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Seismic Lifetime Vulnerability Curve Development of Isolated Buildings with LRB Under Probable Mainshock-Aftershock Scenarios in Tehran

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ABSTRACT: This research deals with the application of lead rubber bearing isolation (LRB) systems in reducing the seismic risk of buildings located in Tehran metro city from technical and economic points of view. In this regard, first, three separate 5-, 10-, and 15-story buildings with the steel moment resisting frames system are considered. These models are designed in two separate scenarios: with and without the base isolation system. Next, all the active faults of Tehran and its surrounding area are considered to generate the probable earthquake scenarios in the 50-year life span of the buildings. This simulation contains the probable mainshock-aftershock event scenarios and the corresponding accelerograms for each of the generated events. Afterward, by adopting the Monte-Carlo simulation technique, an adequate number of random earthquake hazard scenarios are generated. Then, the buildings' performances are evaluated under mainshock-aftershock sequences using the nonlinear dynamic time history analysis approach. In addition, by using the damage and loss models considering the fatality and injury, building physical damage, and time-dependent economic losses, the lifetime seismic risks of buildings are estimated. The outcomes highlight that the LRB system is well capable of improving the building behavior and hence reducing the life-cycle cost of buildings tangibly which will be elaborated in this paper.

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1- Introduction

Nowadays, the number of building projects constructed with the vibration control systems is growing very fast in the area prone to the high seismic hazard level, as a verified practical solution for mitigating the imposed risk. However, the application of such systems in developing countries are facing some problem from an economic point of view. Many clients of construction projects are not interested in applying such devices since they believe that they should pay more for these systems. However, it is not correct, since they only consider the initial cost of their building. Therefore, it is vital to deal with the application of vibration control systems, specifically base isolation systems, in terms of their lifetime seismic risk.

By reviewing the literature, there are several works [1,2] that only deal with the application of vibration control systems through a technical perspective. Besides, in some other research works, Kumar et al. [3], and Yu et al. [4] worked on the seismic risk of nuclear power plants equipped with base isolation systems. The main shortcoming of these works was the ignorance of the aftershocks' effects. On the other side, Khansefid et al. [5], and Zhai et al. [6] attempted to simulate the effects of aftershocks on the seismic performance of the isolated building. Unfortunately, none of these works did the analysis through risk-based approaches. More recently, Khansefid [7] tried to propose a more advanced approach to estimate the lifetime seismic risk of buildings with vibration control systems.

This study is an attempt to deal with the lifetime seismic risk of base-isolated structures with LRB system under future probable mainshock-aftershocks (MA) via developing the vulnerability curves. In this regard, 3 sets of 5-, 10-, and 15-story buildings located in Tehran metro city are considered. The seismic hazard scenarios during the building life span are developed using advanced methods [8-10]. Afterward, via the nonlinear dynamic time history analysis approach, the response of building models to the MA hazard scenarios, and, consequently the building damages and losses are estimated.

2- Methodology

For the lifetime seismic risk assessment of isolated buildings, three sets of 5-, 10-, and 15-story typical building models in Tehran metro city are considered. They are designed without/with the lead rubber bearing isolation systems optimally. Afterward, through the Monte-Carlo simulation approach and by using the advanced model proposed by

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Khansefid and Bakhshi [8], 6000 random earthquake hazard scenarios in Tehran are simulated. This model works by generating random event scenarios including probable mainshocks and aftershocks during the building lifetime [9] by considering 12 active faults of Tehran province including Mosha, North Tehran, Kahrizak, Robat Karim, Eshtehard, etc. Afterward, nonstationary stochastic accelerograms corresponding to each of generated random events are simulated [10]. In the next step, the response of each of the building models is obtained for each of the earthquake scenario realizations taking the whole MA sequences into account by performing nonlinear dynamic time history analysis, while the structural behavior of buildings is modeled using the nonlinear multi-degree of freedom mass-spring system [11]. Afterward, the structural damage of models is estimated by using the available fragility curves [12]. Finally, by considering the building physical damage, occupant injury and death, and the income interruption, the lifetime seismic loss and risk of buildings are estimated through available loss models of buildings [12-14].

3- Results and Discussion

In this part, the main outcomes of the research are presented. Figure 1 shows the exceedance probability of the estimated lifetime loss values of all building models with/without isolation systems. By considering the 10% probability level which is also called probable maximum loss, it is revealed that the usage of LRB system will lead to a significant (35%) reduction in the estimated loss, on average. In other words, the owner of buildings could invest up to 18% of it is total project cost for the base isolation system economically.

