Variation in the Displacement of Base Isolation System Caused by an Uncertainty of Mechanical Properties

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1. Introduction

A performance-based approach was introduced in the seismic design criteria of nuclear power plants such as the ASCE 43-05 [1]. In this approach, a risk-based concept considering the probability of unacceptable performance was suggested. Therefore, it is indispensable that design variables are regarded as stochastic variables and their distributions should be estimated. In the design of a base isolation system, the displacement response of an isolator induced by an earthquake event is most important design variable. The displacement response is affected by mechanical properties of an isolator as well as an input ground motion. In this study, the several contribution factors to the displacement response of an isolation system using elastomeric lead rubber bearings (LRB) were evaluated by the simplified analysis methods.

2. Variation in the Translation Displacement

2.1 Simplified Method for the Estimation of a Isolator Displacement

In the isolation system, the superstructure can be assumed as a rigid body, and then the isolation system is modeled as the single degree of freedom system with a bilinear kinematic hardening behavior. The bilinear model is defined by three parameters, which are an initial stiffness, a second stiffness and a characteristic strength as shown in Fig 1. The initial stiffness is determined by the shear stiffness of a cylindrical central lead core and the second stiffness is determined by the shear stiffness of a rubber part surrounding the read core. The characteristic strength is the y-intercept of the line after the yielding and it is determined by the shear strength of the lead part.

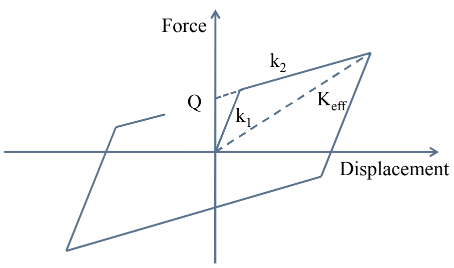

Fig. 1. Hysteresis curve of the single degree of freedom isolation system

For the simplified method to estimate the displacement response of a single degree freedom system, the acceleration-displacement response spectrum (ADRS) format was used [2]. In this method, the response spectrum representing an input ground motion is converted to the demand spectrum on the plane of an acceleration and displacement axis and then, the intersection point with the capacity spectrum representing the bilinear curve is obtained as shown in Fig 2. The displacement of the intersection point is regarded as the displacement response of the isolation system excited by the input ground motion.

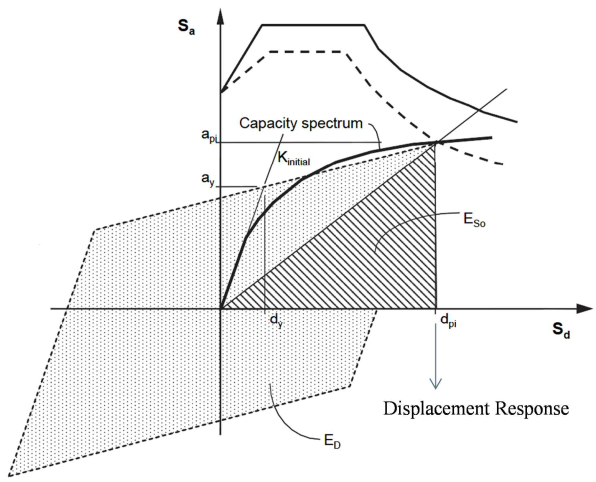

Fig. 2. Graphical representation of the ADRS method [2]

2.2 Displacement Variation by Mechanical Properties of Isolator

The mechanical property of the isolation system shall not vary by more than 20% with 95% probability. This uncertainty restriction is the same as that the standard deviation is less than 0.1 [3]. The effect on the displacement response by the bilinear mechanical properties was estimated using the parameters of ±20% variance as summarized in Table I. It is assumed that the k_1 is not varied because the shear stiffness of very pure lead has a constant value. For the best estimate case, the parameters are k_1 = 25.35 kN/mm, k_2 = 1.95 kN/mm and Q = 376.8 kN. The vertical force of the superstructure is 2971 kN. The U.S. NRC Reg. Guide 1.60 spectrum scaled with 0.5g ZPA was used as an input ground motion spectrum. In this example, the characteristic strength has more effect on the displacement response of an isolator.

