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THE EFFECT OF SEISMIC ISOLATION ON THE RESPONSE OF BRIDGES

Ali Vatanshenas[1], Davood Sharif Bajestany[2] and Arian Aghelfard[3]

[1,2,3] Engineering Faculty, Islamic Azad University Central Tehran Branch, Tehran, Iran
e-mail: a.vatanshenas@gmail.com, davoodshb@gmail.com,
arian_aghelfard@yahoo.com

ABSTRACT: Precast concrete I girder and voided slab bridges are frequently used in many parts of the world. Therefore, understanding the seismic performance of these structures is important. The behavior of these structures during different strong ground motions were investigated in this study. Lead rubber bearings (LRB) were used to isolate these bridges from near-field earthquakes. The LRB isolator performed well in both bridges. It was observed that the performance of isolated bridges by LRB isolators were highly dependent on frequency contents of the earthquakes. In terms of deck displacement and deck acceleration there was no significant difference between the seismic responses of the considered structures under near-field earthquakes. It was shown that LRB isolator in voided slab bridge had to move and resist more compared to the precast concrete I girder bridge in order to absorb earthquake energy.

KEYWORDS: Lead rubber bearing; Near-field earthquakes; Nonlinear time history analysis; Seismic isolation.

1 INTRODUCTION

Bridges are one of the most important structures created for transportation purposes. Building these structures is more expensive than regular roads. This is due to the fact that these structures need additional investigations for designing and operation. Precast concrete I girder and voided slab bridges isolated by lead rubber bearings are suitable for low and medium range distances. These types of bridges are more common in countries which steel structures are considered expensive or unreliable because of low quality production in some parts of the world. Investigating the behavior of these structures is essential during strong ground motions. Earthquakes are divided into two main groups: near-field and far-field earthquakes. Far-field earthquakes have minor effect on bridges in terms of base shear and ductility compared to near-field earthquakes which can significantly damage the vulnerable bridges [1]. Near-field earthquakes impose greater structural responses to the seismically isolated bridges compared to the far-field earthquakes [2]. The most important characteristic of near-field earthquakes that makes structures vulnerable is their pulse like behavior near the faults [3 to 5]. Lead rubber bearings are vastly used in bridges [6]. These bearings are mostly made out of a central lead core, rubber and steel plates (*Fig.1*). Lead core absorbs input energy entered to the structure [7]. Lead core yields under shear forces caused by earthquake [8]. The steel plates force the lead core to deform under lateral forces applied to the isolation system [9].

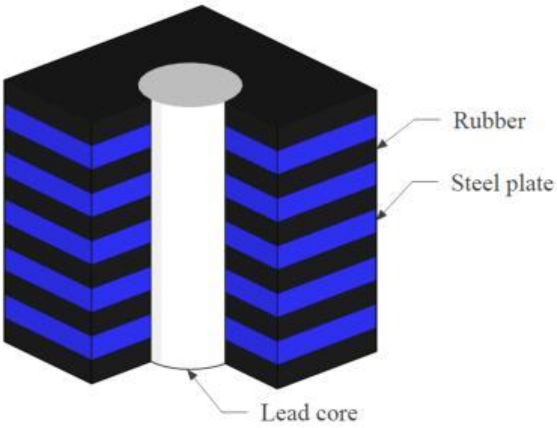

Figure 1. Lead rubber bearing components

2 VERIFICATION

The correct modeling of LRB isolators are investigated in this section. The structure used for verification is a 10 story building illustrated in *Fig.2* which has been studied by [10]. Four LRB isolators are used between the columns of the first floor and the foundation. These isolators properties are given in Table 1. The hysteresis behavior of a single LRB bearing under Chi Chi earthquake record is obtained using SAP2000 software [11] in *Fig.3.* The comparison between the *Fig.3* and *Fig.4* that is related to the research done by [10], shows a suitable similarity which indicates that the modeling of LRB isolators are correct in this research.

Table 1. The LRB isolator characteristics

Properties	Values
effective stiffness (KN/m)	713
initial stiffness (KN/m)	5419
effective damping	0.1
yield force (KN)	59.61
vertical stiffness (KN/m)	200687

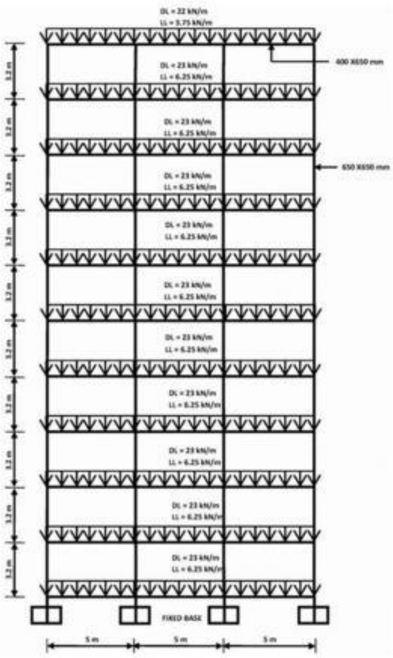

Figure 2. The 10 story building used for verification [10]

