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INVESTIGATING THE PERFORMANCE OF BOX GIRDER BRIDGES UNDER NEAR-FIELD EARTHQUAKES

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ABSTRACT: In this study the performance of two box girder bridges under near-field earthquakes was investigated. Lateral responses of two continuous span bridges were compared under two cases: with lead rubber bearings (LRB) and with rigid connections between the superstructure and substructure. Lead rubber bearings are one of the most popular seismic isolators which are used in a variety of structures such as buildings and bridges. Fifteen isolators were installed under the deck of the isolated bridge. It was observed that the superstructure received less acceleration when the bridge was equipped with lead rubber bearing isolators. There was a significant difference between the isolated and non-isolated structures in terms of base shear force and the isolated bridge showed better performance under near-filed earthquakes. This suitable performance of the isolated structure was due to the proper hysteric behavior of the lead rubber bearings.

KEYWORDS: Bridge structures; Near-field earthquakes; Nonlinear time history analysis; Seismic isolation.

1 INTRODUCTION

Bridges are one of the most common structures in all around the world. Using these types of structures are undeniable in everyday life. Bridges were made to make us capable to reach the places we were not able to travel or making it much easier for us. Bridges are not cheap structures in fact they are much more expensive than normal highway roads. In addition to bridges expensive construction, safety of people and moving vehicles that consume these structures should be satisfied and their behaviour shall become upgraded and improved by using engineering technics. One of these technics is the usage of seismic isolators, which nowadays are becoming more popular day by day in the seismically active regions where deadly earthquakes occur. Based on the structural demands, available materials and economical aspects, bridges divide into different types. One of the most commonly used bridge structures is the box girder bridge which is lighter than he solid slab bridges and shows an adequate performance under gravity loads including moving loads like cars and trucks. In this study, the lateral behaviour of these commonly used structures situated in seismically active regions, under strong ground motions with pulse like behaviour was studied. Usually near-field ground motions create larger seismic responses than far-field ground motions. As a matter of fact, near fault earthquakes could be more destructive [1]. Near-fault earthquakes have a significant effect on the seismic response of continuous box girder bridges due to the huge amplitude pulse effect of near-fault records. Unfortunately, many highway bridge seismic design codes do not consider near fault effect so it can raise the vulnerability risk of structures [2]. Bridges which are equipped with seismic isolators have appropriate efficiency in near fault ground motions and there is a considerable decline displacement in the longitudinal directions of the bridges [3]. Isolated Bridges under far-field earthquake records receive fewer base shear force than the ones under near-field earthquake records. Ratio of peak ground velocity over peak ground acceleration (PGV/PGA) and ground motion energy are two significant parameters which depend on each other and have an effect on base shear force and displacement of the intermediate-period and short-period isolated bridges [4]. Previous researches have determined that changes in modeling parameters like damping and skew angle affect the seismic response of bridges. It was concluded that the bridges which were equipped with seismic isolation systems showed a decrease in the curvature demand of columns but increase in the displacement of abutments [5]. The failure mode analysis has expressed that isolated continuous box girder bridges are fractured at the isolator bearings in the middle part of the piers and isolation bearings on the abutments [6].

2 LEAD RUBBER BEARING PROPERTIES

Seismic isolators divide into two main groups of elastomeric bearings and friction bearings. Lead rubber bearings are one of the most popular elastomeric seismic isolation systems among structural engineers. These types of isolators are widely used in bridges [7]. Lead rubber bearings are made of three general parts: a lead core, rubber layers and steel plates (*Fig.1*). Lead plug yields under minor shear forces caused by earthquakes and dissipates energy [8,9]. Steel plates force the lead plug to deform under shear forces [10]. The effective stiffness of the LRB isolators is obtained by equation (1). In this equation K_2, Q and D, are post yield stiffness, intercept of the force axis and the hysteresis loop and isolators displacement respectively [10]. The effective damping is also obtained by the equation (2) [10].

