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Arian AGHELFARD[1], Mohammad Sadegh ROHANIMANESH[2], Ali VATANSHENAS[3]

INVESTIGATING THE PERFORMANCE OF BRIDGES EQUIPPED WITH ELASTOMERIC BEARINGS REINFORCED WITH FIBRE UNDER TRAFFIC AND SEISMIC LOADS

Summary. The seismic elastomeric bearings reinforced with fibre is considered as a new technology in comparison to other conventional isolator systems in civil engineering. In this type of bearing, recycled fibres replaced traditional steel plates used in common bearings. Therefore, this type of bearing has been studied in recent years due to both environmental and cost-saving advantages. The shortage of references about the application of this type of bearing in the bridge industry, and particularly the continuous-span bridges, prompted the researchers in this study to investigate the performance of the isolated reinforced concrete box girder bridges with continuous spans. Reducing the acceleration transmission from the substructure to the superstructure is one of the main advantages of using seismic bearings. Based on the study of the structural models, it was found that, in most cases, elastomeric bearings reinforced with fibres showed a suitable performance and reduced the acceleration applied to the superstructure by absorbing the earthquake energy.

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[1] Department of Civil Engineering, Islamic Azad University Central Tehran Branch, Tehran, Iran. Email: arian_aghelfard@yahoo.com

[2] Department of Civil Engineering, Islamic Azad University Central Tehran Branch, Tehran, Iran. Email: m.s.rohanimanesh@iauctb.ac.ir

[3] Department of Civil Engineering, Tampere University, Tampere, Finland. Email: ali.vatanshenas@tuni.fi

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1. INTRODUCTION

With the development of transportation networks, the importance of bridges has increased drastically with the growth in population. Due to the transfer of traffic load, bridges are regarded as important elements of transportation systems. Seismic isolation can be considered as the most important strategy to improve the seismic performance of bridges. The assessment of bridges affected by the near-field earthquakes with large pulses indicates that the seismic response values of bridges are significantly greater than those obtained by a few pulse recordings [1]. Research on the near-field earthquakes began in the late 1970s, however, more attention was paid to its effects on structures, particularly, bridges after the 1990s. Hausner and Hudson were among the first to study this issue. They concluded that the vulnerability of bridges under the near-field earthquakes, even for an average peak ground acceleration (PGA) and earthquake magnitudes was a remarkable value [2]. Investigating the characteristics of the earthquake spectrum in some of the near-field earthquakes, including the duration and frequency, revealed that the impacts due to the near-field earthquakes were very effective on the structure response [3]. Investigation of the dynamical performance of a bridge with reinforced concrete piers under several near and far-field records the PGA of which were scaled to the same value, showed that in the far-field earthquakes, the base shear force and ductility of the structure decreased compared to the near-field earthquakes [4]. Near-field earthquakes include critical pulses. Although these earthquakes may have small magnitudes in Richter, they have a high potential of damage [5, 6, 7].

Experimental studies show that the seismic elastomeric isolators reinforced with fibres can be considered as a suitable choice in structural engineering. When this type of bearing experiences a lateral displacement, parts of its upper and lower sides are separated from the supporting surfaces and the isolator experiences a semi-roll lateral deflection, reducing the effective lateral stiffness of the isolator, and thereby increase of the isolator period, enhancing its efficiency as a seismic isolator. Lateral stiffness is one of the most important mechanical characteristics of seismic isolators. Given the lack of flexural strength in the fibre reinforcement layers and the absence of steel sheets, seismic elastomeric bearings reinforced with fibres exposed to lateral loading go under the unique lateral roll deflection. However, it is noteworthy that in elastomeric seismic bearings reinforced with fibres, if the ratio of bearing height to size is less than a certain value, the reduction in the effective stiffness due to the torsional deflection may cause instability [8]. Another advantage of this type of isolator is its energy absorption due to the internal interaction between the elastomeric layers and the fibre reinforcement [9]. Moreover, the application of fibre bearings due to the use of cheaper materials when compared to other types of seismic isolators is economically advantageous.

