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SEISMIC PERFORMANCE ASSESSMENT OF A TWO SPAN CONCRETE BRIDGE BY APPLYING INCREMENTAL DYNAMIC ANALYSIS

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ABSTRACT

Bridges are key elements of transportation systems. Previous seismically induced damages to these structures revealed the necessity of seismic vulnerability assessment of them according to performance-based earthquake engineering philosophy. The purpose of this study is applying Incremental Dynamic Analysis for seismic assessment of a typical two span concrete bridge according to this philosophy. Incremental dynamic analysis consists of scaled time history analyses to gain structural performance under different levels of ground motion excitation. 2D model of the bridge structure was constructed in Open System for Earthquake Engineering Simulation. Peak Ground acceleration and column curvature ductility factor were chosen as intensity measure and seismic performance indicator, respectively. Eight time history records of past earthquakes were scaled and applied incrementally to the numerical model to evaluate seismic performance of the bridge. Damage states were defined as slight, moderate, extensive and collapse state. The resulted curves can be used to estimate mean annual frequency of exceeding each damage state.

Keywords: Damage states; non-linear time history analysis; seismic performance evaluation; two span concrete bridge; performance-based earthquake engineering.

1. INTRODUCTION

Observed damages in past earthquakes proved that bridges are seismically vulnerable. Due to significant cost of constructing bridges and the need to bridges' immediate operation, a performance-based earthquake engineering methodology is necessary in design and assessment of the bridges. Such methodology requires accurate prediction of seismic capacity of the bridges and seismic demand associated to them. To achieve this goal, a

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newly born analysis method is proposed by Vamvatsikos and Cornell [1] called incremental dynamic analysis (IDA).

In recent studies on seismic performance assessment of bridges, Nielson and DesRoches [2] considered multiple vulnerable components in steel and concrete girder bridges using non- linear analytical models, and a suite of synthetic ground motions, and Choe et al. [3, 4] applied nonlinear static analysis to consider possible capacity reduction and fragility increase of a typical single-bent bridge in California with RC columns in marine splash zones.

In current study, IDA is applied to reach the relationship between the seismic capacity and the demand of the structure and estimate the structural performance accurately. The procedure consists of performing non-linear time history analyses to a structural model under a suit of scaled ground motion records with different levels of intensity. IDA curve is a plot representing the relationship between an intensity measure, (IM), such as PGA or Sa, and a damage parameter (DM), such as displacement [1].

IDA curves provide appropriate result formats which can be integrated with can be integrated with hazard curves to reach mean annual frequency of exceeding predefined damage states and calculate equivalent annual loss of a bridge system subjected to different seismic scenarios [5] or developing fragility curves of the bridges as another means of achieving the probability of exceeding different damage states.

2. BRIDGE DESCRIPTION

A typical two-span continuous, post-tensioned bridge, designed based on Single-Mode Spectral Method of the 15th Edition of the AASHTO Standard Specifications for Highway Bridges [6], was chosen from Example No. 1 of Federal Highway Administration (FHWA) Seismic Design of Bridges Series [7]. It has three-column integral bent and spread footings, as shown in Figure1 and Figure2 Column reinforcement details are illustrated in Figure3, as well.

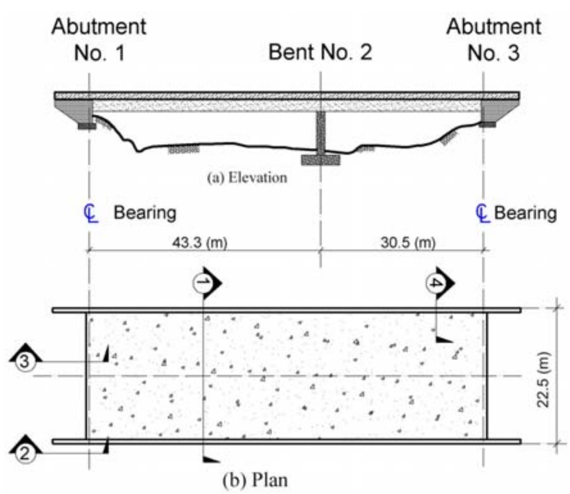

Figure 1. Plan and elevation view of the selected bridge [7]

Considering weight of the superstructure and half of the weight of columns, the bridge has a seismic weight of 21.7 MN. The superstructure cross-sectional has an area of 11.15 m^2 with second moment of area of 440.2 m^4 and 4.96 m^4 about the strong and weak cross-sectional axes, respectively. The cross-sectional area of the cap beam is 2.32 m^2. The columns are circular with radius of 0.65 m and longitudinal reinforcement ratio of 1.9%. Concrete is assumed to have a nominal 28-day compressive strength of 27.6 MPa and a modulus of elasticity of 24,831 MPa and the reinforcement has a nominal yield strength of 413.9 MPa.