$$K_{eff} = K_2 + Q/D \qquad (1)$$

$$B_{eff} = (\text{area of the hysteresis loop}) / 2\pi\, K_{eff}\, D^2 \qquad (2)$$

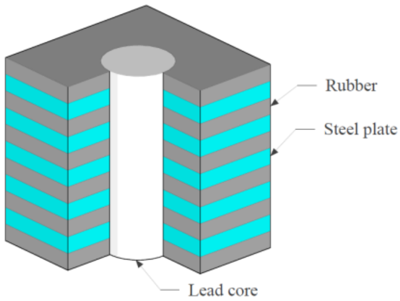

Figure 1. Lead rubber bearing components

3 VERIFICATION

Correct modelling of seismic isolators can be reached by several ways including experiments and comparing numerical analysis results with well-known scientific papers published in famous engineering journals. Therefore, authors decided to add this section to this paper to show that the proper modelling of the isolators is very important and using vague or non-scientific methods for modelling these elements are not desirable under any conditions. The considered structure for this purpose is a two dimensional 10-storey steel moment frame building seismically isolated by LRB isolators that has been investigated in a research done by [11] (*Fig.2*). The LRBs used in this structure have the following characteristics: vertical stiffness of 200687 KN/m, effective stiffness of 713 KN/m, initial stiffness of 5419 KN/m, effective damping of 0.1 and yield force of 59.61 KN.

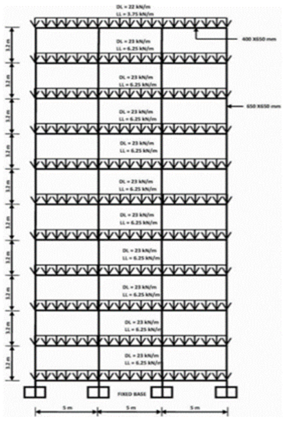

Figure 2. The structure used for verification [11]

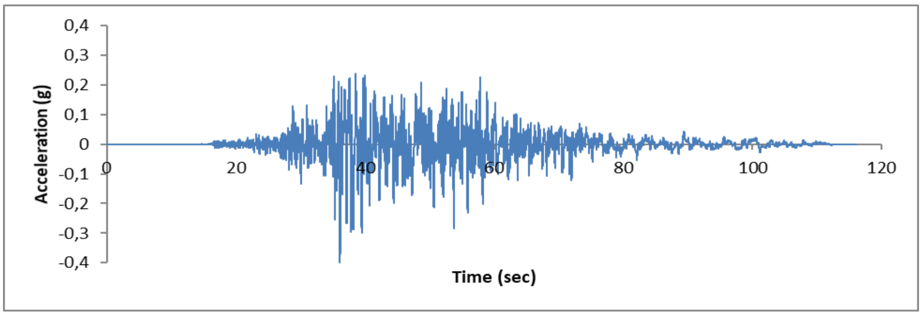

Figure 3. Chi Chi earthquake record used for verification

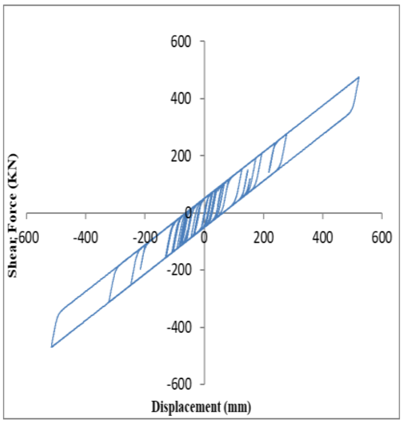

Figure 4. Hysteresis diagram of an isolator obtained by authors [12,13]

