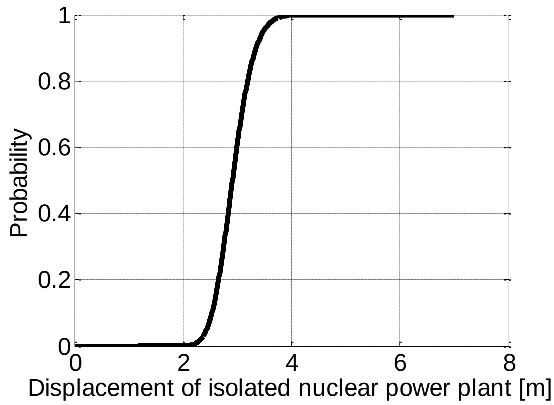
(d) Seismic response distribution with 0.835g



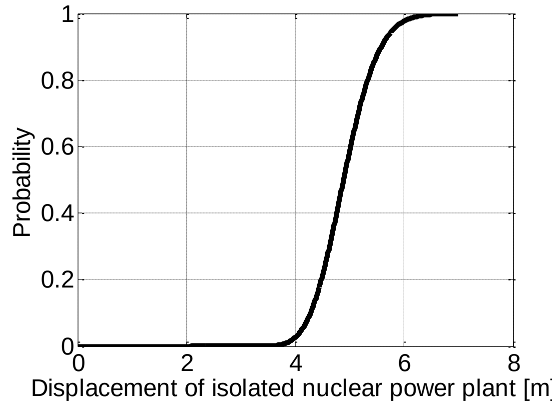
(e) Seismic response distribution with 1.0g



(f) Seismic response distribution with 1.5g



(g) Seismic response distribution with 2.0g



(h) Seismic response distribution with 3.0g

Figure 4. Maximum seismic response distribution of isolated nuclear power plant

CONCLUSION

The seismic safety of nuclear power plants perform seismic probabilistic safety assessment. The seismic response distribution of the isolated nuclear power plant should be calculated in order to perform seismic probabilistic safety assessment. However, a huge amount of computational costs must be paid to obtain the seismic response distribution for seismic response analyses due to the nonlinearity of the seismic isolation system. In this study, the stochastic response database is used to obtain the seismic response distribution of isolated nuclear power plant without seismic response analyses. The nuclear power plant structure is APR1400, and the isolation system is designed using the ASCE design code. The maximum displacement of seismic response distribution was obtained from the stochastic response database. It was obtained with various seismic intensities (PGA level) of 0.3 *g*, 0.5 *g*, 0.75 *g*, 0.835 *g*, 1 *g*, 1.5 *g*, 2.0 *g* and 3.0 *g*. It is shown that the maximum seismic response distributions are increased when seismic intensities are increased. The dispersion of seismic response distribution are decreased when seismic intensities are increased. And also, it is confirmed that seismic response of nuclear power plant using seismic isolation system can be obtained very effectively by using the stochastic response database. As further study, the calculation of the seismic fragility curve for an isolated nuclear power plant by using the stochastic response database is ongoing.

ACKNOWLEDGEMENTS

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REFERENCES

Jun, Y.S. (2010), “Technical review of seismic isolation systems for NPP application”, *Proceedings of the Earthquake Engineering Workshop, EESK*, Jeju, Korea, September.

Eem, S.H., Jung, H.J., Kim M.K., and Choi I.K. (2013), “Seismic fragility evaluation of isolated NPP containment structure considering soil-structure interaction effect”, *EESK Journal of Earthquake Engineering*, **17**, 53-59.

Galambos, T.V., Ellingwood, B., MacGregor, J.G., and Cornell, C.A. (1982), "Probability based load criteria: Assessment of current design practice", *Journal of Structural Division, ASCE,* **108**, 959-977.

Eem, S. H., and Jung, H. J. (2015), "Seismic response distribution estimation for isolated structures using stochastic response database", *Earthquakes and Structures*, **9**, 937-956.

KEPCO E & C (2012), Development and engineering of practical base isolation system for nuclear power plant export. Report 2011T100200078, Korea Institute Energy Technology Evaluation and Planning Report.

American Society of Civil Engineers (2005), "Seismic design criteria for structures, systems, and components in nuclear facilities", *ASCE 43-05*, ASCE, Reston, VA.