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Seismic Control of Skewed Highway Bridge Using Seismic Control System

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Abstract*— Highway bridges play a vital link role in surface transportation network, and their failures not only cause disruption of service but also danger people life. Seismic base isolation is an important technique that is used for reduce the seismic vulnerability by decreasing the seismic demand instead of increasing the seismic capacity. Present work deals with study of response of bridge using seismic control systems. For present study, a two-span prestressed concrete box girder highway bridge is considered and analyzed for seismic forces using SAP2000 software. The seismic response and behavior of Box Girder Bridge is studied by linear time history analysis using Newmark's beta method. For the analysis four different ground motion data selected and scaled for target spectra as per zone IV. The highway bridge is isolated with Lead Rubber Bearing (LRB). The response of bridge system under earthquakes has been compared with the corresponding bridge with and without the isolation system. It is observed that LRB is highly effective for controlling not only the seismic response of the bridge but also include the structural response on the cost of slight increase in the displacement of the deck.

***Key Words*— skewed Highway Bridge; lead rubber bearing; time history analysis**

INTRODUCTION

Bridges are widely present in today's built environment, carrying highways through cities and Countries and serving as the transportation lifeline of modern civilization. It provokes many benefits for the people and especially, promotes inter-regional trades and reduces traffic crowding and emergency movement. Past year have seen number of calamitous failures of Highway Bridge due to strong earthquake ground motions such as Northridge earthquake 1994, Kobe earthquake 1995 and chi-chi earthquake 1999 [Panchal and Jangid, 2008]. Due to seismic damage in the bridge tends to stop the transportation system and it harms economy ruinously. Seismic isolation appeared as one of the important techniques to protect the structures like buildings, bridges etc., from the destructive effects of earthquakes. Basically, the main purpose of base isolation system is to decouple the structure from the seismic ground motion which results in reducing the structural damages. Seismic isolation techniques minimized the seismic responses on the highway bridge by increasing the fundamental period of the bridge and increased energy dissipating capability [Kunde and Jangid, 2006].

In the past numerous research and studies were carried out for investigating the effectiveness of seismic isolation devices for seismic resistant design of bridges. Panchal and Jangid (2008) conducted a numerical studied of bridge isolated by the variable curvature friction pendulum system (VCFPS) and found that under near fault ground motion, the VCFPS is quite effective in controlling the seismic response of bridge within desirable range. Chavan and Mrunal (2015) investigated the effect of seismic isolation on the seismic response of bridge components. In their study, first existing bridge with Elastomeric bridge bearing is modeled and analyzed to get the seismic response of bridge components and then this result are compared with Elastomeric isolator in place of elastomeric bearing. They concluded that elastomeric isolator reduces significant amount of the base shear as compared to Elastomeric bearing. Kunde and Jangid (2003) presented a state-of-the-art review on the behavior of isolated bridge to seismic excitation which includes the literature on theoretical aspects of seismic isolation, parametric behavior of base isolated bridge. Jangid (2004) presented the seismic response of bridge isolated by lead rubber bearing to bidirectional seismic excitation and also investigated the effectiveness of LRB by comparing the response of isolated and un-isolated bridges which showed that the bidirectional interaction of the restoring forces of the LRB has significant effect on seismic response of the isolated bridge. Haque, *et. al.* (2010) evaluated the seismic responses of a base-isolated highway bridge with different isolators. They analyzed a multi-span continuous seismically isolated highway bridge with three types of bearings such as natural, high damping, and lead rubber bearings and indicated that isolation reduced the response of stiff bridge system and can be used to design a safe bridge system. Soneji and Jangid (2005) investigated the effectiveness of elastomeric and sliding types of isolation systems for the seismic response control of cable-stayed bridges and The seismic response of the isolated cable-stayed bridge is compared with that of the bridge without isolation system which showed that the isolation systems are effective for reducing the absolute acceleration of the deck and the base shear response of the tower. Sabamehr and Bagchi (2017) investigated the seismic response of two-span prestressed concrete box girder bridge isolated with LRB And FPS and concluded that the fundamental period of bridge is increased by used of base isolation systems and it quit effective in reducing the seismic response of bridge. Madhekar and Jangid (2009) studied the dynamic response of a benchmark highway bridge isolated with variable friction pendulum system (VFPS) under six earthquake motions and compared with the conventional friction pendulum system (FPS). They concluded that the VFPS is quite effective in reducing the peak response quantities of the bridge as compared to sample controllers. The review of the past studies indicates that as there are research works available on seismic control of highway bridges. It would be interesting to study the seismic behavior of skewed Highway Bridge using lead rubber bearing (LRB).

