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Seismic Response of an Isolated Curved Bridge with Lead Rubber Bearing by Considering Design Aspect

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Abstract

Studies on the application of the lead rubber bearing (LRB) isolation system to various structures carried out as one of the measures to improve seismic performance. Curved bridges play noteworthy role in the modern transportation system. Due to complex interchange and the desire to conform to existing geometric confinements have made this type of structures more alluring. Horizontally curved bridges make up of a noteworthy portion of the bridge population in various countries. In the present study, Lead rubber bearings have been used in an Isolated Curved bridges. Seismic loadings have been considered for three recorded ground motions from PEER strongmotion database (PEER 2014) without scaling viz. (1) Imperial Valley (1940) with two orthogonal horizontal ground motion components (PGA0.313g and PGA0.215g); (2) Kobe (1995) with two orthogonal horizontal ground motion components (PGA 0.83g and PGA 0.63g) and (3) Turkey (1992) with two orthogonal horizontal ground motion components (PGA 0.5g and PGA 0.39g). These three ground motions have been considered to represent conditions close to far-fault, near-fault and forward directivity of earthquakes, respectively. Unidirectional and Bi-directional loading have been considered in the present study. Design aspects of the Lead rubber bearings has been considered by deploying the interaction diagram of bearing displacement between the unidirectional and bi-directional responses. It has been found that the bidirectional loading should be considered while designing the isolators.

Keywords:SeismicResponse, Lead Rubber Bearing, Bi-directional Loading, Curved Bridges

1. Introduction

Lead-Rubber Bearing (LRB) (Robinson and Tucker 1977; Turkington et al. 1989a; Abrahamson and Mitchell 2003) is an important device among elastomer-based isolation systems. In this bearing, rubber provides lateral flexibility to elongate the period of the structure, whereas, lead core dissipates energy during cyclic movement under earthquake ground motion.

Benzoni *et al.* (2009) conducted an experimental investigation on the effects of axial load and strain rate on the performance of a full-scale lead-core elastomeric bearing for bridge applications. The bearing response was examined with particular attention to the variation of critical performance characteristics in order to produce a set of information that could be employed in a physically motivated numerical model. Choun *et al.* (2014) studied the effect of the variability of the mechanical properties of lead rubber bearings on the response of a seismic isolation system. Material variability in manufacturing, aging, and operation temperature was assumed, and two variation models of an isolation system were considered. To estimate the effect of ground motion characteristics on the response, 27 earthquake record sets with different peak A/V ratios were selected, and three components of ground motions were used for a seismic response analysis. The response in an isolation system and a superstructure increases considerably for ground motions with low A/V ratios. The variation in the mechanical properties of isolators results in a significant influence on the shear strains of the isolators and the acceleration response of the superstructure.

Hammed *et al.* (2008) investigated the effect of lead rubber bearings and ground motion characteristics on the response of seismically isolated bridges. The important parameters included were: ground motion characteristic by considering the ratio of peak ground acceleration and peak ground velocity (PGA/PGV) as damage index.

Gaurona *et. al.* (2018) found that limit states of performance are nearly impossible to define experimentally because most bearings do not exhibit any visual damage before failure, although experimental data indicate that slight to moderate damage obviously occurs in bearings under large

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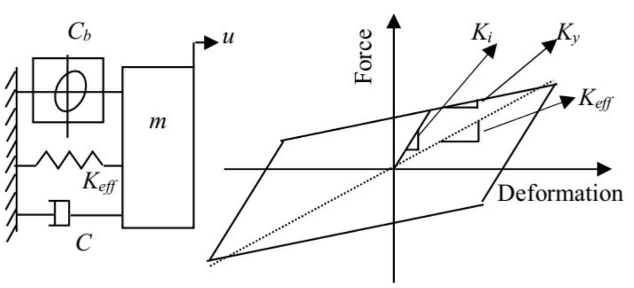
displacements.Oliveto *el al* (2019) states that the behavior of high damping rubber bearings is highly complex. The models that are currently available are generally limited to unidirectional motion and, in most cases, difficult to extend to general bidirectional loading. One of the major limitations is their inability to characterize the behavior of the bearings at different levels of shear deformation. Achillopoulou *et.al.* (2020) states that nowadays, transport infrastructure stakeholders have shifted the requirements in risk and resilience assessment. The expectation is that risk is estimated efficiently, almost in real-time with high accuracy, aiming at maximising the functionality and minimising losses.Hassan *et. al.* (2020) investigated that the long-duration motions cause more damage to different bridge components as compared to the short-duration motions in-terms of higher deck acceleration, pier base shear, and residual isolator displacement. It was also observed that ground motions having similar magnitude with different significant durations can significantly affect the isolator as well as the bridge response.Jianga *et.al.* (2020) can provide effective and practical guidance for design and retrofitting of near-field bridges.