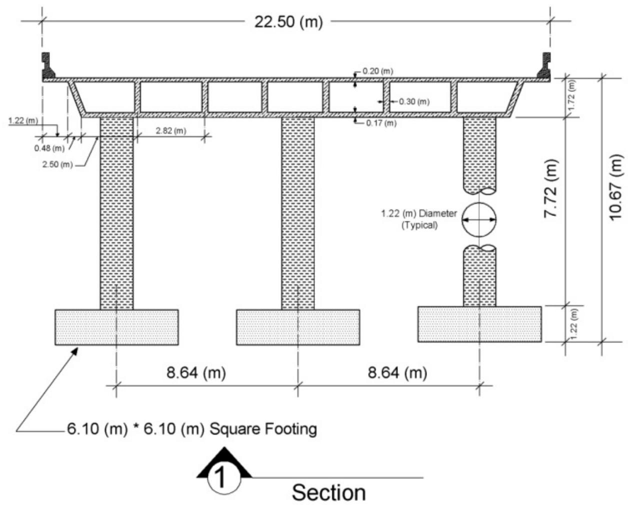

Figure 2. Cross-section of the selected bridge [7]

3. BRIDGE MODELING

For analytical modeling of the bridge, Open System for Earthquake Engineering Simulation (OpenSees) program [8] is used. OpenSees is an open-source finite element software for earthquake engineering [9], which lets modeling and computational simulation in earthquake engineering according to performance-based earthquake engineering (PBEE) methodology introduced by the Pacific Earthquake Engineering Research Center (PEER).

OpenSees is a convenient tool for current study as it contains different combinations of elements and materials, it makes wide range of solution procedures and algorithms available for nonlinear analysis and it is completely programmable.

According to primarily three dimensional modeling of the bridge, shown in Figure3, to assess its performance in longitudinal and transverse direction, the natural period of longitudinal mode is less than one second and the modal participating mass ratio of this mode is greater than 90%. Finally a two dimensional model is conducted to perform IDA in longitudinal axis.

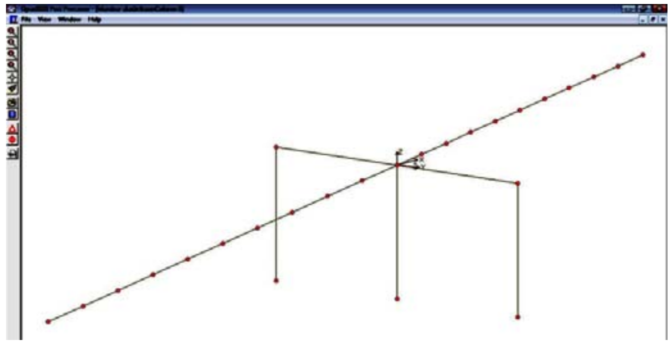

Figure 3. The 3D model of the bridge in Opensees

The OpenSees model of the bridge is constructed of linear beam column elements representing the superstructure and nonlinear column fiber section elements for the columns, as seen in Figure4. The orientation of the model is such that the global x, and y directions are in the longitudinal and directions of the bridge, respectively. Nodes and elements representing superstructure pass through mid-depth of it and nodes and elements demonstrating columns are located at centerlines of them. Lumped masses are defined at the tenth points of each span. The superstructure is assumed to behave linearly and P-delta effects are included in the analysis.

