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SEISMIC VULNERABILITY ASSESSMENT OF REINFORCED CONCRETE BRIDGE PIER USING FRAGILITY CURVE

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Abstract*—Nepal being earthquake prone zone has seen many high magnitude earthquakes in recent history causing serious damages to bridge and its components. Bridges should remain serviceable even after earthquake for emergency activities and rescue operations. For assessing the seismic vulnerability of bridges, fragility curves are very important tool. Hence, this paper focuses on the use of analytical method for development of fragility curve for reinforced concrete bridge pier. Capacity of bridge is determined by nonlinear static analysis and Demand parameter is estimated using linear time history analysis. Time history data of five historic earthquakes are used to perform time history analysis. Characterization of fragility functions is done by assuming log normal distribution. It is obtained that initiation of damage in selected pier at 0.7g for Immediate occupancy level and around 1.2g for Life Safety and Collapse Prevention level. Considering a particular value of PGA as 1.5g, there is probability of exceedance the performance level IO, LS and CP are 91.60%, 20.05% and 8.52% respectively.

Keywords*—bridge, seismic vulnerability, fragility curve, lognormal distribution, performance level

I. INTRODUCTION

Highways bridges being the integral part of robust transportation network, their functionality greatly affects the whole transportation system. Safety and serviceability of bridges should remain intact after seismic event for efficient rescue operations to minimize economic loss as well as loss of life. Load transfer mechanism of bridge is such that load from superstructure is to be transferred to the ground by pier, so pier is considered as most crucial member of bridge structure.

Fragility curves are mainly used for determining effect of earthquakes in structure. For obtaining fragility curve various methods like analytical, empirical, expert opinion can be used. In this paper, analytical method is used as it has advantage in making use in the situation where there is insufficient seismic damage data. Elastic spectral [1], nonlinear static [2] and non-linear dynamic analysis [3] are some of the approaches for performing analytical method. Among these analytical methods, nonlinear static and nonlinear time history analysis are the most widely used and the most reliable methods for deriving fragility curves of structures [4].

Fragility curves has been developed over several years for its implementation in quantifying seismic risks for highways [5] and bridges [6] [7] [8] [9] [10]. For assessing seismic vulnerability of highway bridges, fragility curves are important tool. Main aim of this paper is to express fragility functions for bridge pier using analytical methods which reflects the seismic vulnerability of bridge pier.

II. METHODOLOGY

In this study, commonly used Circular hammer head Reinforced Concrete Bridge pier is selected and modeled using finite element method in SAP2000 v19.0.0 computer software. Static Nonlinear Pushover analysis is performed for determining capacity of pier and linear time history analysis is performed using five past earthquakes' ground motion for determining displacement demand.

A. Pier properties

Dead and live load from superstructure are considered as a point load at bearing level. The diameter of the pier is of two meters. Longitudinal girders are simply rest on elastomeric bearing. Reinforcement detail and the model of bridge pier are shown in Figure 1 and Figure 2 respectively. Pier bottom is modeled as fixed

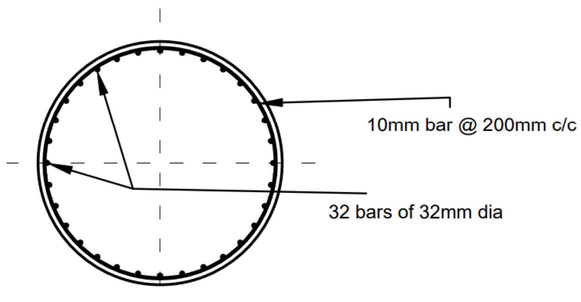

Figure 1 Reinforcement detail of pier column

support not permitting displacement and rotation in any direction.

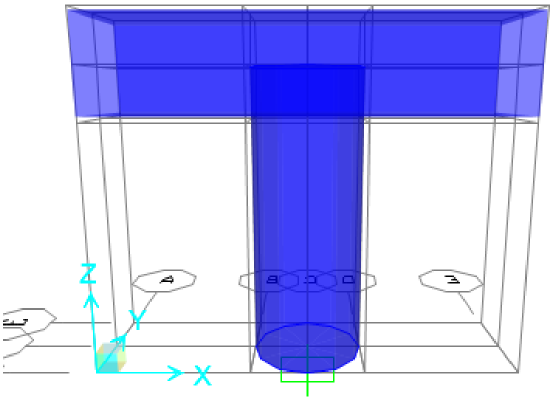

Figure 2 Finite element model of pier

B. *Ground Motions*

Five different ground motions are employed in the analysis among which one is Gorkha earthquake, 2015 and other are historic earthquakes taken from PEER database. Selected ground motions are of different PGA values from which response of structure for different PGA is captured. Detail of the ground motion selected are shown in Table 1.