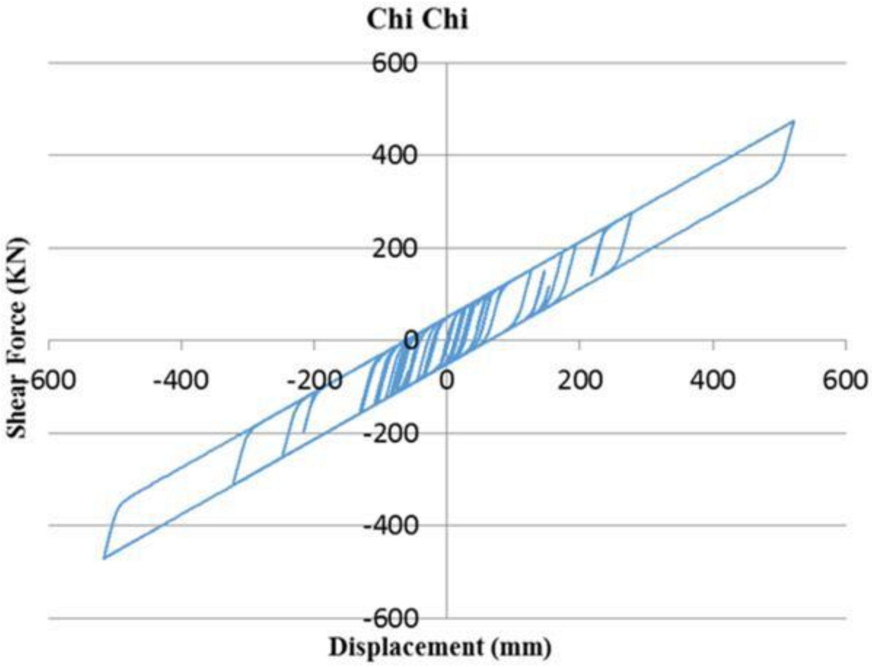

Figure 3. Hysteresis diagram obtained in this study

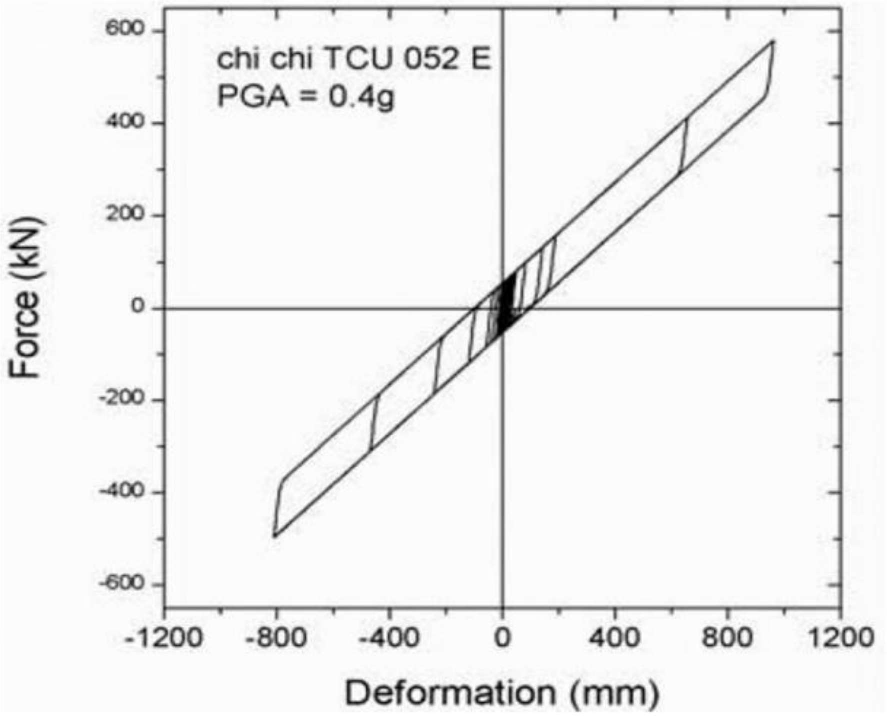

Figure 4. Hysteresis diagram obtained by [10]

3 MODELING

Two precast concrete I girder and voided slab bridges were modeled with the span length of 20 meters. The transverse schematic of these two bridges is illustrated in *Fig.5*. The deck cross sections of precast concrete I girder and voided slab bridges are also shown in *Fig.6* and *Fig.7* respectively. The gravity loads of the considered bridges are the dead load of deck section, pedestrian sidewalk load of 2 KN/m^2 and the moving load of a 400-KN truck which its details are shown in *Fig.8*. The lateral forces applied to the structures are near-field earthquake records shown in Table 2. The selected records are chosen in a way to have similar characteristics such as soil type, distance from epicenter, fault type and magnitude. The LRB isolators properties are exactly the same used in the verification section. The first two modes of the bridges are given in Table 3. According to Table 3 the voided slab bridge has higher period comparing to precast concrete I girder bridge.