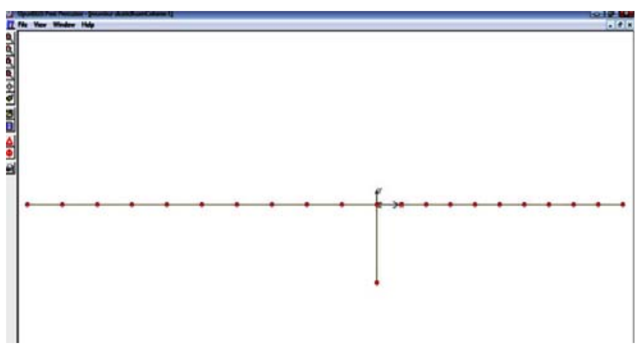

Figure 4. The 2D model of the bridge in Opensees

The bridge columns are assumed to behave nonlinearly and defined as fiber section elements. For core and cover concrete, Concrete01 material in the Opensees is used which is based on uniaxial Kent- Scott-Park concrete model and bilinear Steel01 material in the Opensees is used for the reinforcements. Concrete core is defined by 8 slices and 7 layers and concrete cover is defined by 8 slices and two layers. This is the minimum number of layers which results in accurate output.

Abutment is modeled by using springs in longitudinal axis of superstructure and fixed supports against rotation and vertical translation. The stiffness of the longitudinal springs is calculated based on Caltrans bridge design specifications [10], assuming 76 m of glacial sand and gravel. Soil-structure interaction is also considered by horizontal, vertical and rotational springs with stiffness calculated according to study of Lam et al. [11] in column supports.

4. PERFORMING ANALYSES

4.1 Ground Motion Selection

The next step to perform IDA is selecting ground motions which can be representative of possible seismic hazards [12]. Therefore, 10 time history records with moment magnitudes between 6.5 and 7 are selected which are obtained from the PEER Strong Motion Database [13]. Selected ground motions are represented in Table 1.

Table 1: Selected ground motions

No	Event	Station	Year	M	R (km)	PGA (g)
1	Tabas	Dayhook	1978	7.4	1309	0.406
2	Imperial Valley	Compuertas	1979	6.5	32.6	0.147
3	Imperial Valley	Compuertas	1979	6.9	25.8	0.259
4	San Fernando	LA, Hollywood Stor Lot	1971	6.6	21.2	0.174
5	Imperial Valley	El Centro Array #12	1979	6.5	18.2	0.143
6	Imperial Valley	Cucapah	1979	6.5	23.6	0.309
7	Northridge	LA, Hollywood Storage FF	1994	6.7	25.5	0.358
8	Imperial Valley	Chihuahua	1979	6.5	28.7	0.254
9	Loma Prieta	Halls Valley	1989	6.9	31.6	0.103
10	San Fernando	LA, Hollywood Stor Lot	1971	6.6	21.2	0.21

Table 2: Description of damage states [14]

Damage state	**Degree I, Slight/minor damage**	**Degree II, Moderate damage**	**Degree III, Extensive damage**	**Degree IV, Complete damage**
Description HAZUS 97	Minor cracking and spalling to the abutment, cracks in shear keys at abutments, minor spalling and cracks at hinges, minor spalling at the column (damage requires no more than cosmetic repair) minor cracking to the deck	Any column experiencing moderate cracking and spalling (column structurally still sound), any connection having cracked shear keys or bent bolts, or moderate settlement of the approach	Any column degrading without collapse (column structurally unsafe), any connection losing some bearing support, or major settlement of the approach	Any column collapsing and connection losing all bearing support, which may lead to imminent deck collapse

4.2 Defining damage states

Another important step in IDA is selecting seismic damage indicator of the bridge structure. Previous studies proposed different damage indexes, from which drift of the column is the most common one. Table 2 shows qualitative descriptions of damage states derived from

HAZUS 97 [14]. According to these definitions, in current study, drift of the column is used based on study of Mander and Basoz [15] with limit states of 0.007 for slight damage, 0.015 for moderate damage, 0.025 for extensive damage and 0.05 for complete damage.

Advanced hunt & fill algorithm is applied in scaling each record to cover the entire range of structural response, from elastic state to yielding and failure in order to minimize the number of analyses, which involves rapidly increasing levels of PGA until the bridge reaches its ultimate state, and then additional analyses at intermediate PGA-levels to increase the accuracy at lower levels of PGA [16]. IDA curves for the eight selected records are shown in Figure5.