Next, the most important outcome of this research is the loss curves of buildings which are shown in Figure 2 for all models considering the aftershock effects. Generally, the application of LRB system reduces the estimated loss value considerably, especially in the more intensive earthquake scenarios (PGA>6m/s^2). However, in the low-intensity levels (PGA<1m/s^2), there are no significant differences between the estimated loss of uncontrolled (Fix) and isolated (Iso) buildings. This is observed due to the inactivation of LRB in low-intensity earthquakes.

Last but not least is the effect of aftershocks on the estimated seismic risk shown in Figure 3. As it is depicted, by neglecting the effects of aftershocks, the seismic risk is estimated 40% and 48% less than the case of considering them for isolated and uncontrolled buildings, on average. In addition, among different loss types, the physical losses (47% underestimation) are more sensitive to the consideration of aftershock effects than the economic loss (40% underestimation).

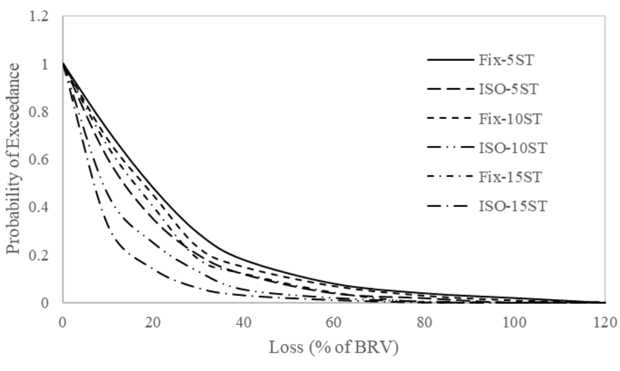

Fig. 1. Exceedance probability curve of the estimated loss value of 5-, 10-, 15-story buildings with/without lead rubber bearing isolation system

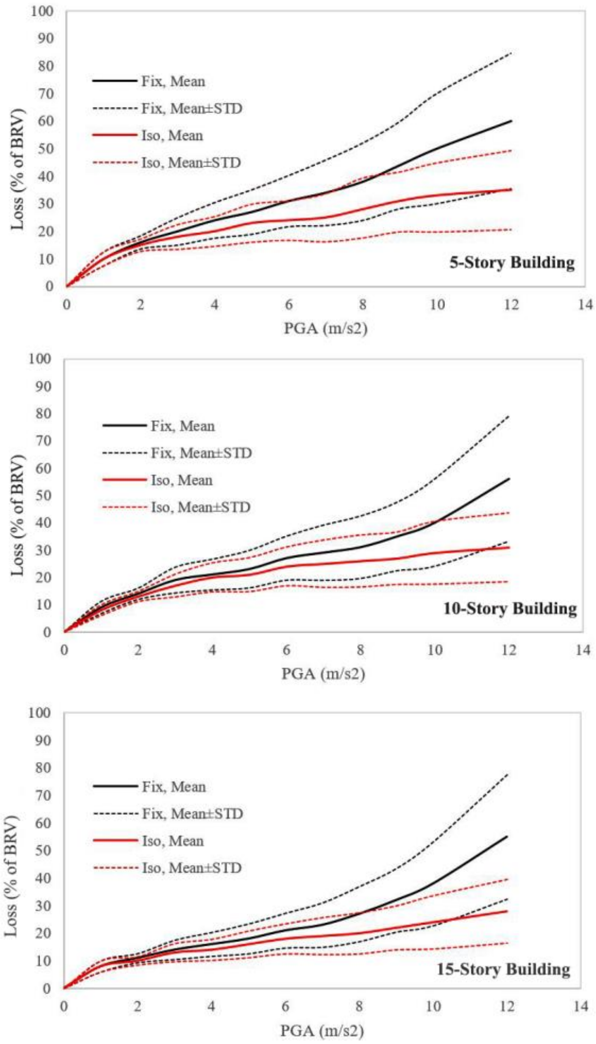

Fig. 2. Loss curves of building models, a) 5-story building b) 10-story building, c) 15-story building

