I－B191

Development of Fragility Curves for RC Bridge Pier Based on Hyogoken-Nanbu Earthquake Records

The University of Tokyo, Institute of Industrial Science, Student Member Kazi Rezaul Karim
The University of Tokyo, Institute of Industrial Science, Member Fumio Yamazaki

1. **Introduction**: To estimate a damage level (**Slight**, **Moderate**, **Extensive** and **Complete**) of highway bridges due to earthquake ground motion, we need a set of fragility curves, which predict the damage level for a given level of ground motion indices (e.g., PGA). Due to the seismic action a bridge may or may not be collapsed completely. Even, if it is not collapsed completely some damages occur because of the seismic action. This kind of damage information is very much necessary to take in advance the necessary steps for the prevention of the future collapse of the bridges. In this study, considering all structural parameters and structural responses, an analytical approach has been adopted to obtain the fragility curves for RC bridges. In order to do so and for simplicity a hypothetical RC Bridge pier is considered in this study.

2. **Pier model and Static Analysis:** Though the pier is taken as hypothetical one but for better understanding its detailing and all the required parameters are taken from recent (July 1998) seismic design codes for Highway Bridges in Japan. Pier model and cross section are shown in Figure1 (a) and (b). The yield and ultimate capacity of the pier is obtained following the procedure that is given in the seismic design codes. However, the Moment-Curvature relationship for each cross section is obtained using the program Response-2000. And finally, the Force-Displacement relationship is obtained from moment-curvature diagram. In addition, one steel jacket is provided at the base of the pier upto a height of 2.17m with thickness 16mm to observe the behavior of the pier against the seismic action. The force-displacement relationship of the pier is shown in Figure1(c). From sectional analysis it is found that flexural failure governs the failure mode.

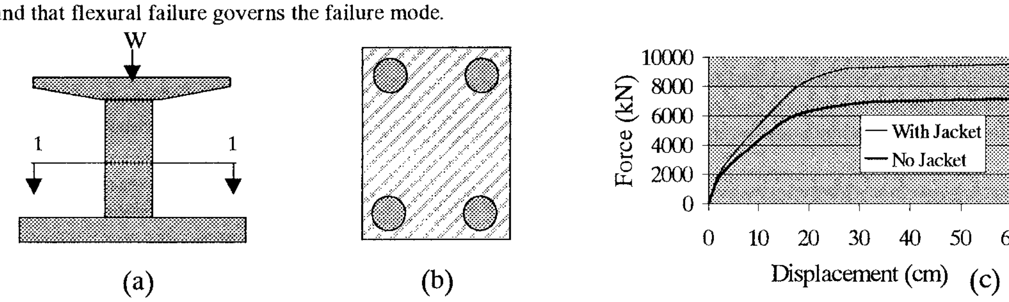

Figure1: (a) Bridge pier model (b) Cross section along 1-1 (c) Force-displacement relationship of the pier.

3. **Dynamic Analysis:** For non-linear dynamic response analysis the pier is modeled as a SDOF (single degree of freedom) system. Input ground motions for dynamic response analysis is taken from the Hyogoken-Nanbu earthquake records. A total of fifty recorded acceleration time histories are chosen as the input ground motions and these are taken on the basis of maximum PGA and PGV. In order to do so, twenty five record stations (both JMA and Non-JMA) are selected from Hyogoken-Nanbu earthquake. However, as the data for extensive and complete damage cases are very limited, the original fifty acceleration time histories were scaled up by 1.5 and 2 times in order to obtain more damage data for extensive and complete damage cases. So, the total number of input ground motions became one hundred and fifty. The distribution of PGA and PGV is shown in Figure2 (a). The ductility demand at the top of the pier is obtained from non-linear dynamic response analysis by using NONLIN program. For non-linear dynamic response analysis a bilinear model is idealized and the post yield stiffness is taken as 10% of the secant stiffness of the pier with 5% damping ratio.

4. **Damage Analysis:** For the assessment of the damages of the bridge pier due to seismic action Park-Ang damage index DI (Park et al. 1985) is applied in this study and the governing equation is given as:

$$DI=(\mu_d + \beta\mu_h)/\mu_u \tag{1}$$

Where, μ_d and μ_u are displacement ductility and ultimate ductility, β factor (mean value) is taken as 0.15 and μ_h is the cumulative energy ductility defined by $\mu_h=E_h/E_e$, where, E_h and E_e are cumulative hysteretic energy and elastic energy of the pier. The relationship between PGA and Damage Index is shown in Figure2 (b). After obtaining the damage index of the pier for given input ground motions it is then calibrated to get the relationship between damage index and damage rank. This calibration is done using the method that is proposed by Ghobarah et al.

Key words: *Ground Motion, Dynamic Analysis, Ductility Demand, Damage Index, Damage Rank, Fragility Curves*
Contact Address: 7-22-1 Roppongi, Minato-ku, Tokyo 106, Japan.

(1997) and Table1 shows the relationship between damage index and damage rank.