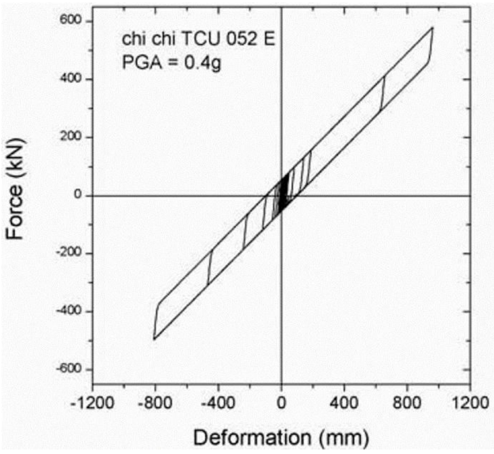

Figure 5. Hysteresis diagram of an isolator obtained by previous researchers [11]

The considered earthquake in this section is one of the Chi Chi earthquake records which has been scaled in a way that its peak ground acceleration (PGA) equals to 0.4g (*Fig.3*). As shown in (*Figs.4,5*) there is a suitable similarity between the hysteresis diagram obtained by authors [12,13] and the one obtained by previous researchers [11].

4 MODELLING

Two bridges are modelled in this study with the same characteristics except the connection between the deck and the substructure, which in one case it is assumed to be a rigid connection between substructure and superstructure and in the other one LRBs are used as the isolators that separate Deck from the substructure. The structures used in this study are two three-dimensional 50m long multi span continuous box girder bridges with the deck width of 10.8m shown in (*Fig.6*). The deck section details are also illustrated in (*Fig.7*). Columns of the bridge structures are circular sections with 1m diameter and Cap beams have the depth and width of 1.2m and 1.5m, respectively. The base isolators used in this research are the same as the ones used in the verification section with the same structural characteristics. Three vehicle lanes are modelled with trucks that have the weight of 400 KN per each truck and are considered as the moving loads along the span length (*Fig.8*). The maximum and minimum moments caused by gravity loads (i.e. Dead loads plus moving loads of trucks) about horizontal axis of the bridge is shown for the entire bridge length in (*Fig.9*). As expected maximum moment happened at the middle of the bridge length where girders are continuously connected and there is no expansion joint provided in that part of the structure.

