Comparison of the Fragility Curves for the Isolated and Non-Isolated Highway Bridges based on Numerical Simulation

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Introduction: The trend of base-isolating highway bridges is on the rise after the recent large earthquakes in Japan, the USA, and other countries. Recent investigation shows that the base-isolated system performs well against seismic forces as the substructures of such system experience less lateral force due to energy dissipation of the isolation device. The objective of this study is to construct the fragility curves of an isolated highway bridge system based on numerical simulation, and to compare them with the ones of a non-isolated system.

Fragility curves: Karim and Yamazaki[1)] developed a set of analytical fragility curves for the highway bridge piers based on numerical simulation and considering the variation of input ground motions. The procedures adopted for constructing the analytical fragility curves are briefly described here while details can be found elsewhere.[1)] In this study, the same analytical approach is adopted to construct the fragility curves of highway bridges. The steps for constructing the analytical fragility curves are as follows: 1) selection of the earthquake ground motion records, 2) normalization of PGA of the selected records to different excitation levels, 3) making a physical model of the structure, 4) performing the both nonlinear static push-over and dynamic response analyses, 5) obtaining the damage indices of the structure in each excitation level using a damage model, 6) calibration of the damage indices for each damage rank to obtain the damage ratio in each excitation level, and 7) construction of the fragility curves using the obtained damage ratio and the ground motion indices for each damage rank assuming a lognormal distribution.

Bridge models and input motions: Two RC bridge structures are considered, of which one is a non-isolated and the other one is an isolated system, and they are designed according to the seismic design code in Japan,[2)] assuming that the size (3m by 3.5m) and reinforcement (1.25% longitudinal and 0.32% tie) of the piers, height of the substructure (10m), length (35m) and weight (572 kN/m) of the superstructure, ground condition (type II), and nominal design strength of concrete (14.7 MPa) and reinforcement (294 MPa) being unchanged. For the non-isolated bridge system, it is assumed that it has four spans, the piers are rectangular, pin-jointed to the superstructure and fixed to the base, and the superstructure is assumed to slide on ordinary frictionless bearings at the abutments. For the isolated bridge system, a Lead-Rubber Bearing (LRB) is used as the isolation device. The yield force and yield stiffness of the LRB are taken as 5% W and 5% W/mm, respectively, which provides a reasonable balance between reduced forces in the piers and increased forces on abutments.[3)] Given the yield force level and the lead yield strength of 10-10.5 MPa, the number and cross sectional area of the lead plugs can be designed.[3)] The advantage of LRB is that it has low yield strength and sufficiently high initial stiffness that results higher energy dissipation. The substructure stiffness for the whole bridge system is given as the sum of the stiffness of all piers.[4)] The physical models of the non-isolated and isolated bridge systems are shown in **Figure 1**. The natural period for the non-isolated system to the longitudinal direction is 0.38s, and it shifts to 1.28s for the isolated system, which falls within the practical range of natural period for isolated systems.[3)] For a nonlinear dynamic response analysis and to get a wider range of the variation of input ground motion, a total of two hundred and fifty (250) records were selected from the 1995 Kobe, the 1994 Northridge, the 1993 Kushiro-Oki, the 1987 Chibaken-Toho-Oki, and the 1999 Chi-Chi earthquakes.

Damage analysis and fragility curves: For a nonlinear dynamic response analysis, the non-isolated bridge is modeled as a SDOF system, a bilinear hysteretic model was considered, and the post-yield stiffness was taken as 10% of the initial stiffness with 5% damping ratio. For the isolated system, it is modeled as a 2DOF system,[4)] a bilinear hysteretic model was considered for the both substructure and isolation device,[3)] the post-yield stiffness was taken as 10% of the initial stiffness for the both substructure and isolation device,[3)] and the damping matrix **C** is evaluated by using the Rayleigh damping.[3)] Using these parameters, the damage to the structures due to ground motions is obtained by performing a series of the both nonlinear static pushover and dynamic response analyses. The damage to the structures is quantified by a damage index DI that is obtained by using Park-Ang damage model,[5)] which is then used to construct the fragility curves.[1)] For the cumulative probability P_f of occurrence of the damage equal to or higher than damage rank R is given as