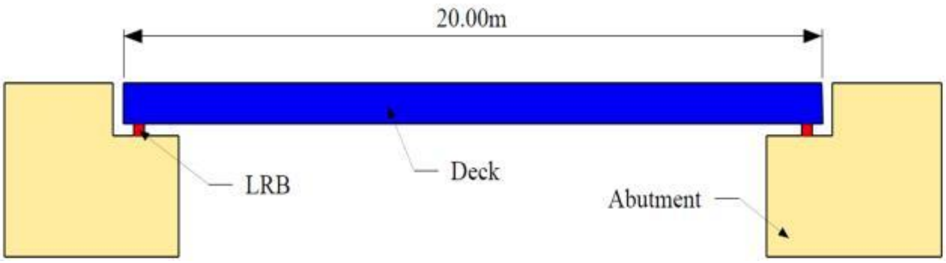

Figure 5. Transverse view of the considered structures

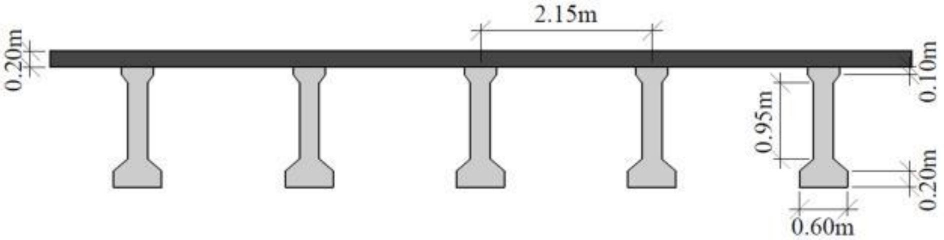

Figure 6. The precast concrete I girder bridge deck cross section

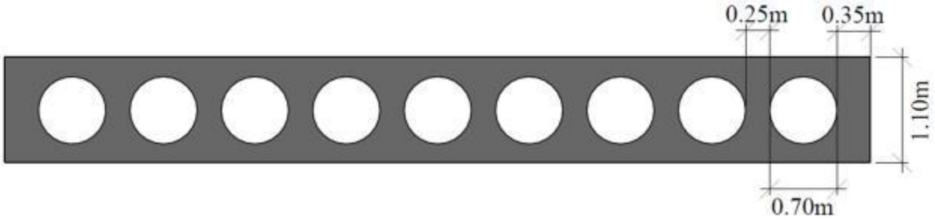

Figure 7. The voided slab bridge deck cross section

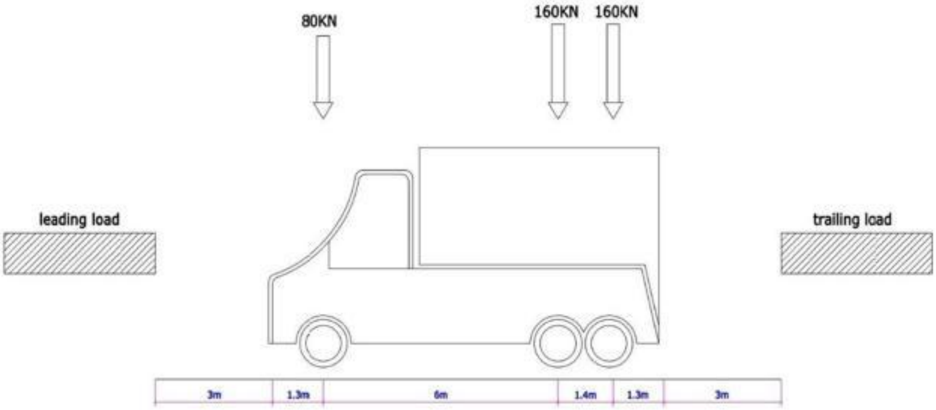

Figure 8. Moving load details

Table 2. The selected earthquake characteristics

Event	Year	Station	Magnitude	Rjb(km)	V_s(m/s)
Parkfield-02, CA	2004	Parkfield - Stone Corral 2E	6.0	5.23	566.33
Chi-Chi, Taiwan-04	1999	CHY024	6.2	19.67	427.73
Chalfant Valley-02	1986	Bishop - Paradise Lodge	6.19	14.97	585.12
Morgan Hill	1984	Anderson Dam (Downstream)	6.19	3.22	488.77
Victoria, Mexico	1980	Cerro Prieto	6.33	13.8	471.53
Basso Tirreno, Italy	1978	Naso	6.0	17.15	620.56
Helena, Montana-01	1935	Carroll College	6.0	2.07	593.35

Table 3. First two modes of the bridges

Bridge types	1st mode (sec)	2nd mode (sec)
Precast concrete I girder	1.456	1.448
Voided slab	1.895	1.895

