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Seismic Performance Evaluation of Urban Bridge using Static Nonlinear Procedure, Case Study: Hafez Bridge

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Abstract

Bridges as key elements in the lifeline of each country or urban transportation play a fundamental role economically, politically and militarily. The possibility of severe damage to bridges that are subjected to earthquake leads to the necessity of seismic evaluation of existing bridges, particularly those which have been either designed regardless of earthquake effects or according to moderate earthquake-resistant consideration. The assessment of safety and stability of these bridges while passing increasingly traffic is of high importance in their seismic performance. In this study, an urban steel bridge in metropolitan Tehran which is accounted for as an important structure in the city transportation is studied using nonlinear static procedure at two hazard levels. The hazard levels were obtained by the use of probabilistic seismic hazard analysis (PSHA). Three-dimensional model of the mentioned bridge is developed and analyzed using nonlinear static procedure (NSP) thus its seismic performance is evaluated accordingly. The results show the vulnerability of this steel bridge during earthquake and the necessity of retrofitting for improving its seismic behaviour.

Keywords: urban bridge; nonlinear static analysis; seismic performance; PSHA

1. INTRODUCTION

Bridges as one of the important man-made structures play a vital role in everyday life of the people of metropolitan city. Serviceability of bridges is of high importance in order to help injured people and required transportation, specially after earthquakes. Strong ground motions in the past decade in the densely populated area had great impacts on many bridges specially those designed according to older codes and demonstrated that these structures are vulnerable. In order to verify current codes which have had great changes compared with old ones and also recognizing of possible deficiencies, the careful study of bridges performance in the recent earthquake is necessary. Therefore, it’s preferable to investigate the

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structures that play a main role in everyday life. Following the popularity of the performance-based design philosophy in civil engineering [Ghobarah, 2001] as a powerful seismic performance evaluation tool, the static nonlinear pushover analysis has become a new trend due to its simplicity compared with the conventional dynamic nonlinear time–history analysis procedure (Saiidi and Sozen, 1971; Fajfar and Gaspersic, 1996; Bracci et al. 1997; Krawinkler and Seneviratna 1998; Usami et al. 2001; Chopra and Goel 2002; Chintanapakdee and Chopra 2003; Zheng et al. 2003; Zhihao et al. 2004; Ranjit et al. 2002] and recommended this method for seismic evaluation in some provisions [SEAOC 1999; ATC 1996; FEMA 356 2000]. In this research the focus is on the investigation of seismic behavior and vulnerability of Hafez-Bridge using nonlinear static procedure. The bridge is located in metropolitan Tehran and is considered as an important structure.

2. SPECIFICATION OF THE BRIDGE

2.1. Geometrical Specifications

The steel bridge of Hafez is 768m in length that has 30 spans. The longest span is 28.5m. The bridge is 10.5 m wide that should have been designed with three lanes for passing trucks but according to available documents the deck for passing trucks (hs-20-44 & slw30) has been calculated in one or two lanes. The columns are cantilever which have variable height above foundation (2.4-5.43 m). The side view of the bridge has been shown in Figure 1.