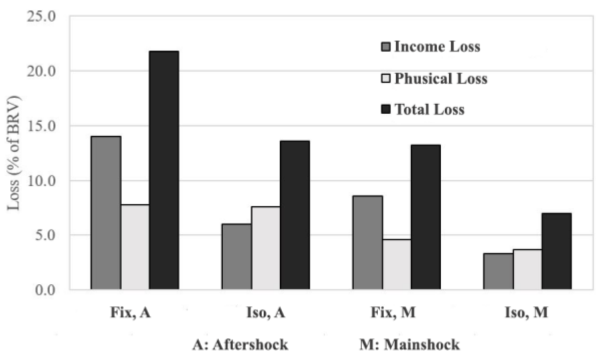

Fig. 1. Phase velocity dispersion curves for a steel pipe with outer diameter of 220 mm and wall thickness of 4.8 mm

4- Conclusions

The main outcome of this research paper was the developed vulnerability curves for the isolated buildings in Tehran considering the lifetime seismic hazard scenarios. In addition, outcomes of this research work proved both technical and economic superiority of lead rubber bearing systems in comparison with the traditional uncontrolled building. The application of LRB reduced the estimate lifetime risk of building by 35%, enjoying its capability in reducing both structural drift and acceleration responses of building, simultaneously. In the end, it is shown that among all active faults in Tehran province, North Tehran, Kahrizak, and Robatkarim have the highest contribution to the estimated risk.

References

[1] I.V. Kalpakidis, M.C. Constantinou, A.S. Whittaker, Modelling strength degradation in lead–rubber bearings under earthquake shaking, Earthquake engineering & structural dynamics, 39(13) (2010).

[2] A. Kanyilmaz, C.A. Castiglioni, Reducing the seismic vulnerability of existing elevated silos by means of base isolation devices, Engineering Structures, 143 (2017).

[3] M. Kumar, A.S. Whittaker, R.P. Kennedy, J.J. Johnson, A. Kammerer, Seismic probabilistic risk assessment for seismically isolated safety-related nuclear facilities, Nuclear Engineering and Design, 313 (2017).

[4] C.C. Yu, C. Bolisetti, J.L. Coleman, B. Kosbab, A.S. Whittaker, Using seismic isolation to reduce risk and capital cost of safety-related nuclear structures, Nuclear Engineering and Design, 326, (2018).

[5] A. Khansefid, A. Maghsoudi-Barmi, A. Bakhshi, Seismic performance assessment of optimally designed base isolation system under mainshock-aftershock sequences, In 8th International Conference on Seismology and Earthquake Engineering, Tehran, Iran (2019).

[6] C.H. Zhai, Z. Zheng, S. Li, X. Pan, Damage accumulation of a base-isolated RCC building under mainshock-aftershock seismic sequences, KSCE Journal of Civil Engineering, 21(1) (2017).

[7] A. Khansefid, Lifetime risk-based seismic performance assessment of buildings equipped with supplemental damping and base isolation systems under probable mainshock-aftershock scenarios, Structures, 34 (2021).

[8] A. Khansefid, A. Bakhshi, New model for simulating random synthetic stochastic earthquake scenarios, Journal of Earthquake Engineering, (2019).

[9] A. Khansefid, A. Bakhshi, Statistical evaluation and probabilistic modeling of aftershock sequences of Iranian plateau, Journal of Seismology, 22(5) (2018).

[10] A. Khansefid, A., Bakhshi, A. Ansari, Empirical predictive model for generating synthetic non-stationary stochastic accelerogram of the Iranian plateau: including far-and near-field effects as well as mainshock and aftershock categorization, Bulletin of Earthquake Engineering, 17(7) (2019).

[11] C. Christopoulos, A. Filiatrault, V.V. Bertero, Principles of passive supplemental damping and seismic isolation, : Iuss press, Pavia, Italy, (2006).

[12] Federal Emergency Management Agency (FEMA), HAZUS-MH 2.1 Earthquake Model Technical Manual, Federal Emergency Management Agency, Washington, D.C., USA, (2013).

[13] A. Khansefid, A. Bakhshi, Advanced two-step integrated optimization of actively controlled nonlinear structure under mainshock–aftershock sequences, Journal of Vibration and Control, 25(4) (2019).

[14] A. Khansefid, An investigation of the structural nonlinearity effects on the building seismic risk assessment under mainshock–aftershock sequences in Tehran metro city, Advances in Structural Engineering, 24(16) (2019) .

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