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A strategy for estimation of aging effect of lead rubber bearings in a base-isolated nuclear power plant

Sung Gook Cho [a], Thuy Dung Vu [b], Dookie Kim [b*]
[a]*R&D Center, JACE KOREA Company, Gyeonggi-do, South KOREA*
[b]*Kunsan National University, Kunsan, South KOREA*
[*]Corresponding author: *kim2kie@chol.com*

1. Introduction

ASCE standard 4-98 [1], which is relevant to the analysis and design of nuclear power plant (NPP), is being updated at the present with including provisions for the analysis and design of seismic isolation systems. NPP structures have been isolated using elastomeric and sliding isolation systems. Lead rubber bearing (LRB) is one type of isolation systems suitable for application to NPP structures. During life cycle, natural rubber is affected by aging, temperature variation, history nature of loading, wear and so on. The durability of LRB against aging might not be adequate when exposed to ozone, oxygen and ultraviolet rays [2]. The stabilities and working capacity of base isolated structures then can be damaged, partly or entirely. Performance of seismically isolated NPP structures therefore needs to be investigated with consideration for the aging effects of LRB. This study has developed an efficient analytical model for the seismically isolated structures to consider the aging effect of the isolators. Finite element (FE) model updating based on mean-iterative neural networks is introduced in this paper. The aging effects of the isolator on the seismic performance of the containment building were identified by experiments and FE analyses.

2. Model Updating

A simplified approach has been adopted for model updating of a base-isolated NPP using the virtual static deflections based on iterative neural networks. Experiment program of thermal aging test has been performed on LRB for the verification of the approach. The static and dynamic analyses using estimated and initial parameters are also performed and compared.

2.1 Experiment and FE model

A LRB product was selected for experimental studies [3]. As shown in Fig. 1, the bearing was a 275-millimeter diameter including a 10-millimeter thickness of outside surrounding rubber, 171-millimeter depth. It consists of 29 layers with thickness of 3-millimeter laminated rubber and 3-millimeter steel plate.

The thermal aging experiments were performed in the accelerated exposure condition of 70°C for about 168 hours, which is equivalent to the estimated life of 60 years (ISO 11346). The vertical load of 565 kN was uniformly applied in order to maintain the designed in-plane pressure. The equivalent lateral load with a 5 Hz sinusoidal wave was employed to cause the almost same displacement as design.

The containment building [4] was modeled with 65.8-meter height using 13 elastic beam column elements. The FE model was developed in Opensees software [5] for an actual base-isolated NPP. A bilinear model [6] with a zero length element [7] was built for numerical analysis of isolation devices.

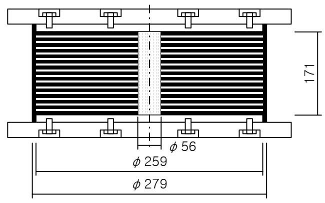

Fig. 1. Lead Rubber Bearing

2.2 Strategy for FE model updating

The general procedure of a new iterative algorithm for parameter model updating loop is developed based on the mean-iterative optimization process. The strategy is divided into two stages: First, the initial defect profile from numerical analysis is trained by NNs in order to identify origin structural parameters; the trained NNs are then used in an iterative algorithm to estimate the parameters given by the measurement signals.

The optimization toolbox in MATLAB, which uses the objective function (Eq. 1) as the objective function, was employed to perform the model updating (an optimization process actually). The process of model updating method was identical to the optimization process as shown in Fig. 2.

$$OFV = \sum_{j=1}^{6}\left(\left(\frac{d_j^{\exp} - d_j^{num}}{d_j^{\exp}}\right)^2\right) \quad (1)$$

where OFV is the cost function, $d_j^{\exp}$ is the experimental displacement and d_j^{num} is the corresponding numerical displacement.

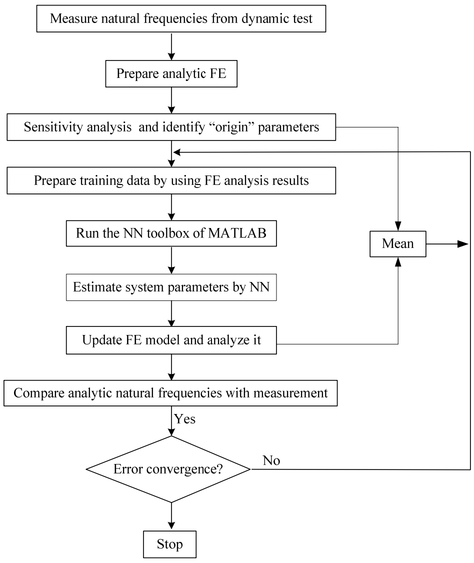

Fig. 2. Flow chart of MINNs

The optimization was converged at the end of about seven iterations. After updating, the cost function value is 0.319 (2.838 before updating), which can conclude that the optimization process worked effectively. Fig. 3 shows the comparisons of the numerical compression-shear curve, after model updating, and the experimental curve. An agreement between the numerical and experimental results demonstrates that the presented method is effective and efficient to estimate the structural parameters considering aging effect.

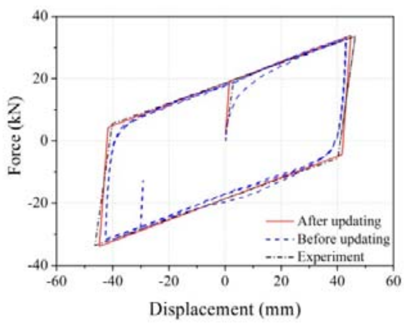

Fig. 3. Shear curves before and after model updating

2.3 Seismic performance after aging

Seismic behavior of the base-isolated NPP was analyzed under El Centro earthquake in order to evaluate the aging effects on the structure. The observed results before and after thermal aging of LRB were compared as shown in Fig. 4

3. Conclusions

A FE model updating strategy is proposed in this paper. Experiments and analyses have been carried out to identify the aging effects of the isolators on the structural behavior. The comparative study results indicate a great potential of the presented method for practical applications. After comparing the seismic performances of the NPP with and without considering the aging effects, it reveals the considerable effects of aging on the seismic performance of the base-isolated NPP.

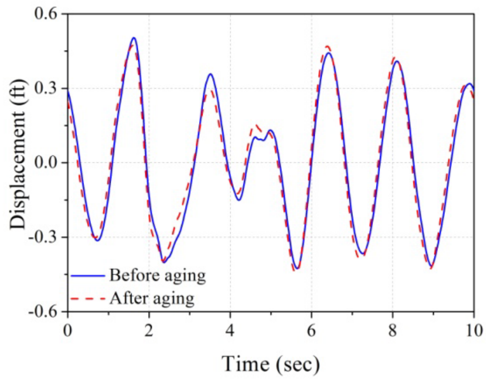

Fig. 4. Seismic displacement responses

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