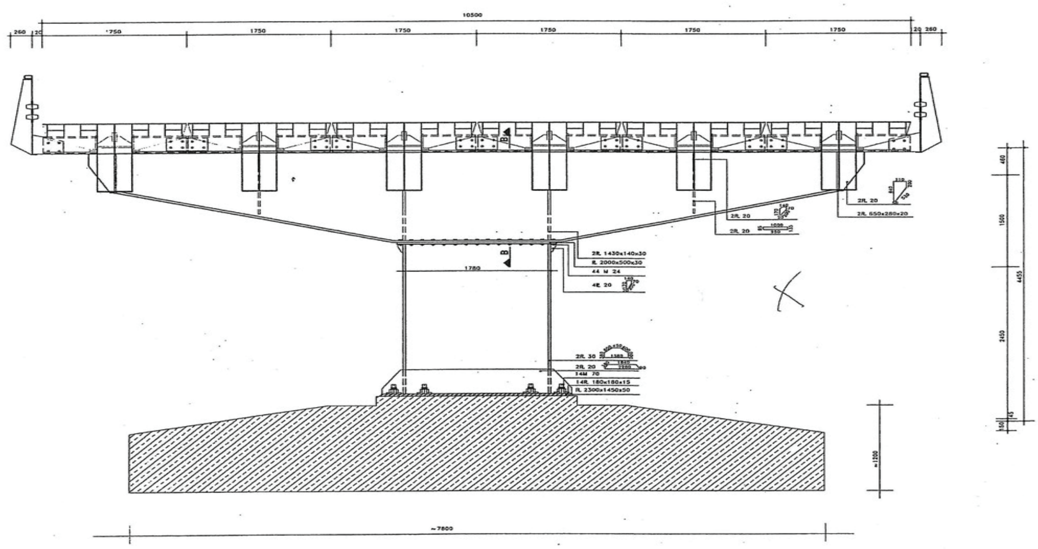

Figure 1: Side view of the bridge

Each of the longitudinal beams is on the neoprene (Figure 2) and the decks on pile-cap. The mentioned bridge includes rectangular columns with dimensions 1.78x0.46 m.

2.2. Material Specifications

Material specifications are mentioned below:

Concrete: F_c=250 kgf/cm^2, E= 253456 kgf/cm^2, υ=0.2; Steel: ST-52, Fy=3400 kgf/cm^2, E= 2038902 kgf/cm^2, υ=0.3

3. MODELING

To model and analyze this bridge, SAP2000 (SAP 2000, Structural Analysis Program 2005) has been used. The model is 3D and the processes of analysis and evaluation are done using this 3D model.

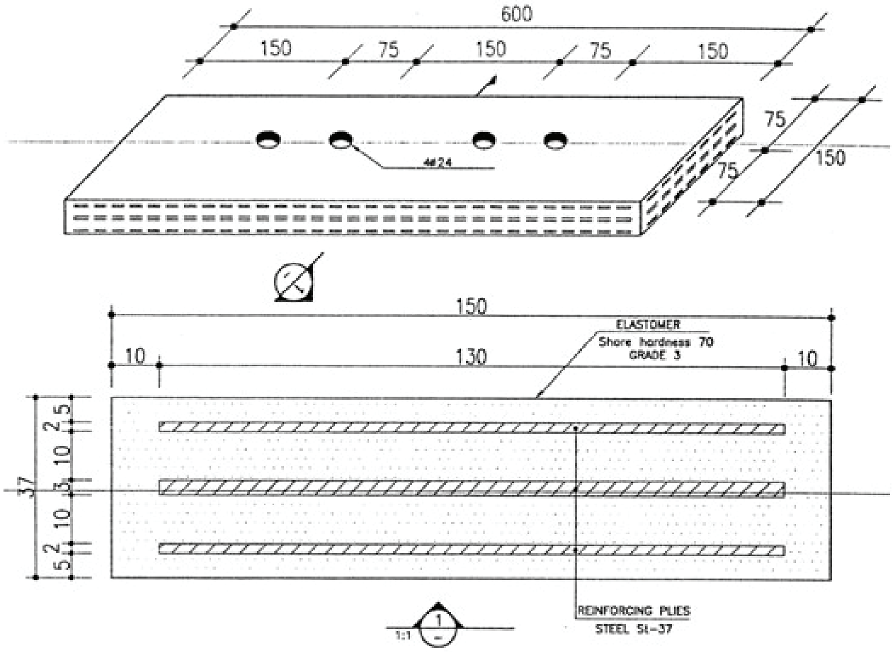

Figure 2: Neoprene of the deck

3.1. Deck modeling

An important technique in deck modeling is regarding the applied diaphragm. These elements prevent beams from individualistic movement and provide required torsion stiffness of the decks. If these diaphragms are not considered, the dominant vibration mode will be torsion-mode. As clear in the detailed plans the bridge is lacking in diaphragm.

3.2. Connection of Deck to Pier

Concrete beams are located on elastomeric support and connected with pile-cap. This element is flexible and with its low shear stiffness has resistance against horizontal movement of slab. The treatment of the elastomer is as follows: at first stage the horizontal stiffness is equal to displacement curve of neoprene. In case the force increases, elastomer resist as much as possible and then is ruined and the only resistant forced will be the friction force. Regarding that the neoprene of this bridge is useless it must be replaced.

3.3. Piers Modeling

Piers have been modeled as equivalent-column, assignment of plastic hinges from the table related to the columns are applied according to FEMA 356.

4. LOADING

4.1. Gravity Loading

The weight of deck including beam, slab, concrete ramp, diaphragm, balustrade, pile-cap and asphalt considered to be 354 kg/m^2. Also live load has been considered as uniform load according to code No. 139 (Bridge loading code). See Figure (3).