In the present study the response of skewed Highway Bridge isolated with LRB is presented. The main objectives of present study are summarized as;

1. To study behavior of bridge with fixed based, rubber isolator.
2. To study the response of skewed Highway Bridge with different scaled historical earthquakes events considering parameters as base shear, deck displacement and acceleration.
3. To compare the response of uncontrolled and controlled highway bridge.

BASE ISOLATION SYSTEM

Base isolation is a pliable material which is provided to decreases the seismic forces of any structure]. It is a state-of-the art method in which the structure (superstructure) is separated from the base (foundation or substructure) by introducing a suspension system between the base and the main structure. There are two common categories of base isolation hardware: sliding bearing and elastomeric bearing. In the present study lead rubber bearing (LRB).

PRINCIPLE OF BASE ISOLATION

The basic principle seismic isolation is to introduce horizontally flexible but vertically stiff components (base isolators) at the base of a structure to substantially uncouple the superstructure from strong earthquake ground motion. The basic concept of base isolation system is lengthening the natural period of the fixed base structures [T. Subramani et. al., 2014].

LEAD RUBBER BEARING

The elastomeric LRB which are generally used for base isolation of structures consist of laminated layers of rubber which is sandwiched together with steel layers and a central lead core as shown in Figure 1. The elastomeric material provides the isolation component with lateral flexibility; the lead core provides energy dissipation (or damping), while the internal steel shims enhance the vertical load capacity. All elements contribute to the lateral stiffness. The rubber layers deform laterally during seismic excitation of the structure, allowing the structure to translate horizontally, and the bearing to absorb energy when the lead core yields. [Luis Andrade et. al.].

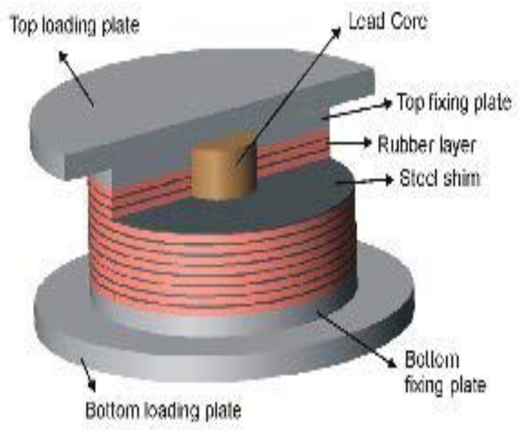


Fig 1 components of LRB

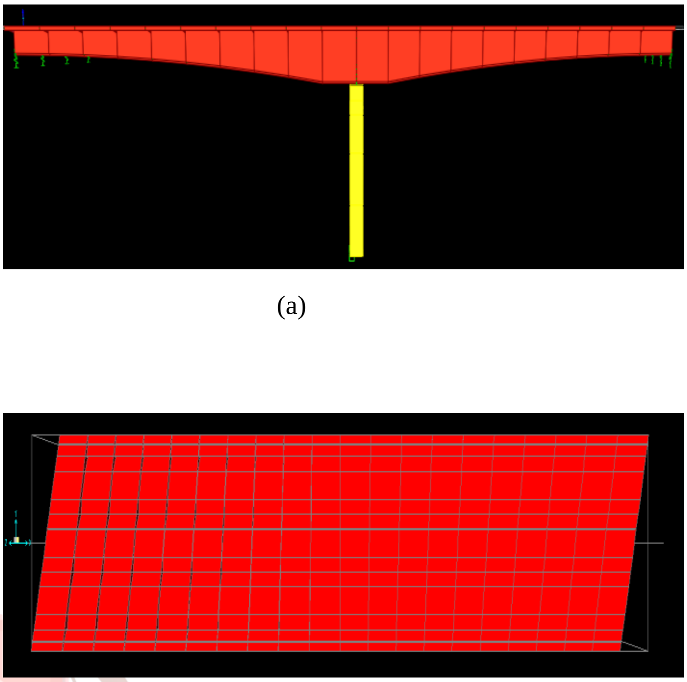
METHODOLOGY

General

For the present work a concrete box girder highway bridge is selected and analysed for seismic forces given in CSI Bridge Manual, 2007. SAP2000 software is used for modelling and analysis of concrete box girder Highway Bridge. The seismic response and behaviour of Box Girder Bridge is studied by linear time history analysis using Newmark's beta method. For the analysis four different ground motion data selected and scaled for target spectra as per zone IV. Further, uncontrolled response of bridge evaluated and compared with the controlled response of bridge.