2. VERIFICATION

In this section, the verification of modelling was accomplished by comparing the hysteresis performance of the bearing modelled by the authors with the experimental results obtained in one of the recent studies. In the experiments conducted, the researchers designed and produced samples of fibre reinforced elastomeric isolators in certain dimensions and placed them under vertical loading and lateral force. The bearing was located inside a hydraulic jack, with a fixed lower plate and a 1.6 MPa pressure load applied on its upper plate. In addition, in the horizontal direction, the cyclic loading was performed in such a way that the bearing experienced strain values of 25, 50, and 100%, respectively (Figure 1) [10]. In the course of the findings, the researchers exploited the elastomeric seismic bearings reinforced with fibres with the specifications listed in Table 1, including the total thickness of the bearing (H), the total thickness of elastomer layers (T_r), the number of reinforcing layers (n_s), the number of elastomer layers, including the top and bottom cover layers (n_r), the thickness of reinforcing fibre plates (t_f), the thickness of the top and bottom cover layers (t_c), the thickness of the middle elastomer layers (t_r), the width (a), and the length (b). The schematics of the bearing on which the test was carried out is demonstrated in Figure 2. The effective stiffness and damping ratio were also considered to be as 2.248 kN/mm and 0.085, respectively. As depicted in Figure 3, the hysteresis and the experimental graphs exhibit an acceptable resemblance.

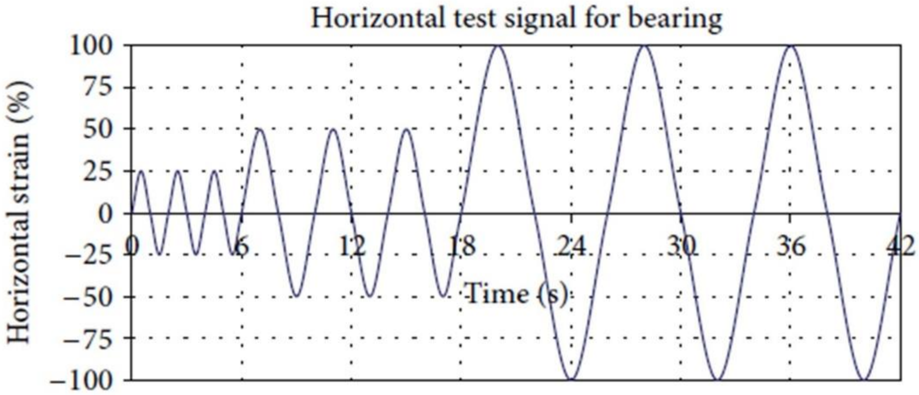


Fig. 1. Lateral loading applied to the sample for verification [10]

Tab. 1

Specifications of the examined bearing

a (mm)	b (mm)	t_r (mm)	t_c (mm)	t_f (mm)	n_s	n_r	T_r (mm)	H
250	400	8	5	0.125	6	7	50	50.75

