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Performance of different seismic isolation systems in highway bridges subjected to near-fault earthquakes

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ABSTRACT: Implementation of base isolation bearings is one of the effective methods to retrofit of bridges. In this study, performance of different seismic isolation systems under near-fault earthquakes is compared by applying nonlinear time history analysis of seismically isolated bridge by five different methods including Lead-Rubber (LRB), High Damping Rubber Bearing (HDRB), Single Friction Pendulum (SFP), Triple Friction Pendulum (TFP) and a typical bridge model by assuming a rigid connection between the deck and bridge piers is evaluated. Responses were estimated by performing nonlinear time history analyses by considering the main aspects of the simulation and by taking into account the nonlinear behavioral complexity of the base isolation bearing in OpenSees software. Results indicated that the frictional base isolations significantly reduce the stresses induced in the piers of bridge in comparison with the typical bridge model, and improve the seismic performance of the bridge substantially. The percentage of reduction for triple frictional pendulum and single frictional pendulum bearings reached 91% and 85%, respectively.

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1-Introduction

Near-fault earthquakes possess important features, such as [1, 2]:

1. Exhibiting the forward and backward directivity effects in the earthquake characteristics

2. Containing powerful pulses with high energy in the earthquake time history

3. Having considerable vertical ground motion component

Experimental results of Buckle et al. (2002) indicated that the critical buckling load decreases with increasing horizontal displacement and also the horizontal stiffness decreases with increasing axial load and horizontal displacement [3].

Warn et al. (2008) examined the LRB response under earthquake simulation test. Results revealed that there was a significant amplification in the vertical response of elastomeric isolator due to the vertical component of the excitation. The observed amplification was approximately in the range of 2 - 5.5 times [4]. Eröz and DesRoches (2013) found out excluding the vertical component of the ground motion in the modeling and analysis of the LRB isolator may result in overlooking a fundamental failure mode [5].

In this paper, performance of different seismic isolation systems under near-fault earthquakes is compared by applying nonlinear time history analysis of seismically isolated bridge by five different methods including Lead-Rubber (LRB), High Damping Rubber Bearing (HDRB), Single Friction Pendulum (SFP), Triple Friction Pendulum (TFP) and a typical bridge model.

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2-Bridge specifications, modeling and strong ground motion

In this study, Kurdistan Highway Bridge, located in Tehran city, was selected for the study in collaboration with Tehran municipality. The bridge is located in the vicinity of the main faults of north, east and south of Tehran. Abutments are modeled as simple support. To model the columns and bent caps of bridge piers, the nonlinear beam-column elements with fiber sections were used. In fiber sections, the uniaxial concrete material (Concrete03) element with compressive strength of confined concrete, tensile strength and nonlinear tension softening was used to model the confined concrete. Also, the uniaxial Kent-Scott-Park concrete material (Concrete01) element with degraded linear unloading/reloading stiffness and no tensile strength was used to model the unconfined concrete. To model the bridge deck, the elastic beam-column element was used in the longitudinal direction [6, 7].

In this paper, main behavioral aspects of the elastomeric bearing as listed below included in the modeling [8]:

1. Coupled bidirectional motion in horizontal directions;

2. Coupling of vertical and horizontal motion;

3. Cavitation and post-cavitation behavior in tension;

4. Strength degradation in cyclic tensile loading due to cavitation;

5. Variation in critical buckling load capacity due to lateral displacement;

Indeed main aspects of the frictional seismic isolation including [5, 9-11]:

1. The normal force changes (N) ;
2. The friction coefficient changes (μ) ;
3. The in-plane bi-directional sliding interaction ;
4. Large deformation effects (P-Δ) ;

were considered in the modeling practice of SIBs in OpenSees software [6].