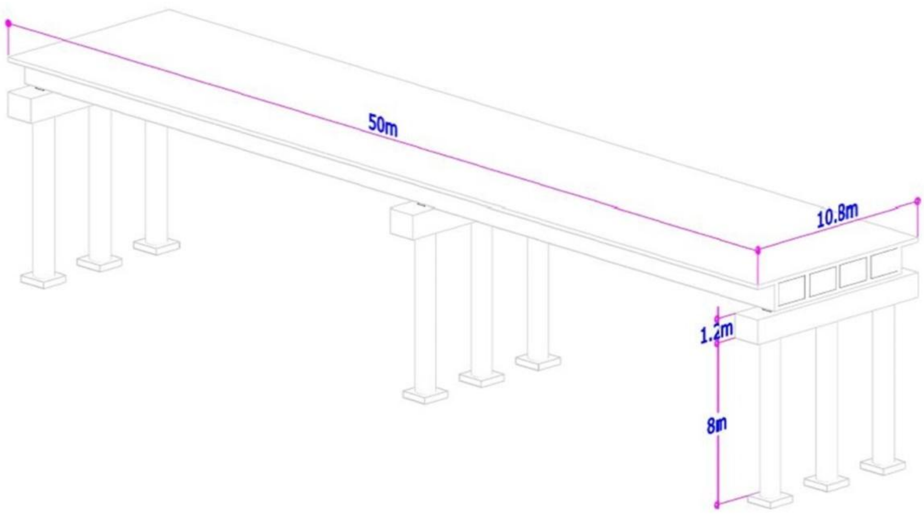

Figure 6. Three-dimensional box girder bridge considered in this study

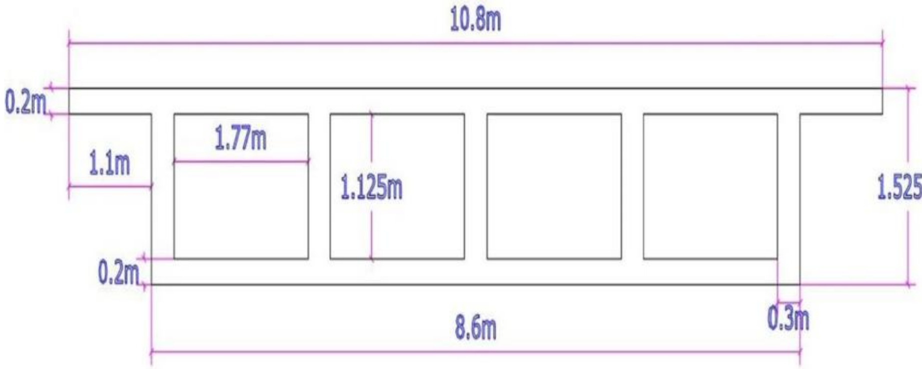

Figure 7. The deck section details of the considered structure

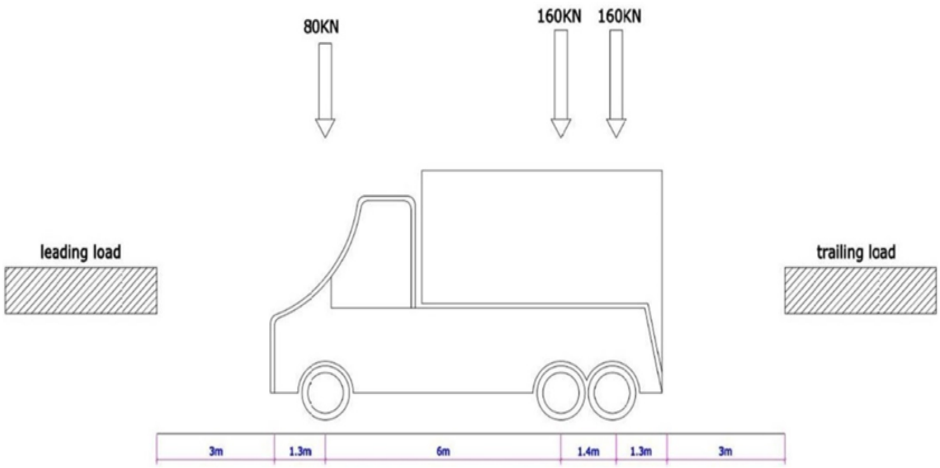

Figure 8. Moving load details [13]

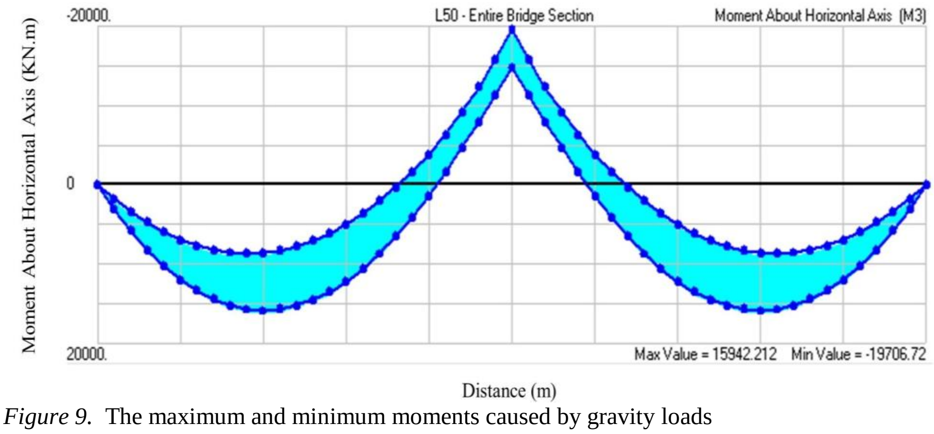

Figure 9. The maximum and minimum moments caused by gravity loads

Seven near-field earthquake records were selected as lateral forces, based on magnitude, fault type, and soil shear wave velocity (Table 1). The magnitudes of the selected earthquakes are in a range of 6.0 to 6.33 and all the faults are strike slip type with the shear wave velocity between 427.73 m/s to 620.56 m/s.