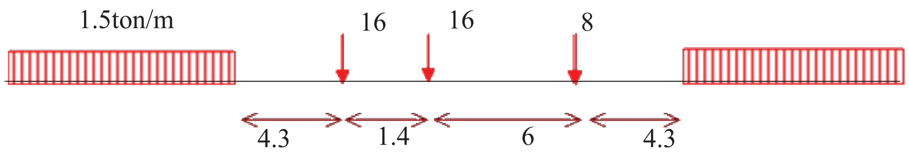

Figure 3: Gravity loading

4.2. Seismic Loading

According to seismic code of bridges design [Bridge loading code], lateral force of earthquake can be determined based on natural period of vibration of structure (bridge) and response spectra. This force is distributed based on main shape mode and applying one of the familiar methods. The lateral force of earthquake on the deck can be calculated as Eq (1).

$$F=CW\ ,\ C = ABI/R \tag{1}$$

Where, W: weight of deck plus x% live load, F: deck force which is applied to mass center, C: earthquake coefficient, A: design acc, I: bridge importance factor, B: response spectrum coefficient, R: behavior factor

In calculation of lateral force of earthquake in case the value of live load is less than half the dead load, the live load is not accounted. Otherwise, two-third of total dead and live load of deck is considered in the calculation. In this research the live load of deck has not been considered.

4.3. Simultaneous Effects of Earthquake Components

Elements and components shall be evaluated for forces and deformations associated with 100% of the design forces in the X direction plus the forces and deformations associated with 30% of the design forces in the perpendicular horizontal Y direction and vice versa. (FEMA 356, 2000).

4.4. The Numbers of Vibration Mode

The numbers of modes used for modal analysis should be at least 3-times of numbers of spans. Also the numbers of modes are restricted to 25 as mentioned in AASHTO-DIV (AASHTO LRFD 2006). The first 15 modes of vibration are put into account for this bridge.

4.5. $p-\Delta$ Effect

Elements and components of structures shall be designed or verified for $p-\Delta$ effects, defined as the combined effects of gravity loads acting in conjunction with lateral drifts due to seismic forces (FEMA 356, 2000). In this research $p-\Delta$ effect has been considered in the analysis.

5. SPECIFYNIG ANALYSIS PARAMETERS

5.1. Rehabilitation Objective

The mentioned bridge is considered as very important structure and the rehabilitation objective according to AASHTO (AASHTO LRFD 2006), FHWA (FHWA 1995) and CALTRANS (Caltrans 2006) was selected as “fair goal”.

5.2. Earthquake Hazard Level

In this paper the result of a probabilistic seismic hazard analysis which has been done in center of Tehran in two hazard levels (HL1 and HL2) has been used (Hamidi, 2007). Hazard level 1 is determined based on 10% earthquake probability of exceedance in 50 years where the return period equals 475 years. Hazard level 2 is determined based on 2% earthquake probability of exceedance in 50 years where the return period equals 2475 years. The obtained design spectra and spectra parameters are shown in Figure (4) & Table (1) respectively.

Table 1: Spectra parameters

	10% (HL1)	2% (HL1)
Ca	0.38	0.64
Cv	0.5	0.8

5.3. Nonlinear Static Procedure (Pushover Analysis)

Following the popularity of the performance-based design philosophy in civil engineering, as a powerful seismic performance evaluation tool, the nonlinear static procedure has become a new trend. This procedure is now widely used in engineering practice to predict seismic demands in building structures (Kalkan and Kunnath, 2007). Some new methods have been developed step by step such as Modal Pushover Analysis (MPA) (Chopra and Goel, 2002) and Adaptive Pushover Procedure (APP) (Antonio and Pinho, 2004). According to FEMA 356, for structures with rigid diaphragms, the mathematical based model of the structure should undergo the monotonically increasing lateral forces or displacements until either a target displacement is reached or the structure collapses.