4 INVESTIGATING THE DECK DISPLACEMENT

Seismic isolation exceeds deck displacement and can cause pounding between the deck and abutments, therefore checking deck displacement is considered as an important issue in this study. Nonlinear time history analysis is used as the most accurate analysis type to determine the deck displacement in different periods of time during selected earthquakes. The maximum superstructure displacements are given in Table 4. As shown in this table there is an erratic behavior between the maximum displacements which shows that deck displacement is highly dependent on the frequency content of the input records to the structures. According to *Figs.9-15* which illustrate the deck displacements through time under earthquake records, there are not significant differences between the deck displacements in precast concrete I girder and voided slab bridges. It can be inferred that LRB isolators performed well in both structures and the weight of the deck did not have noticeable effect on their performance.

Table 4. Maximum superstructure displacements

Bridge Types	Parkfield-02, CA	Chi-Chi, Taiwan-04	Chalfant Valley-02	Morgan Hill	Victoria, Mexico	Basso Tirreno, Italy	Helena, Montana-01
Precast concrete I girder (mm)	7.358	8.366	5.629	26.87	60	11.31	7.657
Voided slab (mm)	6.698	15.6	5.146	21.41	83.41	14.06	7.863

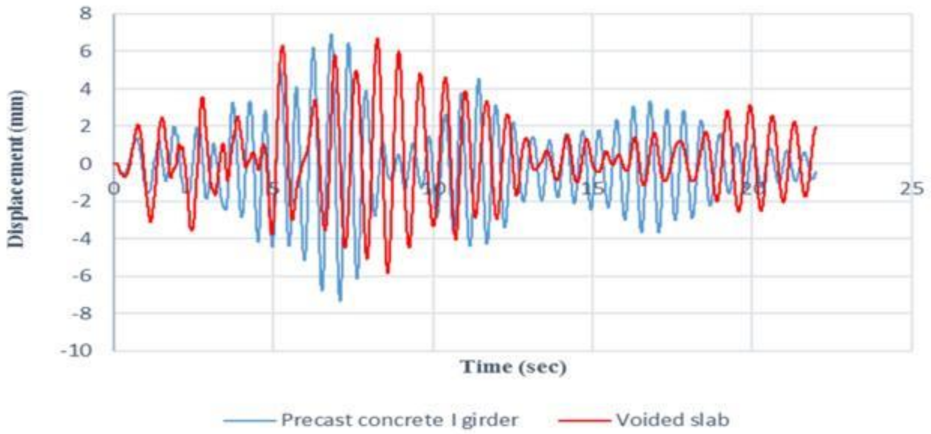

Figure 9. Comparison of superstructure displacement under Parkfield earthquake

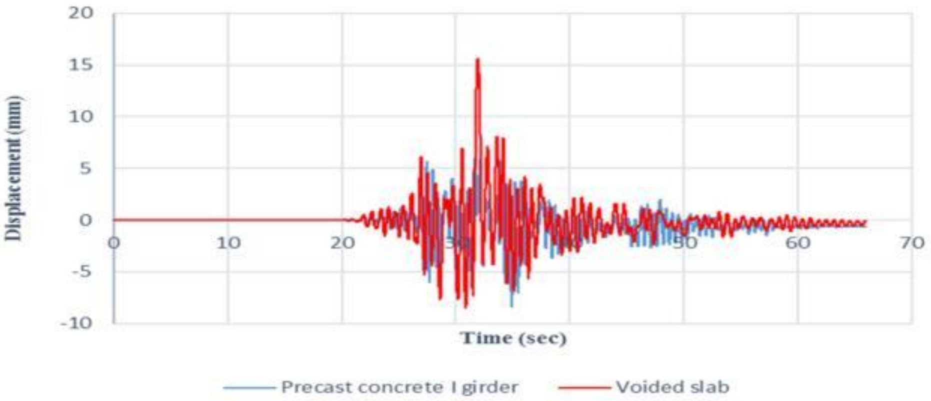

Figure 10. Comparison of superstructure displacement under Chi Chi earthquake

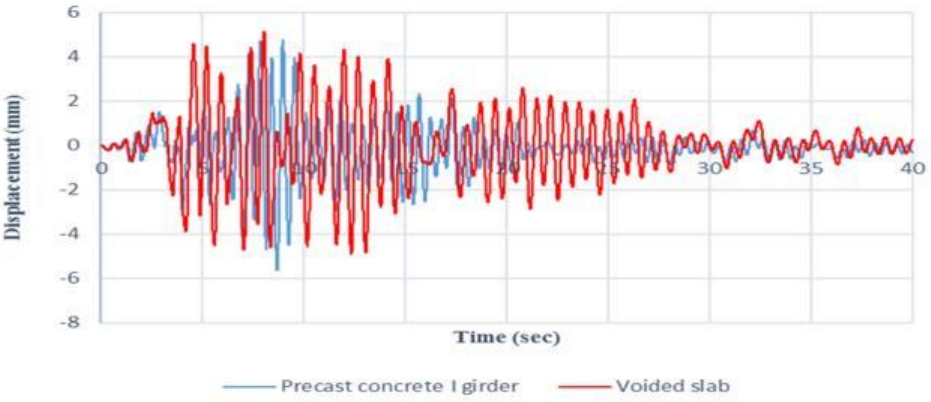

Figure 11. Comparison of superstructure displacement under Chelfant Valley earthquake