Table 1. The selected earthquake characteristics

Event	Year	Station	Magnitude	Fault type	Rjb(km)	V_s(m/s)
Helena, Montana	1935	Carroll College	6.0	Strike slip	2.07	593.35
Victoria	1980	Cerro Prieto	6.33	Strike slip	13.8	471.53
Morgan Hill	1984	Anderson Dam (Downstream)	6.19	Strike slip	3.22	488.77
Chalfant Valley	1986	Bishop - Paradise Lodge	6,19	Strike slip	14.97	585.12
Chi-Chi	1999	CHY024	6,2	Strike slip	19.67	427.73
Basso Tirreno,	1978	Naso	6,0	Strike slip	17.15	620.56
Parkfield	2004	Parkfield - Stone Corral 2E	6,0	Strike slip	5.23	566.33

5 COMPARISION BASED ON BASE SHEAR FORCE

One of the main advantages of using seismic isolators in structures is to increase the period of the structures, and as a result the forces applied to the structures decrease compared to the case where there is no seismic isolator used. Nonlinear time history analysis was used to determine the effect of LRB isolators on the response of bridges using SAP2000 software [14]. As shown in Table 2 after replacing isolators with the rigid connections in the considered structure, periods of the bridge increased significantly which caused the reduction in base shear forces under all of the earthquake records selected in the previous section (Table 3) (*Figs.10,11*). This reduction in base shear force is due to the adequate performance of LRB isolators, which is obtained from their hysteresis loops. Hysteresis diagrams of one of the LRB isolators under Chi Chi and Morgan Hill earthquake records is given in (*Figs.12,13*). Investigating the shear force-lateral displacement or hysteresis diagram of the LRB isolators gives valuable information about their performance during strong ground motions. The area surrounded inside the hysteresis loops shows the absorbed energy via that special isolator. In addition to dissipated energy, the maximum shear force and lateral displacement of the isolator is obtained by these plots.

Table 2. First two periods of the bridges (sec)

Bridge type	1^{st} mode	2^{nd} mode
Without LRB	0.752	0.477
With LRB	2.338	2.155

Table 3. Maximum base shear forces (kN)

Condition	Victoria	Chi-Chi	Morgan Hill	Chalfant Valley	Helena, Montana	Basso Tirreno	Parkfield
Without LRB	6504	1182	4116	678.5	687	1981	602.5
With LRB	1633	1053	828.4	481.5	340.2	635.2	515.7

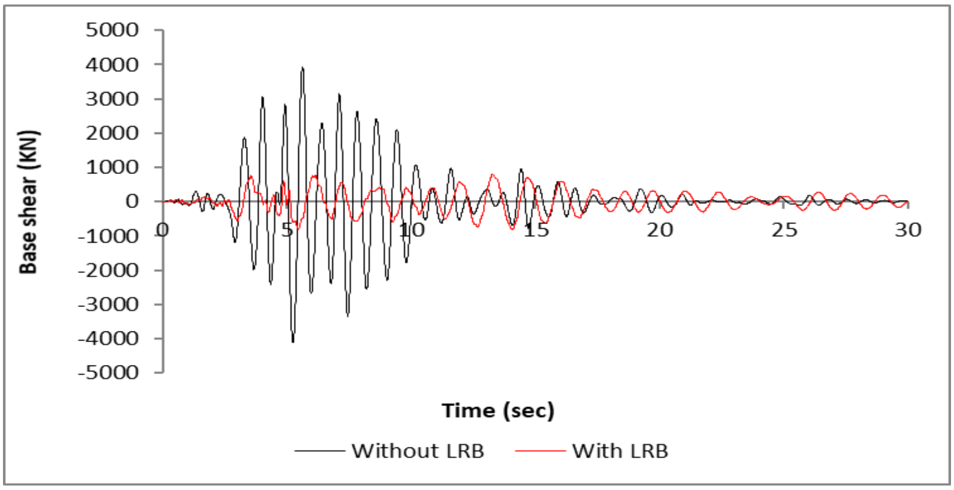

Figure 10. Comparison of base shear force between the two bridges under Morgan Hill earthquake