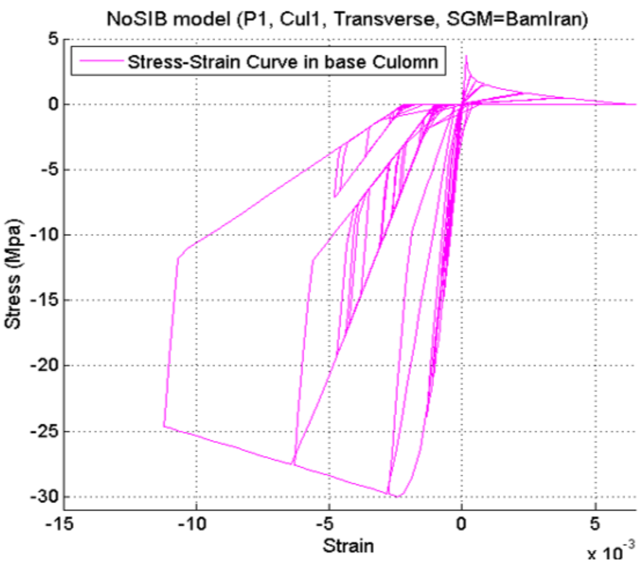
Four near-field earthquake records are selected herein. Table 1 presents the characteristics of the ground motions, including magnitude, nearest distance to the fault plane, peak ground acceleration, the shear wave velocity of the top 30 m of the subsurface profile (VS30). The selected accelerograms are compatible with soil type (II). Moreover, selected records were scaled according to the seismic hazard level of the bridge site.

3- Results and Discussion

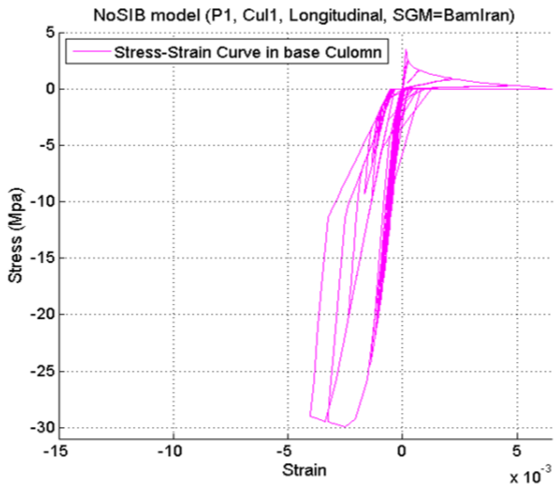
Figure 1 illustrates the pier hysteresis curve of the typical bridge model under Bam (2003) strong ground motion record. Also, Figures 2 and 3 illustrate the stress-strain curve of the SIB model by frictional and elastomeric seismic isolator, respectively. It can be seen that the column behaves nonlinear and experience large stress and strain.

Table 1. Specification of the ground motions used in the analyses

Earthquake	Year	M_w	Station Name	R_{jb} (km)	PGA (g)
Northridge-01(JGB)	1994	6.69	Jensen Filter Plant	0.0	0.995
Loma Prieta	1989	6.93	Saratoga - Aloha	7.58	0.514
Bam (Iran)	2003	6.6	Bam	0.05	0.808
Manjil (Iran)	1990	7.37	Abbar	12.55	0.538

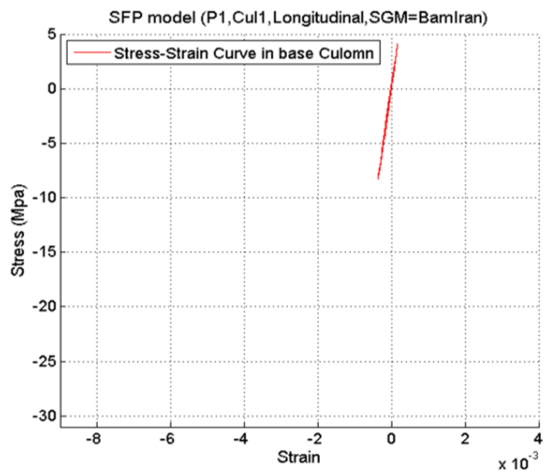


(a)



(b)

Figure 1. The pier stress-strain curve of the typical bridge model in the (a) transverse and (b) longitudinal direction.