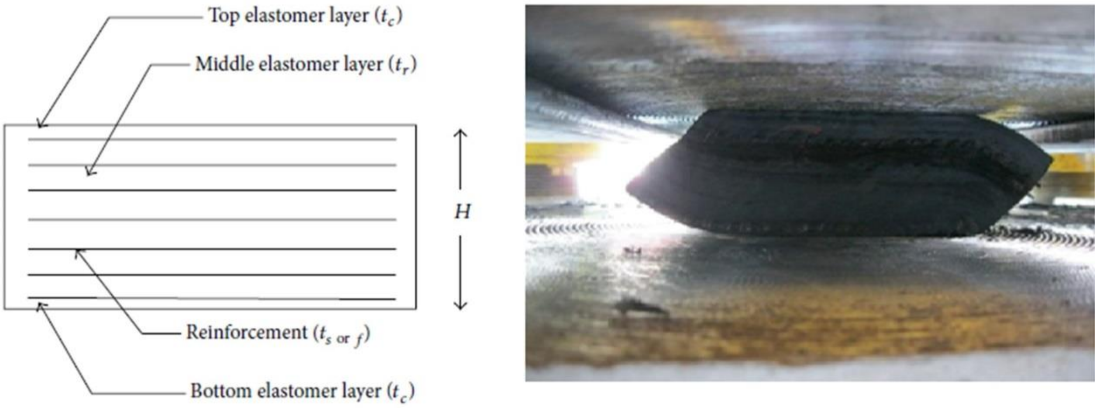
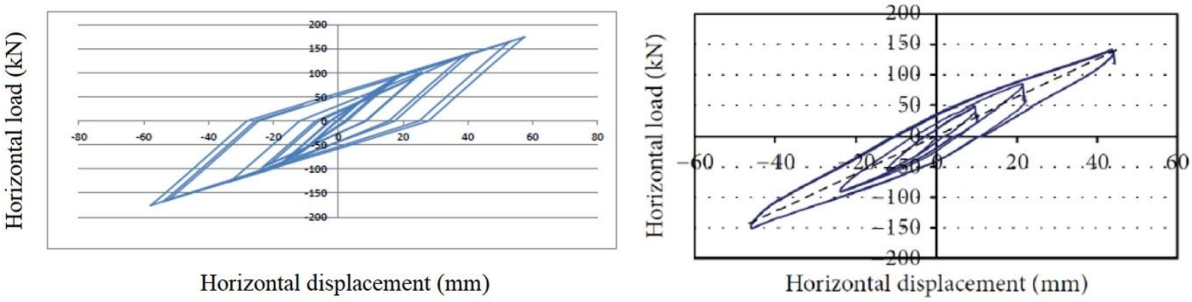


Fig. 2. Components of the bearing [10]



(a) (b)

Fig. 3. Comparison of the hysteresis diagrams obtained in this study (a) and the experimental results (b) [10]

3. SELECTION OF APPROPRIATE EARTHQUAKES FOR TIME HISTORY ANALYSIS

Time history analysis is a type of dynamic analyses of structures. In this method, the effect of earthquake excitation on a structure is measured more realistically compared to other analytical methods. However, due to the more complex and difficult details of this method, engineers often use this method only for designing of special and important buildings. The earthquakes chosen to conduct time history analysis should have characteristics similar to the probable earthquake in the area under study. These characteristics include magnitude, distance from the epicenter, fault mechanism, and soil type. In this study, according to Table 2, five earthquakes with magnitudes ranging from 6 to 7.14 Richter, in near-fault regions, all having a fault mechanism of strike-slip type, were employed. The shear wave velocity of the studied zone was also considered to range from 375 to 750 m/s at a distance of 30 m depth of the ground. To perform the time history analysis, two horizontal records perpendicular to each other were used for each selected earthquake. Furthermore, considered earthquakes were scaled according to [11].

One of the most important limitations considered for the selection of earthquakes was the “Significant duration”. In the occurrence of an earthquake, the measured time from the start of data recording by the accelerometer until the moment of ending the recording is called the earthquake duration. However, the major oscillations of the earthquake are more important in an interval of this time, so that in the intervals before and after this time, the earthquake accelerations are negligible. Investigation of the significant duration of earthquakes was carried out in two ways, the enclosed duration and the arias intensity method. The enclosed duration method is calculated in such a way that the time interval between the first and the last time the acceleration values obtained from the motion of the earth exceed a certain value, which is usually equal to the absolute value of 0.05 g. The resulting value is the earthquake significant duration. It is remarkable that this method has an approximate and simple nature, that is, in the limited moments of the acceleration record, significant pulses may occur, making it difficult to interpret the significant duration through this method. Therefore, in this study, the second method (arias intensity) was observed to achieve results that were more accurate. Scientifically, this method is more valid than the enclosed time method, and its results are more reliable. In this approach, the interpretation is performed on cumulative energy diagrams of earthquake records. Additionally, the time interval in which the accumulated energy due to the earthquake has a certain amount (usually between 5-95%)

regarded as the earthquake significant duration. After examining the two methods above, all the earthquakes selected had minimum significant duration of 10 s. For better understanding, the graphs associated with the two methods are displayed for one of the components of the Imperial Valley earthquake (Figure 4).