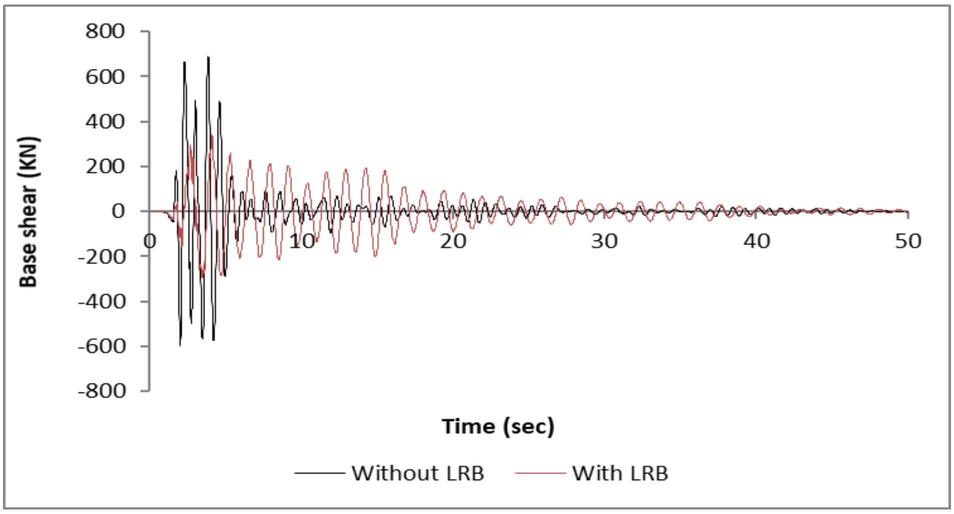

Figure 11. Comparison of base shear force between the two bridges under Helena, Montana earthquake