2. Modelling and Analysis

The curved bridges with different combination of design parameters of the bearings have been modelled using the software SAP2000. The bridge superstructure and the piers have been modelled using beam elements with mass lumped at discrete points. Since the piers are resting on rock, these have been modelled as fixed at the base. The abutments have been assumed to be rigid. The lead rubber bearings have been modelled as link elements. The behaviour of the lead rubber bearings has been shown in Fig.1(a-b). Coupled plasticity behaviour of lead rubber bearings has been assigned in the link elements. In non-isolated case, the bridge is supported by roller bearings at the abutment and fixed at the base of piers. In isolated case, lead rubber bearings are used both at abutments as well as between the deck and pier. Two nos. of isolation bearings are considered at each abutment and four nos. are considered at each pier locations. In the present study, the straight line connecting two abutments of the bridge is chosen as the global longitudinal (X) axis and the perpendicular horizontal axis w.r.to the straight line is considered as the global transverse (Y) axis of the bridge. Global Z direction is considered as the vertical axis of the bridge. For seismic loads, Nonlinear Dynamic Analysis (NLTHA) have been performed. In case of response of bridges, the resultant of the response in the two orthogonal horizontal directions is considered. This is because, the considered bridge is a curved bridge and the resultant of the response of perpendicular orthogonal directions will be more effective from design consideration of bridge.

2.1 Coupled plasticity behaviour of isolation bearings

The coupled behaviour of the HDR Bearings has been considered according to the hysteretic model proposed by Wen (1976), and Park et al. (1986), and recommended for base-isolation analysis by Nagarajaiah et al. (1991).
The coupled force-deformation relationship is given by,



(a) (b)

Fig. 1 High Damping Rubber Bearing
(a) analytical model, **(b)** force-deformation behaviour

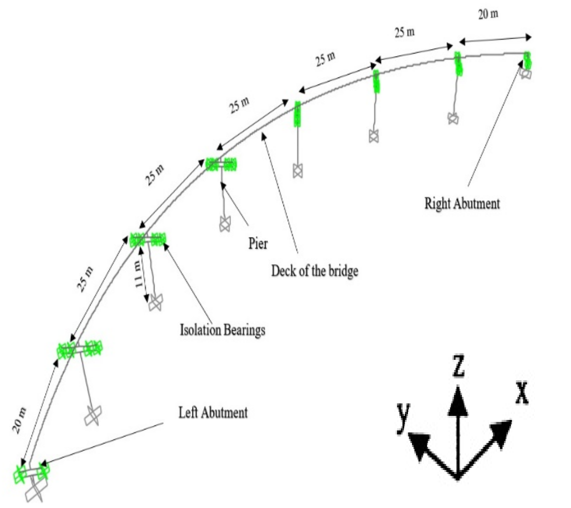


Fig. 2 Curved bridge considered for the study

$$F_1 = R_1 K_{e1} u_1 + (1 - R_1) F_{y1} z_1 \,\ldots\ldots\ldots(1)$$

$$F_2 = R_2 K_{e2} u_2 + (1 - R_2) F_{y2} z_2 \,\ldots\ldots\ldots(2)$$

where, K_{e1} and K_{e2} are the elastic stiffnesses in two orthogonal horizontal directions,

F_{y1} and F_{y2} are the yield forces and u_1 and u_2 are displacements in the two directions,

R_1 and R_2 are the ratios of post-yield stiffnesses to elastic stiffnesses and z_1 and z_2 are internal hysteretic variables and these variables have a range of ± 1, with the yield surface is represented by equation 3.

$$\sqrt{z_1^2 + z_2^2} = 1 \quad \ldots..(3)$$

2.2 Seismic loading considered for the study

Seismic loadings have been considered for three recorded ground motions from PEER strong motion database (PEER 2014) without scaling viz. (1) Imperial Valley (1940) with two orthogonal horizontal ground motion components (PGA0.313g and PGA0.215g); (2) Kobe (1995) with two orthogonal horizontal ground motion components (PGA 0.83g and PGA 0.63g) and (3) Turkey (1992) with two orthogonal horizontal ground motion components (PGA 0.5g and PGA 0.39g) as shown in Table 1. These three ground motions have been considered to represent conditions close to far-fault, near-fault and forward directivity of earthquakes, respectively.