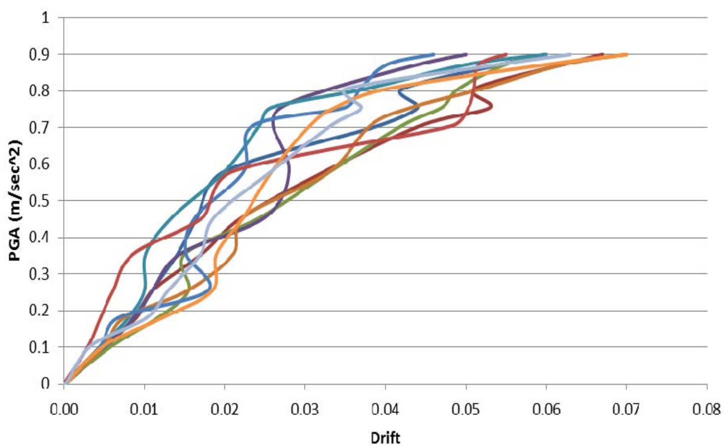

Figure 5. Derived IDA curves of time-history records

5. DISCUSSION AND CONCLUSION

Generated IDA curves associated to each of the eight records are shown in Table 2 and bounds of damage states are defined and added to the graph. The IDA curves demonstrate a wide range of behavior from record-to-record in different scale factors. Therefore, a summary of the curves is needed to judge about behavior of the bridge in a specific PGA.

There are different ways of summarizing the IDA curves, from which the probability distribution is selected to interpret the results in meaningful statistic curves. Applying the spline interpolation between data, at each level of intensity, the central values of the structural demand, μ (herein, the mean), plus the $\mu \pm 1\sigma$ (16th and 84th percentile) are calculated to account for the diversity between results of different records by relating the possible response to a measure of dispersion (herein, the standard deviation). The resulted graph is illustrated in Figure6. As an example to interpret the results, given PGA=0.6g, 16% of the records result in drift less than 0.022, 50% result in drift less than 0.027 and 84% result in drift less than 0.032. The value for other levels of intensity can be extracted from Figure7, easily.

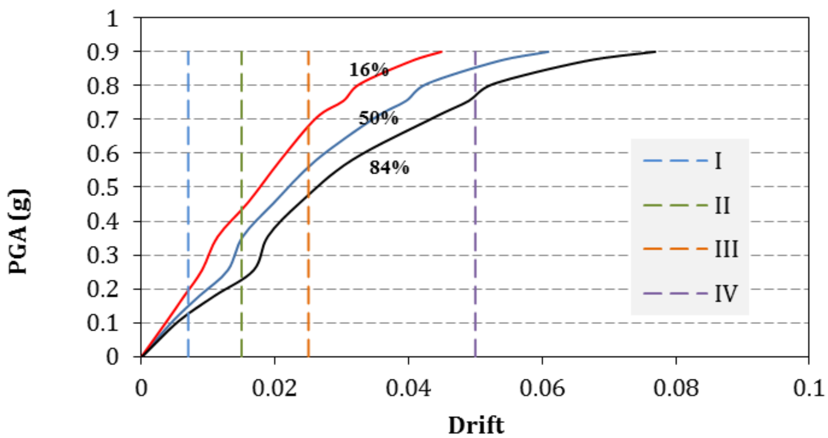

Figure 6. Summarized IDA curves

Among different seismic analysis methods which can be used to assess seismic performance of a bridge structure, in this study IDA has been applied, as it has some advantages against previous methods which are in summary: better understanding of the range of demands versus the range of levels of a ground motion record, assessing structural behavior under severe ground motion levels, gaining a better pattern of structural response under sever ground motion levels, estimating dynamic capacity of the global structural system and comparing the output under different ground motions [1].

In the described procedure to generate IDA curves, the need to rerun for each intensity measure is resolved by interpolating the discrete points and using the hunt & filling algorithm minimizes the required number of analyses, thus making the procedure less time consuming.

The result of this study can be used as the input to seismic fragility analysis of the bridge in generating fragility curves to gain the possibility of exceeding each damage state. Furthermore, to develop this study, more seismic damage indicators of the bridge, such as abutment displacement, can be taken to account.

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