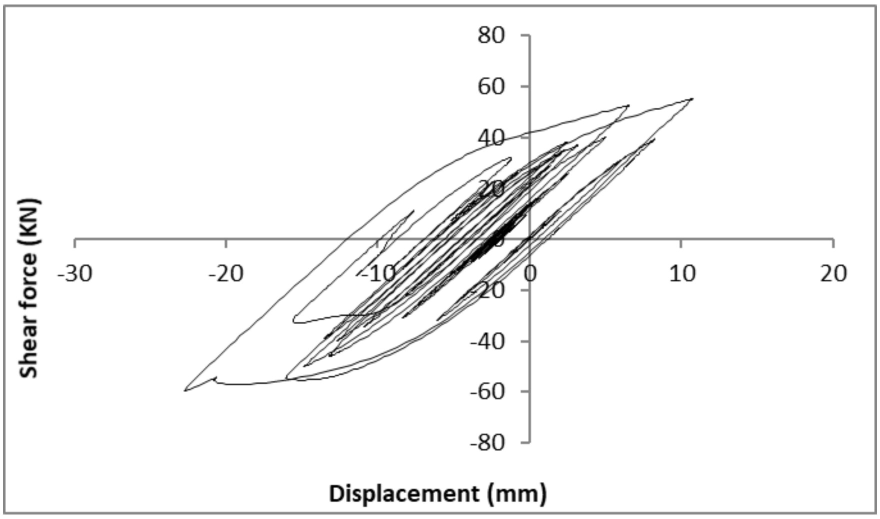

Figure 12. Hysteresis diagram of the LRB isolator under Chi Chi earthquake

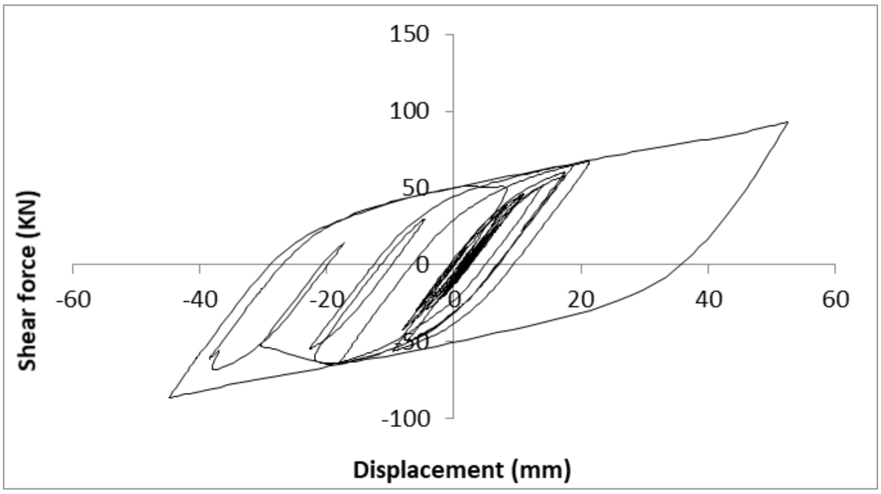

Figure 13. Hysteresis diagram of the LRB isolator under Morgan Hill earthquake

6 COMPARISION BASED ON SUPERSTRUCTURE ACCELERATION

There are basically three main design methods which an earthquake or bridge engineer can use for designing any structure including bridges. In the first method, the engineer increases the strength and the stiffness of the structural elements to resist the earthquake force. This method is not economical because for increasing strength and stiffness designer shall use more materials and using more materials means this method might theoretically be right but not practical in seismically active regions. The second method focuses on absorbing earthquake input energy via plastic deformations of the structural members. This method is more practical than the first one but may be not very useful for highly important structures like bridges. Because immediate performance of bridges are desired even after severe earthquakes and an engineer shall not be interested in this method too. The third method, which is the base of this study focuses on reducing the demand of the input energy not increasing the capacity of the structure. This method is achieved by isolating the structure or parts of it from the source of input energy. The main advantage of using seismic isolators is separating the superstructure from motions of the substructure. As shown in (*Figs.14,15*) after using seismic isolators between the superstructure and substructure the superstructure acceleration reduced significantly. The maximum and the ratio of superstructure accelerations for the two considered structures is illustrated in Table 4. In most of the cases, the ratio of superstructure accelerations is less than one, which shows the proper behaviour of the LRB isolators in the considered bridge. This ratio is not a constant value under all of the earthquakes which shows that the behaviour of LRB isolators depend on the frequency contents of the input earthquakes.