Table1: Relationship between damage index and damage rank

Damage Index	0.00<DI<=0.14	0.14<DI<=0.40	0.40<DI<=0.60	0.60<DI<1.00	1.00<=DI
Damage Rank	D	C	B	A	As
Definition	No damage	Slight damage	Moderate damage	Extensive damage	Complete damage

5. **Fragility Curves:** For each damage rank we have one data set (PGA and DI) and these are obtained from the relationship that is given in Table1. Based on these data, fragility curves for bridge pier are constructed assuming lognormal distribution for the cumulative probability P_R of occurrence of the damage equal or higher than rank R as follows:

$$P_R = \Phi[(\ln X-\lambda)/\zeta] \tag{2}$$

Where, Φ is the standard normal distribution, X is PGA & PGV and λ and ζ are the mean and standard deviation of lnX. The two parameters of the distribution are obtained by the least square method on the lognormal probability paper. And, finally the fragility curves for each damage rank is constructed using these two parameters. The fragility curves are shown in Figure2(c) and (d).

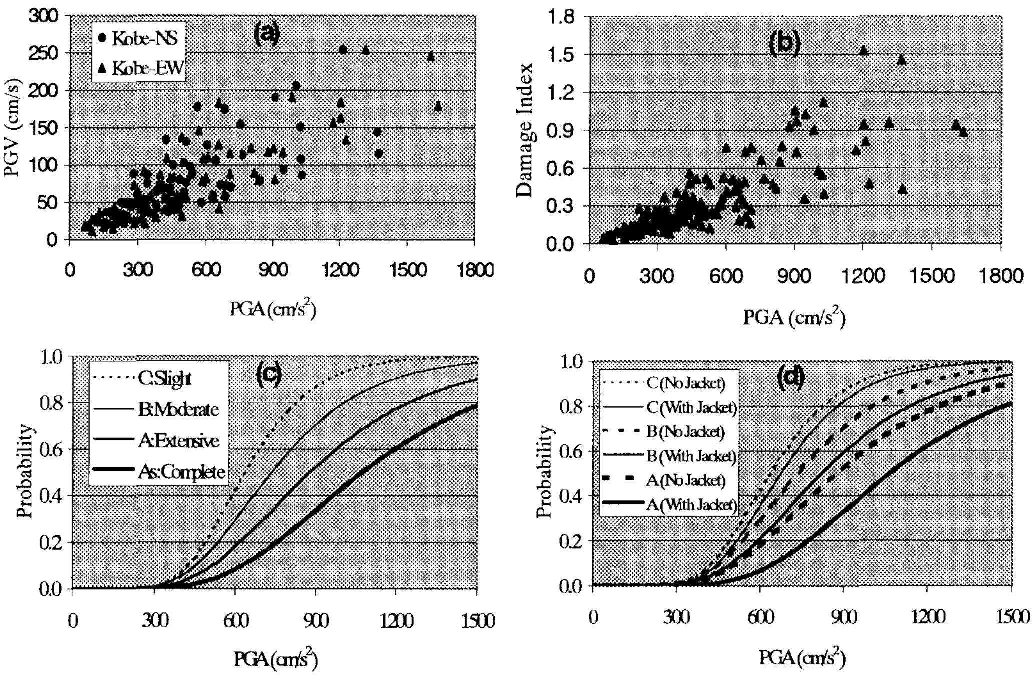

Figure2: (a) Distribution of PGA and PGV of Hyogoken-Nanbu earthquake records (b) Relationship between PGA and Damage Index of RC bridge pier (c) Fragility curves for RC bridge pier without jacket (d) Fragility curves for RC bridge pier with and without steel jacket.

6. **Results and Discussion:** The fragility curves for the bridge pier are constructed for two cases (no jacket and with jacket) using the Hyogoken-Nanbu earthquake records. It is found that damage starts occurring at PGA level of more than 300 cm/s^2. Moreover, it is found that provision of steel jacket results the pier to perform well against the seismic action and there is less probability of damage to occur.

References

Design Specifications of Highway Bridges, Part V. Seismic Design, 1998, Technical Memorandum of EED, PWRI, No. 9801.

Ghobarah, A., N.M. Aly and M. El-Attar, 1997. Performance level criteria and evaluation. *Proceedings on the International Workshop on Seismic Design Methodologies for the next Generation of Codes*, Bled, Slovenia, 207-215.

Kawashima, K. and G.A. Macrae, 1993. The seismic response of bilinear oscillators using Japanese earthquake records. *Journal of Research*, Vol.30, PWRI, Ministry of Construction, Japan.

Priestley, M.J.N., F. Seible and G.M. Calvi. *Seismic Design and Retrofit of Bridges*. John Wiley & Sons, New York, 1996.

Yamazaki, F., J. Ohnishi and S. Tayama. Earthquake damage assessment of expressway structures in Japan. *Proceedings of Asia-Pacific Symposium on Structural Reliability and its Application*, Taipei, Taiwan, R.O.C, 205-214.