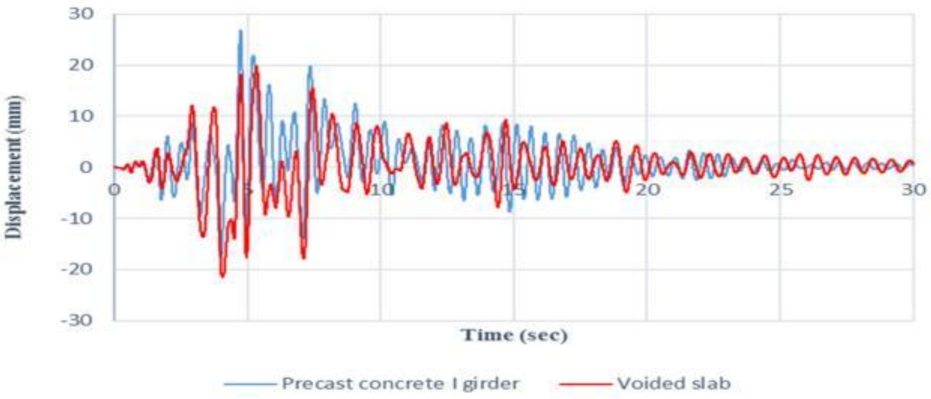

Figure 12. Comparison of superstructure displacement under Morgan Hill earthquake

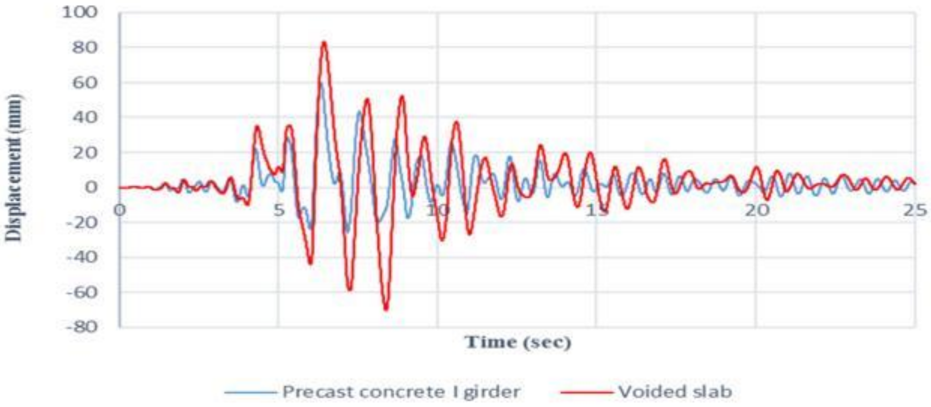

Figure 13. Comparison of superstructure displacement under Victoria earthquake

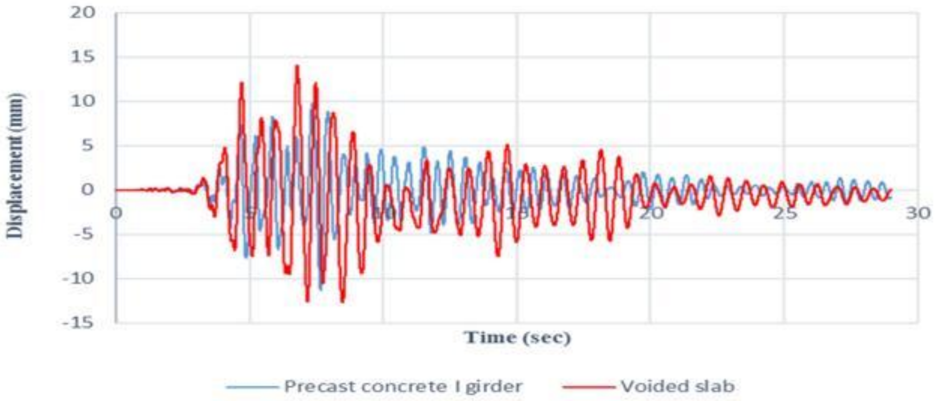

Figure 14. Comparison of superstructure displacement under Basso Tirreno earthquake