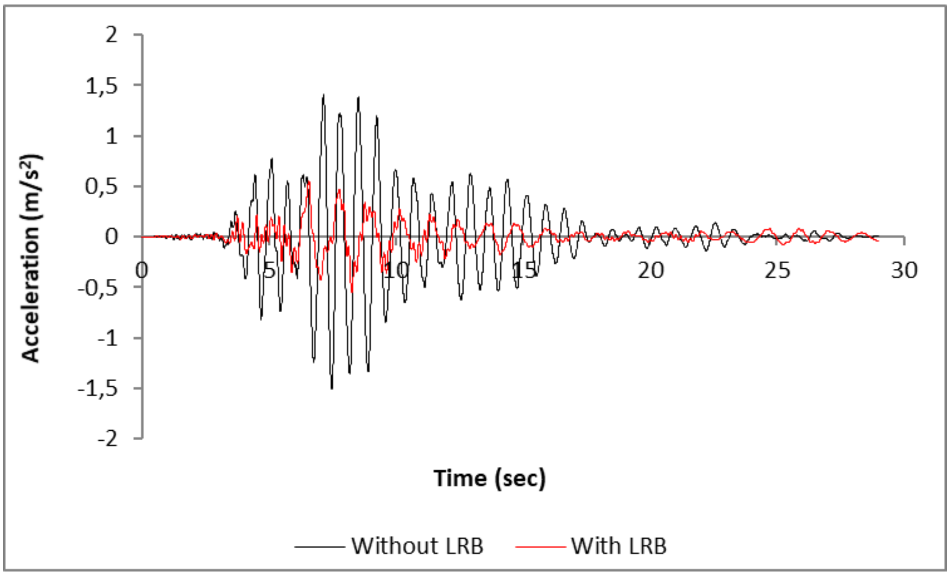

Figure 14. Comparison of superstructure acceleration under Basso Tirreno earthquake

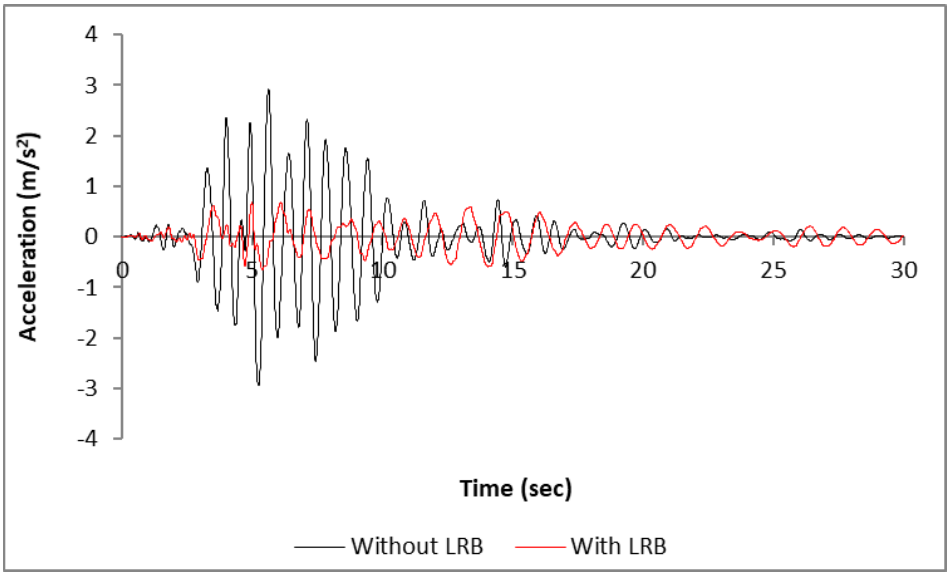

Figure 15. Comparison of superstructure acceleration under Morgan Hill earthquake

Table 4. Maximum and ratio of super structure accelerations

Conditions	Victoria	Chi-Chi	Morgan Hill	Chalfant Valley	Helena, Montana	Basso Tirreno	Parkfield
Without LRB (m/s^2)	4.742	0.84	2.938	0.4947	0.5182	1.507	0.4505
With LRB (m/s^2)	1.169	0.8709	0.6803	0.3549	0.2426	0.5562	0.4215
Ratio	0.24	1.03	0.23	0.717	0.46	0.37	0.93

7 CONCLUSIONS

The effect of adding LRB isolators to the multi span continuous box girder bridges under near-field earthquakes was investigated in this study. These types of bridges are widely used all around the world. Therefore, studying their performance under earthquakes with pulse-like characteristics is of utmost importance. It was observed that bridges with LRB isolators have higher periods than the bridges without seismic isolators. Lead rubber bearings illustrated proper behaviour during near-field earthquakes and dissipated the input energy via their proper hysteric performance. In terms of base shear force and superstructure acceleration the bridge, which had LRB isolators received less base shear force, and acceleration in the superstructure. It can be concluded that LRB isolators had a significant positive effect on the response of considered bridge structure.

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