B. Design Problem

The considered bridge is model using the CSI Bridge Manual, 2007. The considered bridge is a two-span prestressed concrete box girder bridge as shown in figure 2(a). The deck is a concrete box girder with a nominal depth of 1.524 meters. The deck has a parabolic variation in depth from 1.524 meters at the abutments to a maximum of 3.048 meters at the bent support. The bridge has two spans of approximately 30.48 meters each. The bridge has three columns with different heights supporting the deck at mid-span. There are parametric variations along the length of the bridge as well as prestressed tendons assigned to the deck. The bridge abutments are skewed by 15 degrees at the 2 ends of the bridge deck. Figure 2 displays the continuous girder bridge.



(a)

(b)

Fig 2 Continuous Box Gider Bridge (a) Side View (b) Top View.

C. Linear Time History Analysis

To evaluate the performance of the considered bridge linear time history analysis has been performed. For the dynamic analysis, a set of four ground motion records were obtained from the PEER database (http://peer.berkeley.edu/peer_ground_motion_database). The four different earthquake ground motions which are selected to investigate the dynamic response of the modeled structure using time history function namely; Chi-Chi earthquake, Imperial valley earthquake, Kobe earthquake, Northridge earthquake, each time history function is applied one by one to the model using SAP2000. Basically, the ground acceleration should be scaled to match the Spectrum for the corresponding location. [A. Sabamehr and A. Bagchi, 2017] The Seismo-match software is used for scaling the data. (http://www.seismosoft.com/seismomatch). In the analysis the ground motion data is applied in X-direction and responses of the structure are found.

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TABLE1 IMPORTANT FEATURES OF FOUR GROUND MOTIONS.

Earthquake	Date	Magnitude	P.G.A (Scaled)	P.G.A (Un-Scaled)
Chi chi	Sept-20,1999	M7.6	0.3176	0.3610
Imperial Valley	May-16,1940	M7.1	0.3013	0.3152
Kobe	Jan-16,1995	M6.9	0.2529	0.3447
Northridge	Jan-17,1994	M6.7	0.2189	0.5683

D. Seismic Control System In Sap2000

In SAP2000, there are options to assign some types of seismic control system as link parameters. In this study, Lead Rubber Bearing (LRB) is considered as base isolators. For the present study by considering target period of bridge T=2sec, various parameters of LRB is defined in SAP2000.

SEISMIC RESPONSE OF HIGHWAY BRIDGE

In the study, the comparative responses of concrete box girder Highway Bridge with and without seismic control system under various seismic ground motions, by performing the linear time history analysis using Newmark's beta method is carried out. For the analysis four scaled time history of historical earthquake were considered. For comparison, the response of the highway bridge is computed under following condition: (1) bridge without seismic control system; (2) bridge isolated with lead rubber bearing. Time variation of base shear of bridge with and without lead rubber bearing, is shown in figure 3-6 under the all considered earthquake ground motion. It indicates that the base shear in the isolated bridge is considerably reduced (about 80-90%) as compared to un-isolated bridge, implying that lead rubber bearing are effective in reducing the earthquake forces of the bridge.

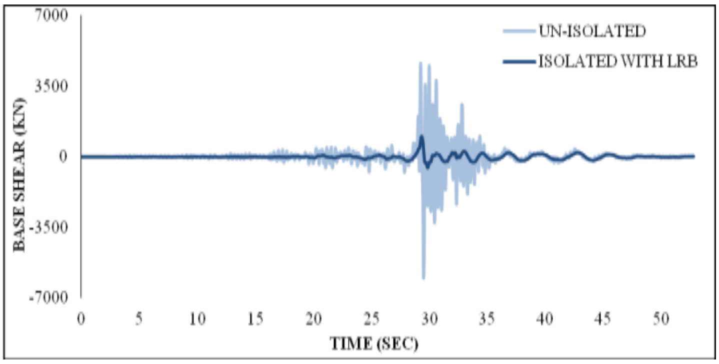

Fig. 3 Time Variation of Base Shear For Isolated (LRB) And Un-Isolated Bridge For Chi Chi Earthquake.