$$P_f(\geq R) = \Phi\left[\frac{\ln X - \lambda_x}{\xi_x}\right] \qquad (1)$$

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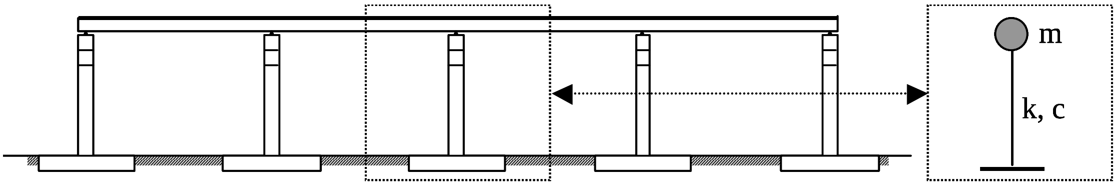
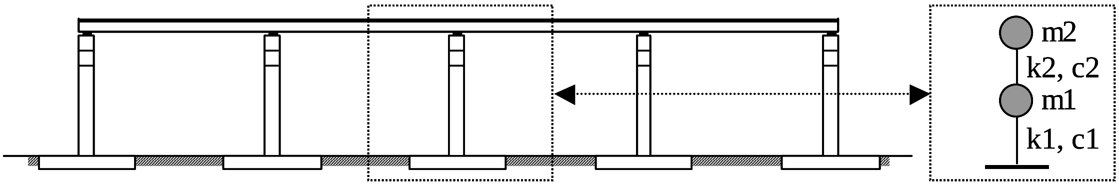


(a) Physical model of a non-isolated bridge system



(b) Physical model of an isolated bridge system

Fig. 1 Physical models of the non-isolated and isolated bridge systems used in this study.

where Φ is the standard normal distribution, X is the ground motion index (e.g., PGA, PGV, and SI), λ_X and ξ_X are the mean and standard deviation of $\ln X$. Two parameters of the fragility curves, i.e., mean λ_X and standard deviation ξ_X are obtained for each damage rank by plotting the damage ratio in each excitation level on a lognormal probability paper, and performing a linear regression analysis.

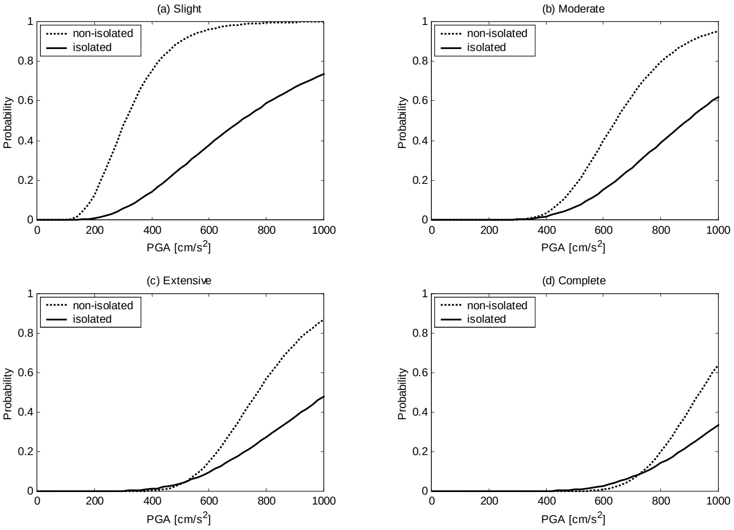


Fig. 2 Comparison of the fragility curves for the non-isolated and isolated bridge systems with respect to PGA.

Figure 2 shows the plots of the fragility curves for all damage ranks obtained for the non-isolated and isolated bridges with respect to PGA only. It can be seen that the level of damage probability for the isolated system is less than that of the non-isolated one. The trend of the base-isolated system is that the substructures of such system experience less lateral force due to the energy dissipation of the isolation device that results the isolated system to perform better against seismic forces than the non-isolated one, and the evidence can be seen on the plots (**Figure 2**). Since, base-isolated bridges are more susceptible to relatively more severe effect of soil-structure interaction (SSI) due to soil liquefaction during an earthquake,$^{4)}$ it is anticipated that there might be an effect on the fragility curves due to SSI, however, this effect is not considered in the present study for which a further research is necessary.

Conclusions: Fragility curves for two bridge models, of which one is a non-isolated and the other one is an isolated system, were obtained with respect to the ground motion parameters based on numerical simulation using two hundred and fifty strong motion records. It was found that the level of damage probability for the isolated bridge structure is less than that of the non-isolated one. However, to draw a solid conclusion, it is necessary to consider the soil-structure interaction effect for which a further research is necessary.

References

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