Tab. 2

Specifications of selected earthquakes

Event	Country	Magnitude	Fault type	Rjb (km)	Vs (m/s)
Parkfield	US	6	Strike slip	9	466.12
Big Bear	US	6.46	Strike slip	7.31	430.36
Imperial Valley	US	6.53	Strike slip	15.19	471.53
Kobe	Japan	6.9	Strike slip	7.08	609
Duzce	Turkey	7.14	Strike slip	3.93	454.2

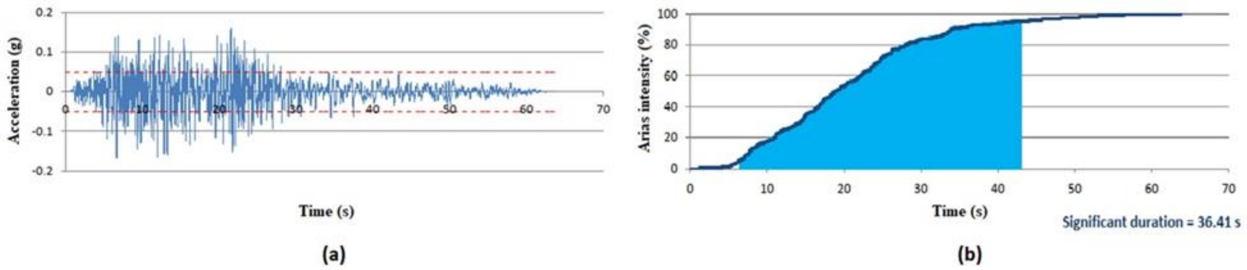


Fig. 4. Significant duration related to one of the Imperial Valley earthquake components by the enclosed time method (a) and the arias intensity method (b)

4. MODELLING

In order to evaluate the behaviour of reinforced concrete box girder bridges equipped with fibre-reinforced elastomeric bearings under near-field earthquakes, three isolated bridges with different spans and identical characteristics, including similar materials, sections, and dimensions were modelled. The bridges modelled had three continuous 40 m (S40), 30 m (S30), and 20 m (S20) spans with the average height of piers of 7.5 m, respectively (Figure 5). The deck cross-section selected for the considered bridges had an area and moment of inertia of 10.42 m^2 and 11.24 m^4, respectively. Given the 16 m bridge width and the assumption of a standard width of 3 m per lane, five lanes were considered for bridges. In each bridge, eight seismic elastomeric bearing isolators reinforced with fibre were exploited, so that in each support, including abutments and bents, two bearings were used. The characteristics of the used bearings were the same as the bearing introduced in the verification section. After modal analysis of bridges, it was observed that the value of the fundamental period of the bridge with a longer span was higher in comparison to the other bridges. So that the first mode periods for the three S40, S30, and S20 bridges were 3.13, 2.65, and 2.17 s, respectively.

