

# SEISMIC VULNERABILITY ASSESSMENT OF COMPLEX HIGHWAY BRIDGE STRUCTURE USING SYSTEM FRAGILITY CURVES

University of Tsukuba, Student Member, ○Muhammad Rashid  
University of Tsukuba, Regular Member, Mayuko Nishio

## 1. INTRODUCTION

The probabilistic seismic vulnerability assessment of bridge infrastructures has rapidly evolved in the last three decades. Fragility curves, which represents the structural vulnerability as a function of the ground motion intensity, are used as a common tool for seismic vulnerability assessments. Several methodologies for developing the fragility functions are proposed in the literature, including empirical, experimental, analytical and hybrid methods. Among them the analytical methods are more widely adopted because of its flexibility and application to any kind of geographic regions especially with insufficient seismic records. The simplified approach for bridge fragility assessment assumes the fragile-most single component. According to which, the response of the single components (usually the pier) governs the bridge performance. This assumption led to underestimate or overestimate the bridge-system seismic performance, depending upon the bridge typology. To assess the bridge-system seismic vulnerability, the response of all major contributing vulnerable components must be considered in fragility framework to avoid significant fragility estimation errors.

This study aims at presenting the procedure for system-level fragility estimation while accounting for all the vulnerability contribution of bridge piers and bearings. This method eliminates the assumption of bridge system as a series system by considering the correlation dependency among the components response. For this purpose, an existing testbed structure is considered and subjected to a series of time history loading. the components fragility curves are developed using the probabilistic seismic demand models (PSDM) and the associated capacity limit states, which are then combined to define the joint probabilistic seismic demand model (JPSDM) for the bridge system for bridge-system fragility functions.

## 2. STRUCTURAL DETAILS AND NUMERICAL MODELING OF THE BRIDGE SYSTEM

The target bridge in this study is a highway bridge, located in Yokohama city Japan. Structurally it is a composite type of system, consisting of steel and reinforced concrete (RC) sections. The geometric complexities are due to the presence of the on-off ramps and horizontal curvature in the mainline. The bridge is supported by five steel and one RC piers and abutments at the end. The characteristic strength of the concrete used in superstructure and substructure are 30 and 24 N/mm<sup>2</sup>, respectively. Throughout the structure, the SM 490Y, 400, and SS 400 steel framing sections are employed, which are super heavy steel plates used for welded structure of bridges in highway construction. For the seismic isolation, the LRBs are provided at the top of the piers.

The analytical modelling was carried out in a finite element environment as shown in Fig. 1, where the bridge superstructure, the bent-top beams and abutments were modeled as a linear beam element. For the non-linear response of the piers, the piers are modeled as fiber-elements. The plastic hinge element is employed for RC pier and represented by Takeda nonlinear model. Using the design standards, the damping coefficient of 3% and 5% are used for the steel and concrete elements, respectively. The multiple shear spring (MSS) bi-linear elements are used to simulate the mechanical characteristics of the lead rubber bearings (LRB). To account for the soil-structure interaction, equivalent linear translational and rotational springs were defined to model the piers and abutment foundations. The stiffness indices were calculated based on the foundation type and soil characteristics based on the Japanese highway design documentation.

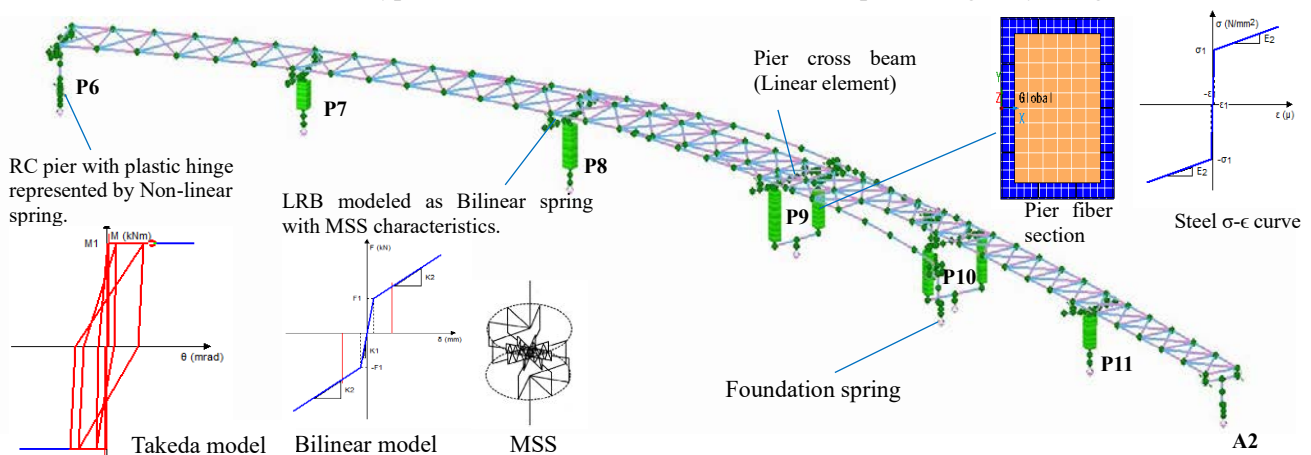


Fig. 1 Analytical model of the target bridge structure

Keywords: Complex bridge, System-fragility, PSDM, Finite element analysis, Seismic vulnerability  
Contact address: Deptt of Engg Mechanics and Energy, University of Tsukuba, 1-1-1 Tennodai, Tsukuba 305-8573, Japan

### 3. INPUT GROUND MOTIONS

The time history analysis is performed using a suit of twenty ground motions extracted from JMA, and K-Net & KiK-Net strong ground motion database. The selected records consist of Level-1 and Level-2 types of waveforms and their response spectra is shown in Fig. 2.