Table I: Displacement responses of the isolation system by mechanical variation

k_1	k_2	Q	Displacement	Ratio
25.35	1.95	376.8	152.5	100.0%
25.35	2.34	376.8	149.5	98.0%
25.35	1.56	376.8	154.8	101.5%
25.35	1.95	452.2	125.4	82.2%
25.35	1.95	301.4	192.7	126.4%
25.35	2.34	452.2	126.6	83.0%
25.35	1.56	301.4	202.1	132.5%
25.35	2.34	301.4	182.4	119.6%
25.35	1.56	452.2	127.8	83.8%

3. Eccentricity Caused by the Variation of Stiffness

In the isolated nuclear power plant, hundreds of isolators are installed below the basemat of a nuclear island structure. If every isolator has same dynamic property, only the translation movement along the orthogonal directions may occur. However, the mechanical properties of each isolator can be different by its uncertainty variation and it generates the rotational movement resulting in different displacement responses according to the isolator location. This rotational movement can be represented as the eccentricity of the center of stiffness.

Let assume that $(n_x \times n_y)$ number of isolators are distributed evenly with equal space, d_x and d_y, in each direction under the basemat of $l_x \times l_y$ dimension as shown in Fig 3. The stiffness of isolators can be represented as the equivalent linear stiffness, k, and its mean and standard deviation is μ and σ, respectively.

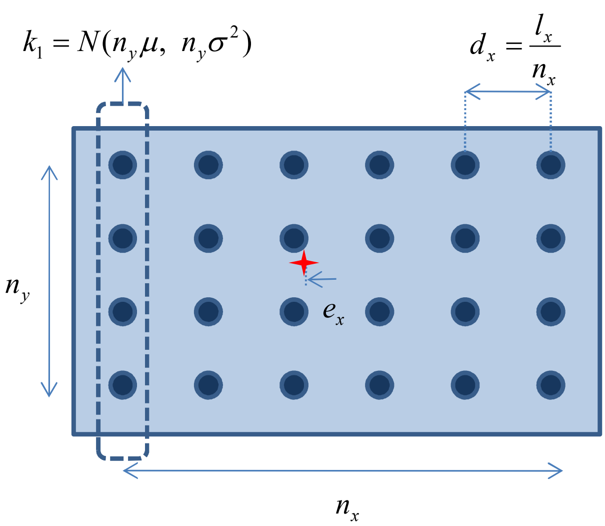

Fig. 3. Arrangement of isolators for the analytical example

By the random error theory, the normal distribution of the eccentricity caused by the uncertainty of isolator stiffness was derived as Equation 1. The relative ratios of the standard deviation of the eccentricity in case of the 4 by 4, 8 by 8, 16 by 16 and 32 by 32 isolators are compared in Table II. If the number of isolators increases in the system, the eccentricity of the system stiffness caused by the uncertainty of each isolator decreases because of the dispersion of uncertainty.

$$e_x = N\left(0,\ \left[\frac{\sqrt{\left[\left(\frac{n_x}{2}\right)^2 + \left(\frac{n_x}{2}-1\right)^2 + \cdots + \left(\frac{n_x}{2}-1\right)^2 + \left(\frac{n_x}{2}\right)^2\right] n_y}}{n_x}\frac{l_x}{K}\sigma\right]^2\right) \quad (1)$$

Table II: Response of the isolation system

(n_x, n_y)	Ratio of the Standard Deviation of Horizontal Stiffness	Ratio of the Standard Deviation of Eccentricity
(2,2)	1.000	1.000
(4,4)	0.500	0.559
(8,8)	0.250	0.286
(16,16)	0.125	0.144
(32,32)	0.063	0.072

4. Conclusions

In this study, the variations of the displacement response of a simplified isolation system were evaluated. The variation of a horizontal translation displacement and the eccentricity of a system stiffness caused by the uncertainty of mechanical property of isolators are quantitatively calculated. These procedures can be used to estimate the probabilistic distribution of the responses of an isolation system efficiently.

ACKNOWLEDGEMENT

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