5.4. Load Combinations

The recommended load combinations for bridges which are used in this paper are:
Gravity Upper bound: Q_G=1.1(Q_D+Q_{SI})+0.5Q_L , Gravity Lower bound: Q_G=0.9(Q_D+Q_{SI}) and
Q= Q_G±Q_E, Where: Q_D=dead load, Q_L=live load, Q_{SL}=weight of upper structure, Q_E=seismic load

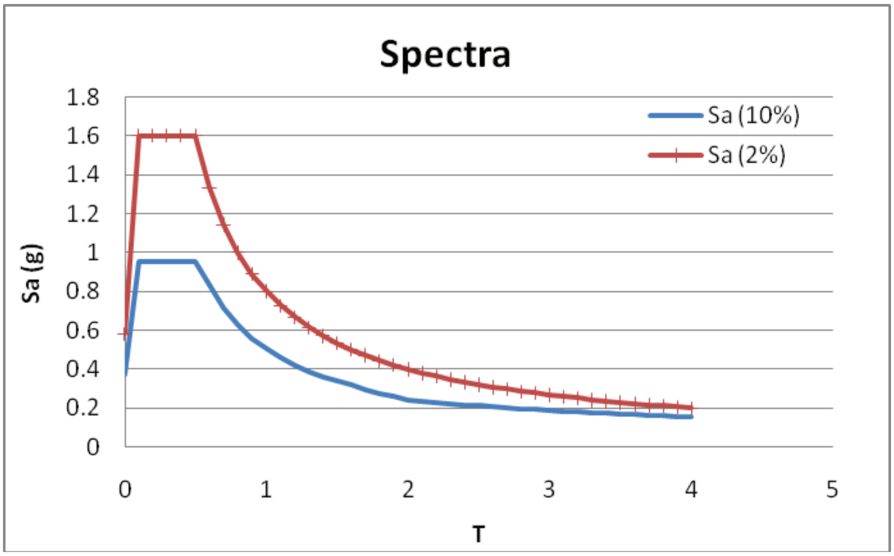

Figure 4: Design spectra based on PSHA (Hamidi, 2007).

6. RESULTS

The mentioned bridge has been analyzed and investigated for two hazard levels in both X & Y directions. The results have shown that the bridge is vulnerable when subjected to earthquake loading in both hazard levels. Capacity spectrum diagram of the bridge at HL1 and X-Direction has been shown in Figure (5) as a sample.

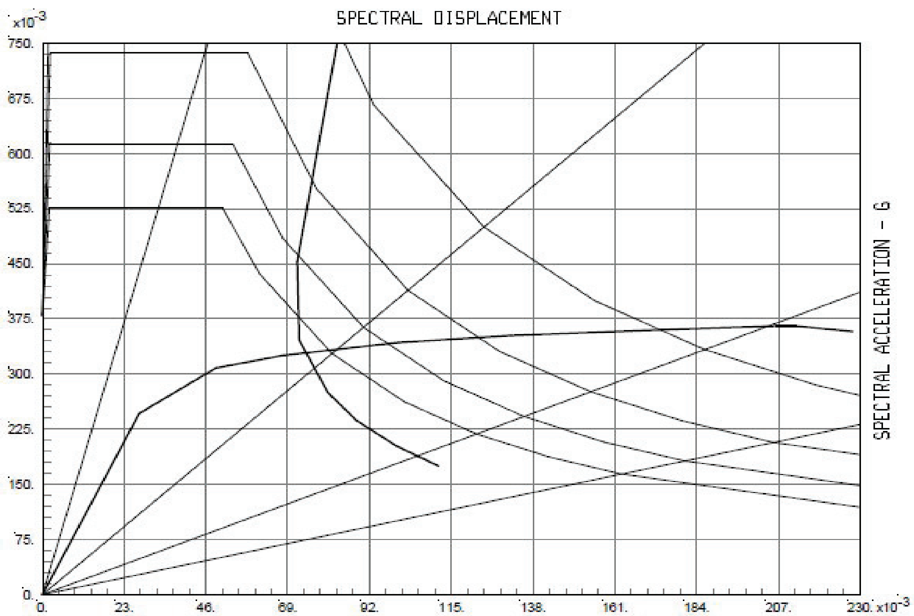

Figure 5: capacity spectrum of the bridge at HL1 & X-Direction

7. CONCLUSIONS

- 1. The results of analysis have shown the vulnerability of the studied bridge.
- 2. The vulnerability of the bridge is evident at both X & Y directions.
- 3. The piers have shown brittle behavior at Y-direction.
- 4. Bridges, those designed according to older codes are considerably expected to be vulnerable due to earthquake recurrence and should be retrofitted accordingly.
- 5. For improving the performance of the bridge, use of lateral diaphragm is recommended.

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