### 4. FRAGILITY FUNCTIONS AND SEISMIC VULNERABILITY ASSESSMENT

The seismic vulnerability of the bridge structure is described in terms of fragility functions, which are based on the nonlinear response history analysis. Using pre-determined damage indices, a damaged state is assigned to each component based on the HAZUS-MH (FEMA, 2003) criteria, as presented in Table 1. The components PSDM are developed using the peak response of the components obtained from the IDA and the associated engineering demand parameter (EDP) value. Ductility demand, shear strain and distortion strain are considered as the EDPs for fragility development for the RC pier, bearings, and steel pier respectively. Using the power law in Eq. (1), the mean and standard deviation for each limit state is calculated through regression analysis. Finally, the fragility curves are derived based on Eq. (2).

$$EDP = a(IM)^b \quad (1)$$

$$P[LS | IM = x] = \Phi \left[ \frac{\ln(x/\lambda_c)}{\sqrt{\beta_d^2 + \beta_c^2}} \right] \quad (2)$$

Where  $a$  and  $b$  are regression coefficients. The  $\Phi$  [\*] represents the standard normal cumulative distribution function,  $\lambda_c$  is the median value of the intensity measure  $IM$  and the term in denominator represents the cumulative dispersion for a particular damage state.

Table 1. Engineering demand parameters (EDP) and limit states definition

Component	Damage state	Slight	Moderate	Extensive	Collapse	Reference
	Failure mode	Spalling	Moderate cracking	Moderate crushing	Severe crushing and collapse	HAZUS (FEMA, 2003)
Concrete Pier	Displacement ductility	$\mu_d > 1$	$\mu_d > 1.2$	$\mu_d > 1.76$	$\mu_d > 4.76$	Hwang et al. (2001)
LRB	Shear strain (%)	$\gamma > 100$	$\gamma > 150$	$\gamma > 200$	$\gamma > 250$	Zhang and Huo (2008)
Steel Pier	Distortion (%)	$\varepsilon_y$		$7*\varepsilon_y$		Bridge design document

Figure 3 shows the PSDMs developed for pier in term of ductility and bearing in term of shear strain, respectively. In addition to the fragility curves for each of the bridge components, the bridge system fragility curves are also plotted in Fig. 4. Clearly, the bridge as a system is more fragile than any one of the bridge components. It can be observed that the system fragility is dominantly affected by the LRB response. The median PGA values for the bridge-system are slightly greater than the values for the bearings.

### 5. CONCLUSIONS

In this study a brief introduction and importance of the system-level seismic vulnerability assessment was presented using the fragility functions. The fragility functions were developed for the components and bridge-system using the probabilistic fragility framework, and it was observed that the system vulnerability increases when the major vulnerable components are taken into considerations. Additionally, the fragility profile shows that the system response is highly sensitive to the response of the bearings. Finally, the findings support the idea of multiple components consideration in system-level fragility development.

### REFERENCES

- Fema, Hazus-Mh. "MR3 Technical Manual: Multi-hazard loss estimation methodology earthquake model." Washington DC: Federal Emergency Management Agency (2003).
- Hwang, H., Liu, J. B.& Chiu, Y.-H. (2001). Seismic fragility analysis of highway bridges. Mid-America Earthquake Center.
- Zhang, J., Huo, Y., Brandenburg, S. J., & Kashighandi, P. (2008). Effects of structural characterizations on fragility functions of bridges subject to seismic shaking and lateral spreading. Earthquake Engineering and Engineering Vibration, 7(4), 369-382.

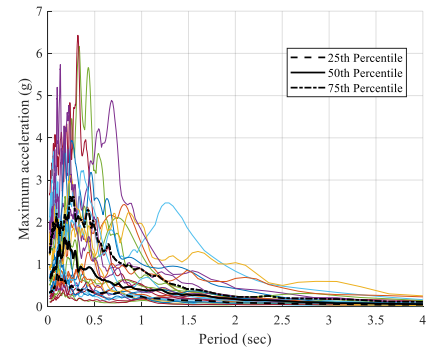


Fig. 2 Response spectra of the selected waveforms

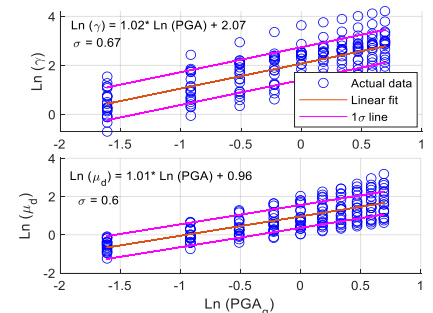


Fig. 3 PSDM for the pier and bearing

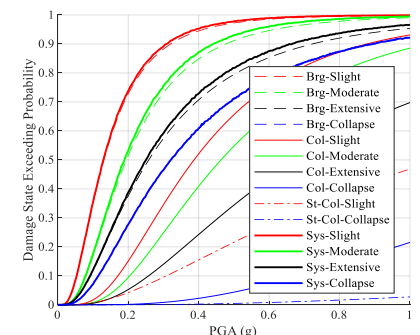


Fig. 4 Bridge components and system fragility curves