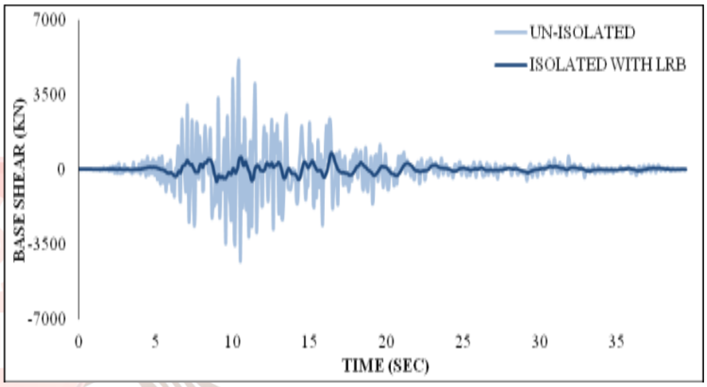

Fig. 4 Time Variation of Base Shear For Isolated (LRB) And Un-Isolated Bridge For Imperial Valley Earthquake

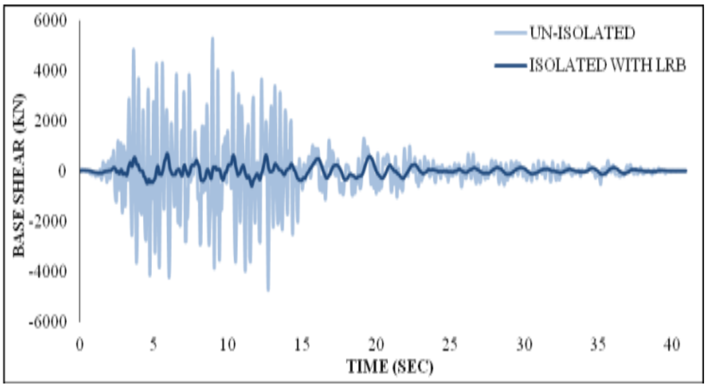

Fig. 5 Time Variation of Base Shear For Isolated (LRB) And Un-Isolated Bridge For Kobe Earthquake

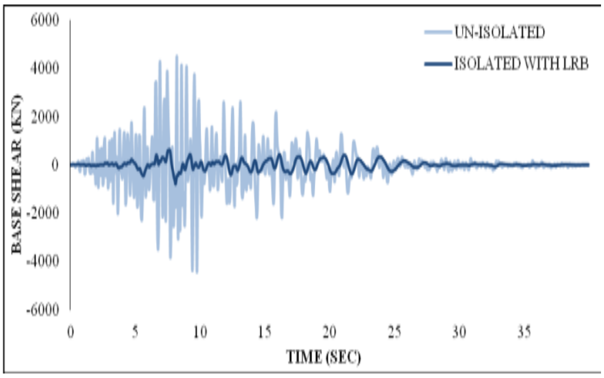

Fig. 6 Time Variation of Base Shear For Isolated (LRB) And Un-Isolated Bridge For Northridge Earthquake

Moreover, the peak response of the bridge with and without isolators for all the considered earthquake ground motions can be grasped at glance from the tables 2-5. As can been seen from the table that the base shear response are significantly reduced in the isolated model bridge as compared with the un-isolated one. Furthermore, the displacement responses of the deck are observed to be relatively higher in isolated bridge in compared with un-isolated one. In order to mitigate this kind of over displacement of the bridge deck, a special kind of energy dissipating devices could be employed.

Table 2 Peak Response Quantities of The Bridge For Both Isolated And Un-Isolated Conditions Under Chi Chi Earthquake.

Earthquake	Chi-Chi 1999	
Parameters	Un-isolated	LRB
Base Shear (kN)	5980.2	1024.448
Displacement (mm)	7.737	77.14
Acceleration (m/s^2)	3.236	3.959

Table 3 Peak Response Quantities of The Bridge For Both Isolated And Un-Isolated Conditions Under Imperial Valley Earthquake.

Earthquake	Imperial Valley 1940	
Parameters	Un-isolated	LRB
Base Shear (kN)	5099.97	751.0
Displacement (mm)	5.946	50.95
Acceleration (m/s^2)	2.711	2.62

Table 4 Peak Response Quantities of The Bridge For Both Isolated And Un-Isolated Conditions Under Kobe Earthquake.

Earthquake	Kobe 1995	
Parameters	Un-isolated	LRB
Base Shear (kN)	5224.11	678.82
Displacement (mm)	7.083	48.36
Acceleration (m/s^2)	3.500	2.44

Table 5 Peak Response Quantities of The Bridge For Both Isolated And Un-Isolated Conditions Under Northridge Earthquake.