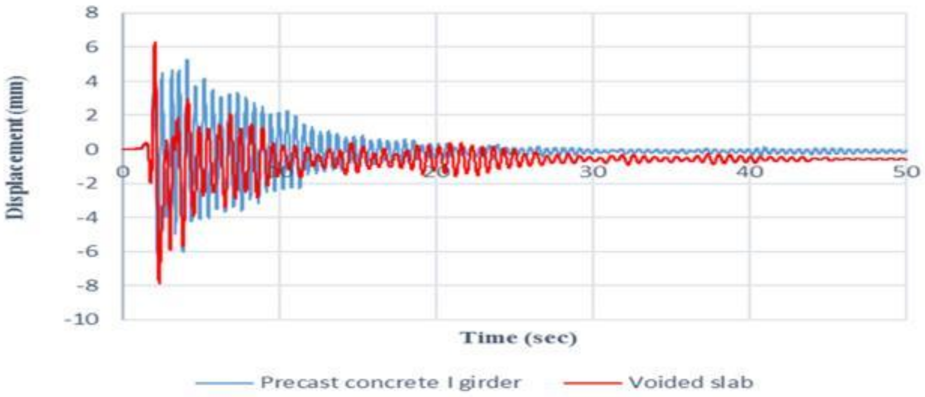

Figure 15. Comparison of superstructure displacement under Helena Montana earthquake

5 INVESTIGATING THE DECK ACCELERATION

The main reason for using seismic isolators in structures is reducing the acceleration applied to the structure. The maximum deck acceleration is given in Table 5. Like previous section there is an erratic behaviour in the obtained data in this table. This uncertain behaviour refers to the difference in the frequency contents of the selected earthquake records. To get a better understanding about this phenomenon the superstructure acceleration time history of precast concrete I girder and voided slab bridges are shown in *Figs.16-22.* According to these figures there are not profound differences in the accelerations applied to the considered structures. The additional weight of voided slab bridge did not have significant influence on the responses of the structures which shows the proper behavior of LRB isolators in both bridges.

Table 5. Maximum superstructure accelerations

Bridge Types	Parkfield-02, CA	Chi-Chi, Taiwan-04	Chalfant Valley-02	Morgan Hill	Victoria, Mexico	Basso Tirreno, Italy	Helena, Montana -01
Precast concrete I girder (m/s^2)	1.524	1.16	1.563	4.751	8.195	2.276	2.006
Voided slab (m/s^2)	1.721	1.19	1.688	4.461	7.768	1.816	1.778