3.Results and Discussions

3.1 Comparison of uni-directional and bi-directional loading effects under Imperial Valley Ground Motion

The effect of bi-directional loading on the response of the curved bridge has been determined for varying time period and damping ratio. The maximum increase in response parameters due to bi-directional loading have been observed for the combination of isolation time period as 3.0 sec and damping ratio as 0.25.

Fig.3 (a) and (b) represent the bearing displacement and force transmitted to the pier for the curved bridge under uni-directional and bi-directional loadings. It has been observed that due to bi-directional loading, the bearing displacement and force transmitted to the pier have been increased by 58.33 % and 58.82 %, respectively. It is also found that the response envelope due to bi-directional loading (red line) exceeded the same for uni-directional loading (black line) by significant amount.

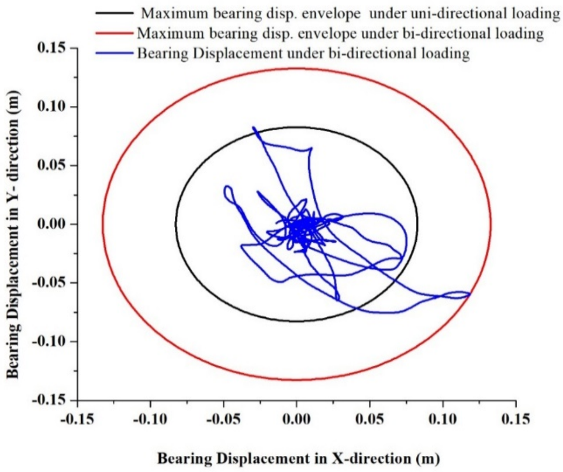
It has also been observed that the deck acceleration, deck displacement and pier torsional moment and have been increased by 15.04 %, 53.41 % and 29.55 %, respectively, under bi-directional loading.

3.2 Comparison of uni-directional and bi-directional loading effects under Kobe Ground Motion

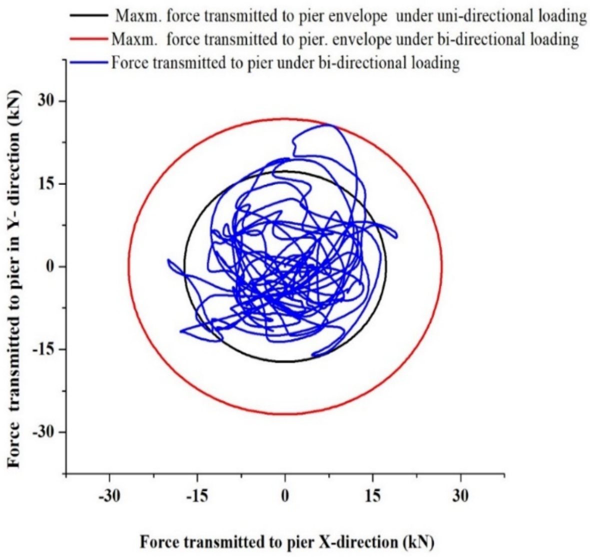
The effect of bi-directional loading on the response of the curved bridge has been determined for varying time period and damping ratio. The maximum increase in response parameters due to bi-directional loading have been observed for the combination of isolation time period as 3.0 sec and damping ratio as 0.1.

Table 1 Ground Motion Considered for the study

Record	Event	Magnitude	Station	Orientation	PGA (*g*)	Distance-to-fault (km)	Predominant period(sec)
1	Imperial Valley (1940)	7.0	117 El Centro Array #9	IMP VALL/I-ELC180	0.31	8.3	0.096
2	Imperial Valley (1940)	7.0	117 El Centro Array #9	IMP VALL/I-ELC270	0.21	8.3	0.14
3	Kobe(1995)	6.9	KJMA	RSN1106_KOBE_KJM000	0.83	0.96	0.11
4	Kobe(1995)	6.9	KJMA	RSN1106_KOBE_KJM090	0.63	0.96	0.12
5	Turkey(1992)	6.9	Erzincan	Erzincan, EW	0.50	4.3	0.16
6	Turkey(1992)	6.9	Erzincan	Erzincan, NS	0.39	4.3	0.282



(a)



(b)