(a)

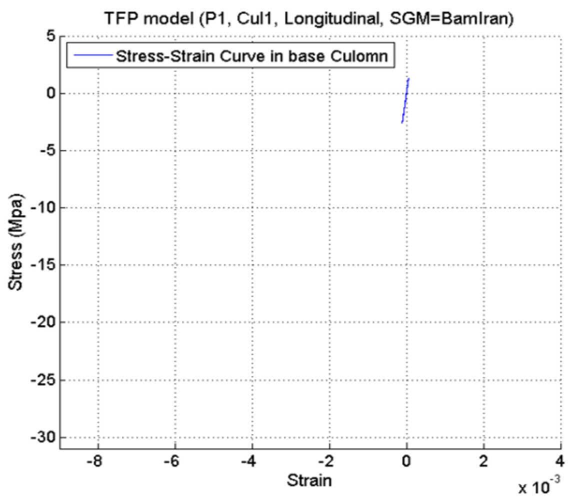
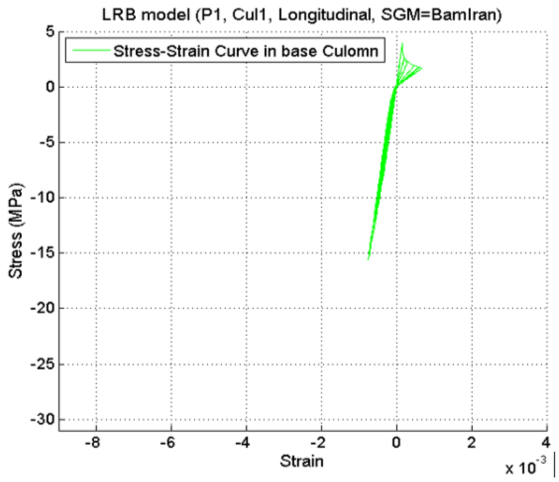
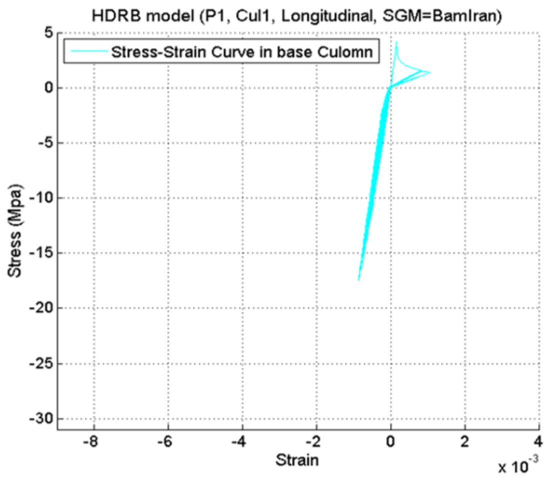


Figure 2. The pier stress-strain curve of the SIB by frictional seismic isolator (a) SFP and (b) TFP.



(a)



(b)

Figure 3. The column stress-strain curve of the SIB model by elastomeric seismic isolator, (a) LRB and (b) HDRB isolator.

According to hysteresis curve of the SIB model, it can be seen that stresses induced in the piers of the SIB model by elastomeric seismic isolator results in nonlinear behavior, but, in case of frictional seismic isolator it can be seen that the bridge piers behave linearly.

4-Conclusions

1. Shear stiffness of the elastomeric isolators decreases by increasing the axial load (P) and reducing the buckling load capacity ($P`_{cr}$) as a parabolic.
2. Although non-linear behavior was observed in SIB with elastomeric isolator, all the seismic isolation bearings reduced the stresses of the bridge piers and cause considerable improvement in the bridge seismic performance level. This stress reduction and associated improvement in the seismic performance level of the SIB with frictional isolator were much more tangible in the case of TFP isolator bearing.
3. The maximum reduction of stress in seismically isolating bridge with TFP was about 91% and the average of reduction was evaluated about 89%. For the seismically isolated bridge with SFP the values were about 85% and 81.5% respectively.

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