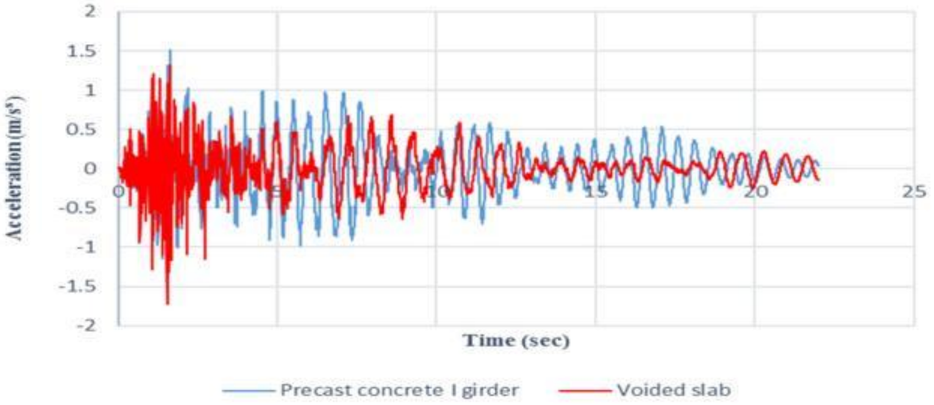

Figure 16. Comparison of superstructure acceleration under Parkfield earthquake

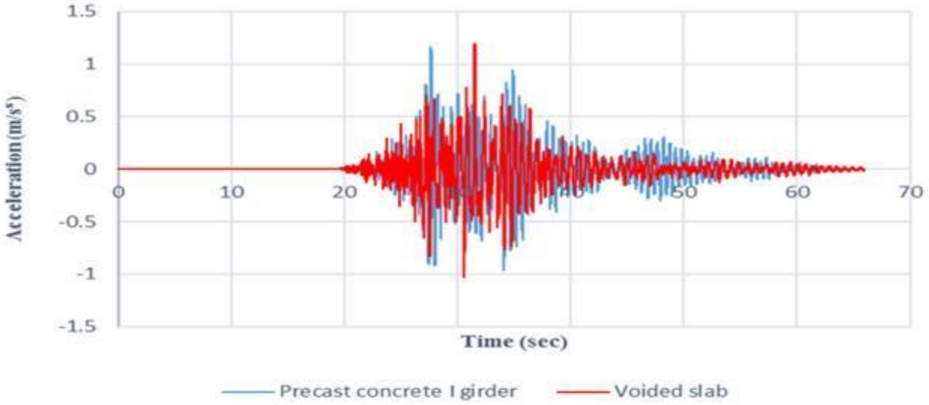

Figure 17. Comparison of superstructure acceleration under Chi Chi earthquake

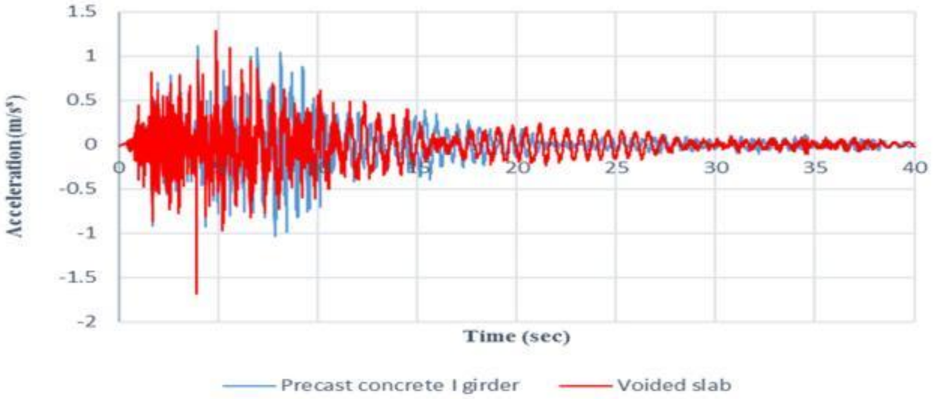

Figure 18. Comparison of superstructure acceleration under Chelfant Valley earthquake

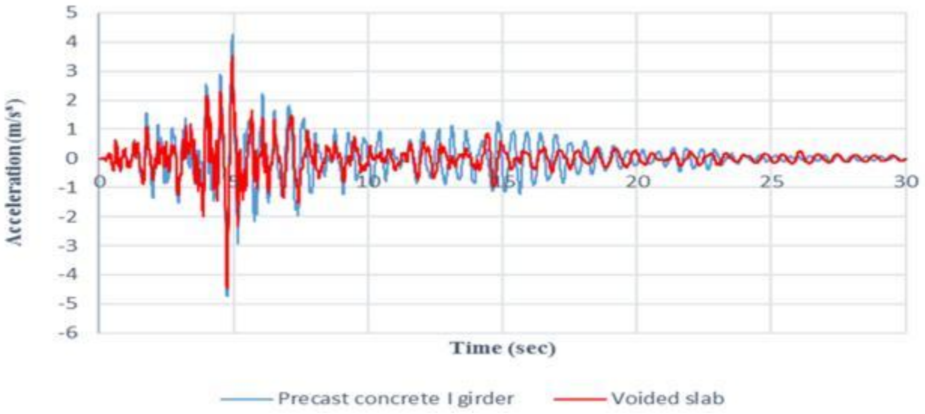

Figure 19. Comparison of superstructure acceleration under Morgan Hill earthquake

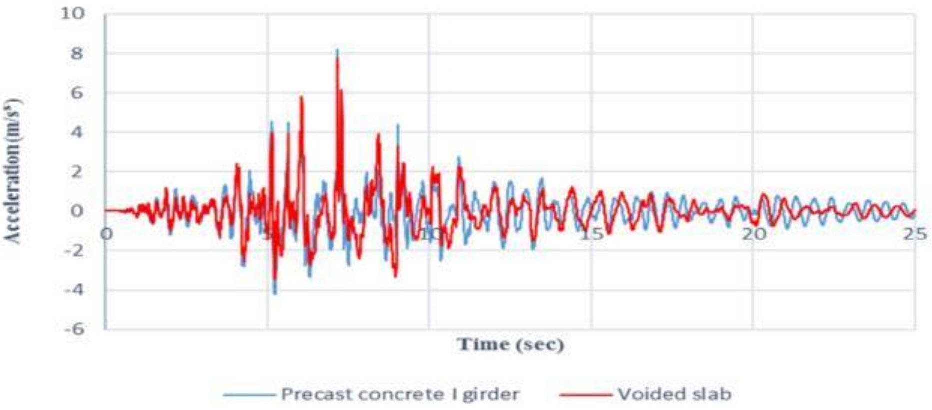

Figure 20. Comparison of superstructure acceleration under Victoria earthquake

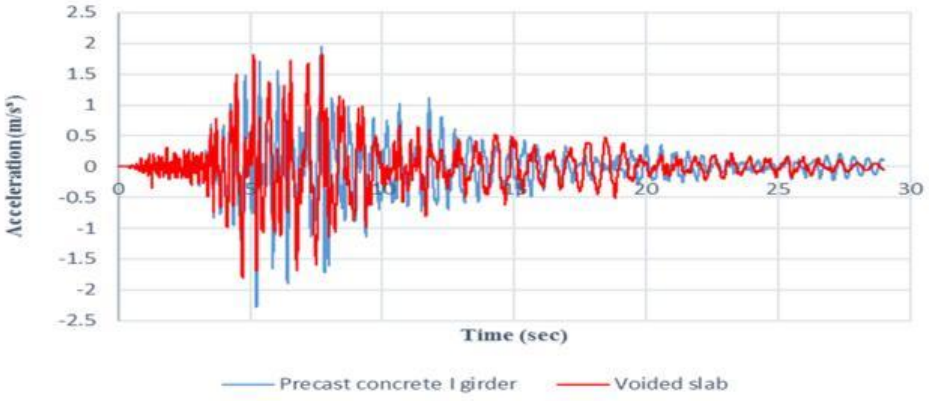

Figure 21. Comparison of superstructure acceleration under Basso Tirreno earthquake