Earthquake	Northridge 1994	
Parameters	Un-isolated	LRB
Base Shear (kN)	4480.61	789.68
Displacement (mm)	6.607	53.23
Acceleration (m/s^2)	3.472	2.39

Comparison of base shear, displacement and acceleration of isolated and un-isolated bridge under all the considered earthquakes are presented in figure 7-9 respectively. From the figure 7 it is observed that the base shear of bridge isolated with lead rubber bearing under all four earthquakes reduced considerably as compared to the un-isolated one. From figure 8 it is observed that the displacement response is relatively higher in isolated bridge in compared with the un-isolated one. In order to avoid this kind of over displacement of the bridge, a special kind of seismic control system be employed. From the figure 9 it is observed that acceleration reduced significantly under all considered earthquake except Chi-Chi earthquake. The reduction of acceleration is more in Northridge earthquake as compared to the other selected earthquakes.

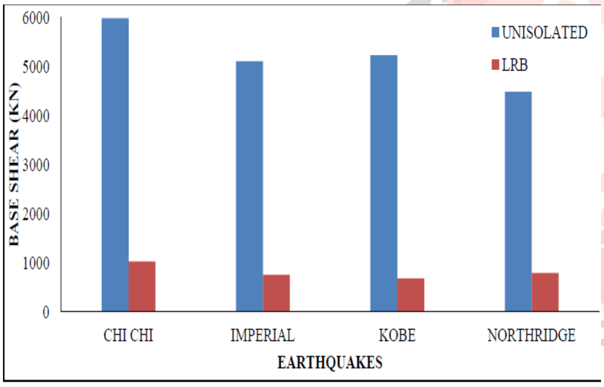

Fig. 7 Comparison of Base Shear for Four Earthquake Ground Motions.

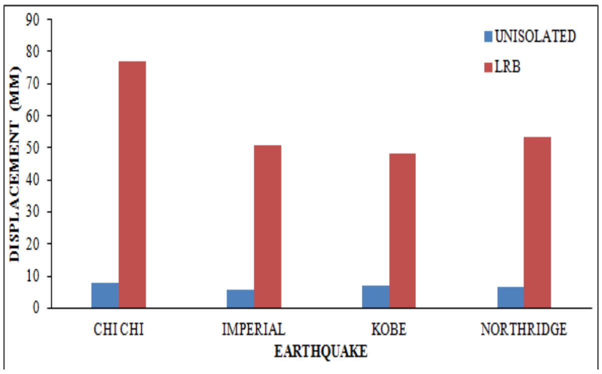

Fig. 8 Comparison of Displacement for Four Earthquake Ground Motions.

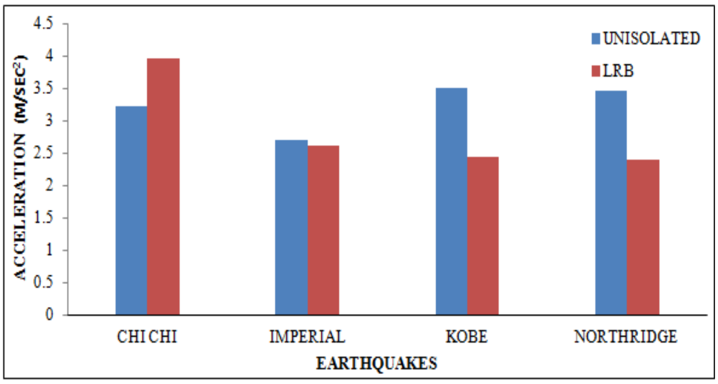

Fig. 9 Comparison of Acceleration for Four Earthquake Ground Motions.

SUMMARY CONCLUSIONS

The effectiveness of Lead Rubber Bearing (LRB) installed in highway bridge subjected to four earthquake ground motion has been investigated. The response of seismically isolated bridge with the Lead Rubber Bearing (LRB) was compared with the non isolated bridge From the trends of the present study, the following conclusions drawn:

1. Use of seismic control system in bridge dissipate major portion of the seismic energy during seismic events. Based on analytical study carried out, it is concluded that use of seismic control system in bridge can be effective in earthquake resistant design.
2. From the study it is observed that the use of LRB, is useful in reducing the response of bridge as compared to the un-isolated bridge.
3. From the comparison it shows that the Lead Rubber Bearing (LRB) is quite effective in reducing base shear as compared to un-isolated one.
4. Based on the analytical study carried out, it is concluded that seismic control of Highway Bridge using Lead Rubber Bearing (LRB) is a successful technique that can be used effectively in controlling the seismic response of structure under the strong seismic ground motions.

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