C. *Fragility Functions*

The fragility or probability of failure (P_f), that the seismic demand (D) exceeds the structural capacity (C) can be described as below. The probability condition on a chosen intensity measure (IM) which represents the level of seismic loading.

$$P\{D \geq C/IM\} = P\{C-D \leq 0, IM\} \quad (1)$$

This probability for a given damage state is modeled as a cumulative lognormal distribution. For structural damage, given the spectral displacement, S_d, the probability of being in or exceeding a damage state, ds, is modeled as:

$$P[ds|S_d] = \phi\left[\frac{1}{\beta_{ds}} ln\left(\frac{S_d}{S_{d,ds}}\right)\right] \quad (2)$$

where:

$S_{d,ds}$ is the median value of spectral displacement at which the building reaches the threshold of the damage state, ds,

β_{ds} is the standard deviation of the natural logarithm of spectral displacement of damage state, ds, and

Φ is the standard normal cumulative distribution function.

Table 1 Detail of ground motions selected for time history analysis

Ground motions	Station	PGA(g)
Northridge , 1994	090 CDMG STATION 24278	0.568
Kocaeli, 1999	YARIMCA(KOERI330)	0.204
Kobe, 1995	KAKOGAWA(CUE90)	0.344
ChiChi, 1999	TCU045	0.181
Gorkha, 2015	Sanothimi Bhaktapur	0.153

III. Results and Discussions

A. *Static Pushover Analysis*

Nonlinear static pushover analysis is performed on the model and capacity of pier for different performance level is determined as shown in Table 2.

Table 2 Capacity of Bridge pier

Performance level	Top displacement, mm
Immediate occupancy (IO)	60.72
Life safety (LS)	105.72
Collapse Prevention (CP)	120.72

B. *Linear Time History Analysis*

All five selected ground motion are used to perform time history analysis from which displacement time histories of bridge pier are obtained. The time history response for Northridge earthquake is shown in Figure 3 and maximum displacement from all earthquake are shown in Table 3.

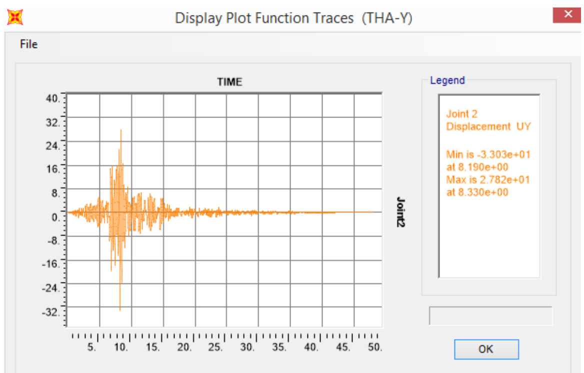

Figure 3 Displacement time history of pier for Northridge earthquake

Table 3 Result of Time History Analysis

Earthquake	Maximum Top Displacement (mm)
Gorkha	3.169
Chichi	4.769
Kocaeli	8.713
Kobe	11.52
Northridge	26.14

C. Fragility Curve

Capacity and Demand are determined from Static Nonlinear Analysis and Linear Time History Analysis respectively. These data are used for deriving analytical fragility curves. Fragility curves are tools for determining the conditional probability of failure or probability that structural demand caused by various levels of seismic motions exceeds the capacity of the structure to resist a given damage state. Displacement demand are calculated for different value peak ground acceleration (PGA) using equation obtained from regression analysis which is

Top Displacement = 59.322*PGA-3.2818 (3)

To get continuous curve PGA values are subdivided from 0.05g to 2g at the interval of 0.05g. The values of probability of being the structure in certain performance level is calculated using Equation (2). Three performance level namely Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) for which probability of exceedance versus PGA are plotted as shown in Figure 4.

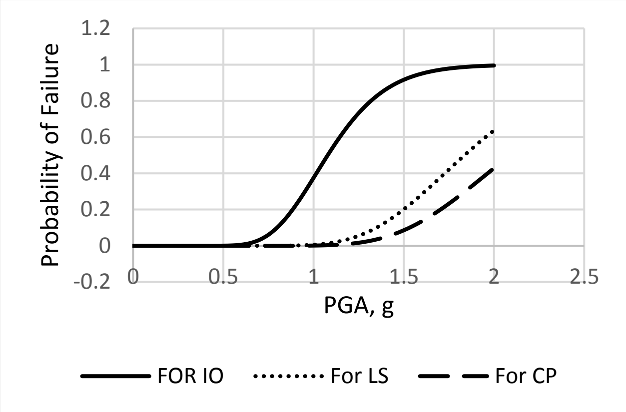

Figure 4 Fragility Curve

Hence fragility curves can be used for efficient expression of seismic vulnerability of highway bridges and other structures.

IV. CONCLUSION

From obtained fragility curve for bridge pier, it can be concluded that

- For selected bridge pier, initiation of damage occurs at 0.7g for Immediate occupancy level and around 1.2g for Life Safety and Collapse Prevention level. So, the selected bridge pier is overdesigned.
- Considering particular value of 1.5g for PGA, the probability of exceedance of performance level of IO, LS and CP are 91.60%, 20.05% and 8.52% respectively.
- Probability of exceedance of certain performance level for different value of PGA can be obtained from fragility curve.

V. LIMITATIONS

Following assumptions are made while performing analysis:

- The effect of superstructure and live load is considered by applying vertical point load at bearing level.
- Soil structure interaction is not considered during analysis. Foundation is modeled as fixed support at the bottom of pier.
- Pier cap is assumed to be of uniform depth but in actual it is tapered in cantilever portion. Failure mechanism and response of pier cap are not considered in analysis.

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