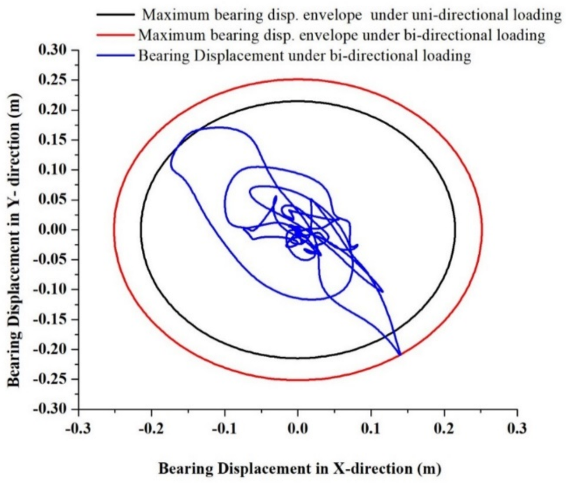
Fig. 3. Bi-directional Effects under Imperial Valley Ground Motion

Fig.4.(a) and (b) represent the bearing displacement and force transmitted to the pier for the curved bridge under uni-directional and bi-directional loadings. It has been observed that due to bi-directional loading, the bearing displacement and force transmitted to the pier have been increased by 17.21 % and 16.28 %, respectively. It is also found that the response envelope due to bi-directional loading (red line) exceeded the same for uni-directional loading (black line) by significant amount.

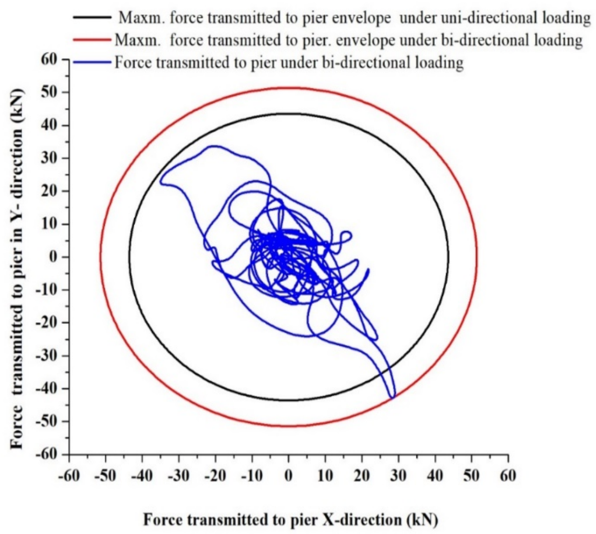
It has also been observed that the deck acceleration, deck displacement and pier torsional moment and have been increased by 9.42 %, 15.42 % and 14.29 %, respectively, under bi-directional loading

3.3Comparison of uni-directional and bi-directional loading effects under Tukey Ground Motion

The effect of bi-directional loading on the response of the curved bridge has been determined for varying time period and damping ratio. The maximum increase in response parameters due to bi-directional loading have been observed for the combination of isolation time period as 1.5 sec and damping ratio as 0.1.



(a)



(b)

Fig. 4. Bi-directional Effects under Kobe Ground Motion

Fig.5 (a) and (b) represent the bearing displacement and force transmitted to the pier for the curved bridge under uni-directional and bi-directional loadings. It has been observed that due to bi-directional loading, the bearing displacement and force transmitted to the pier have been increased by 111 % and 95.29 %, respectively. It is also found that the response envelope due to bi-directional loading (red line) exceeded the same for uni-directional loading (black line) by significant amount.
It has also been observed that the deck acceleration, deck displacement and pier torsional moment and have been increased by 97.58 %, 87.88 % and 85.95 %, respectively, under bi-directional loading.

4. Conclusion

In this paper, the response of the curved bridges with lead rubber bearings has been investigated. The effect of seismic has been considered in the study. The effect of bi-directional loading of earthquake on the response of the bridge has been investigated for three different earthquakes. The Influence of bi-directional loading w.r.to uni-directional loading has been investigated. Some of the important observations have been mentioned as follows.

- The bi-directional loading has resulted in significantly higher bearing displacement and force transmitted to the pier than uni-directional response. The effect has been found to be maximum for Turkey ground motion whereas the Kobe ground motion has resulted in minimum effect.
- From the comparative study of uni-directional and bi-directional loading response, it has been observed that uni-directional response is seriously underestimated in case of LRB bearings also and the design of the bridge should have been done considering the bi-directional effect.

Disclosures

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