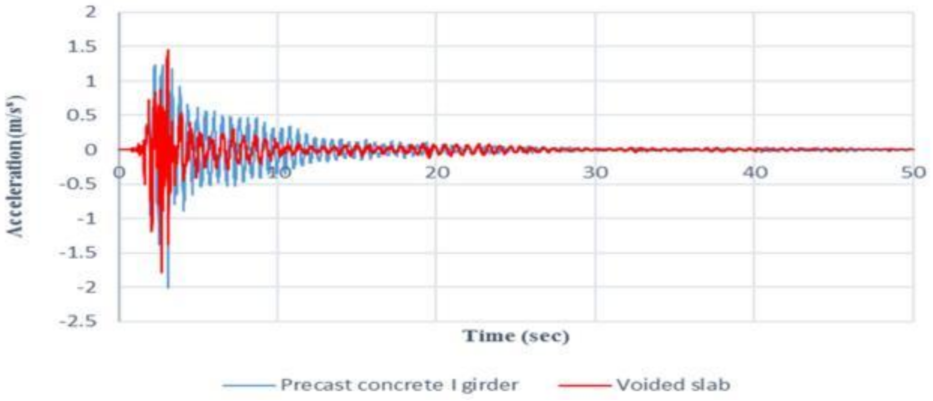

Figure 22. Comparison of superstructure acceleration under Helena Montana earthquake

6 HYSTERESIS DIAGRAMS OF LRB ISOLATORS

It was mentioned in previous sections that LRB isolators are dependent on frequency contents of earthquakes but they performed well in the considered structures despite the difference in their deck weight. To find out how these isolators perform well during strong ground motions, investigating the hysteresis diagrams of these elements are undeniable. Hysteresis diagrams show the performance of a single LRB isolator during a specific earthquake. The hysteresis diagrams of LRB isolators under Victoria earthquake for precast concrete I girder and voided slab bridges are shown in *Fig.23* and *Fig.24* respectively. The area inside these diagrams shows the dissipated energy via the isolator. It is obvious that in voided slab bridge the LRB isolator absorbed more energy compared to the precast concrete I girder bridge. The isolator in voided slab bridge had to move more and resist higher amounts of shear force compared to the other model.

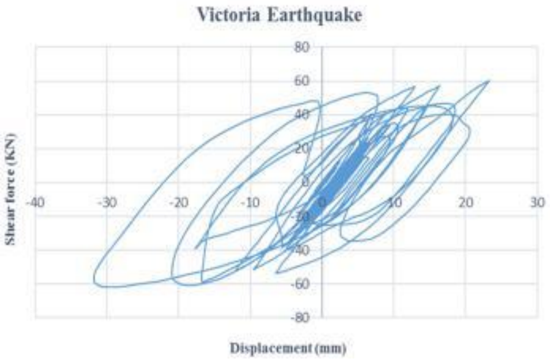

Figure 23. Hysteresis diagram of the LRB isolator installed in Precast concrete I girder bridge

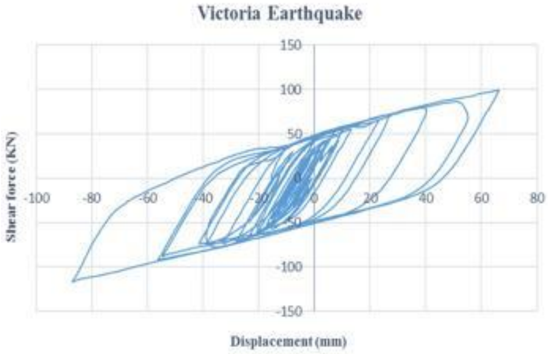

Figure 24. Hysteresis diagram of the LRB isolator installed in Voided slab bridge

7 CONCLUSIONS

The effect of LRB isolators on precast concrete I girder and voided slab bridges were investigated. LRB isolators showed a suitable performance in both cases under near-field earthquakes. In terms of deck displacement and deck acceleration, there was no significant difference between the seismic responses of these two bridges and the results were highly dependent on the frequency contents of the earthquake records. The proper behaviour of LRB isolators were investigated by focusing on the hysteresis diagrams of these elements. It was observed that in the voided slab bridge the isolator had to resist more lateral forces and also move more comparing to the precast concrete I girder bridge to dissipate input energy to the structure.

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