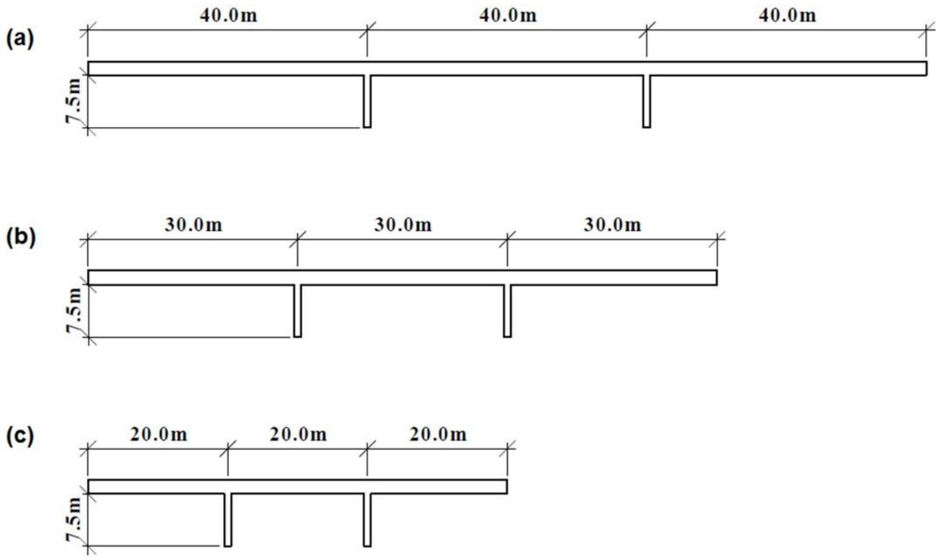


Fig. 5. Transverse view of the bridges S40 (a), S30 (b), and S20 (c)

5. RESULTS OF GRAVITATIONAL LOADING OF BRIDGES

Generally, in terms of loading, the bridge components are divided into two categories of load-bearing and non-bearing components. Load-bearing components are elements with a structural performance and non-bearing components include parts such as cables, tubes, pavement asphalt, insulation, etc., [12]. According to Figure 6, the traffic load was considered as a truck with a weight of 400 kN and a length of 10 m, with the space of 3 m empty in the front and 3 m empty in the back. In the rest of the passage line, a uniform load of 15 kN was placed. Moreover, the load of the sidewalk was 2 kN/m. As shown in Figure 7, the maximum and minimum envelope graphs resulting from the combination of dead loads and the truck moving-load along different bridges were compared with each other. Noticeably, the effect of increasing the span length on the moment applied to the bridges is quite evident, so the higher the span length, the more moment applied to the bridge deck.

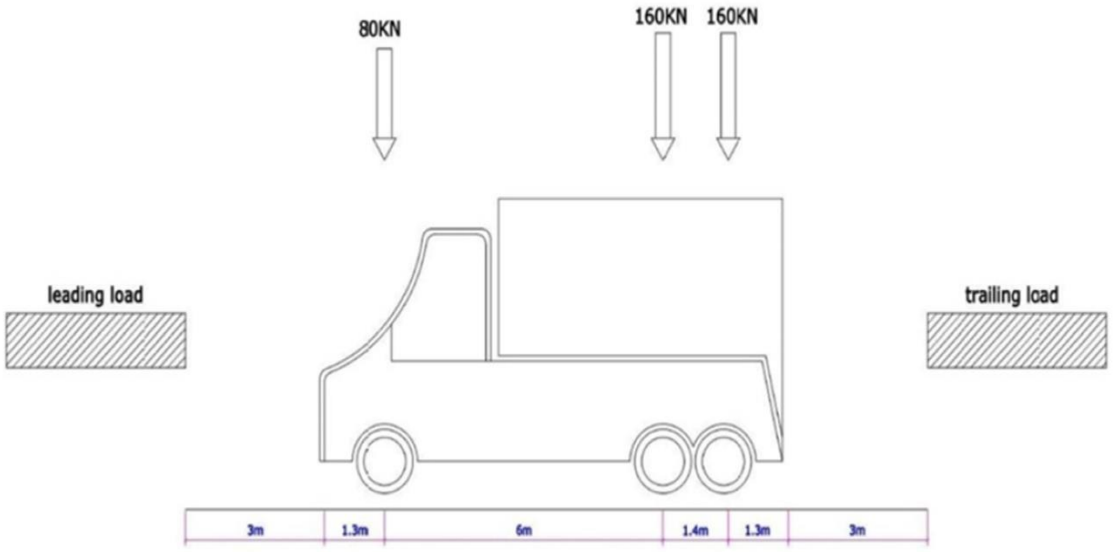


Fig. 6. Traffic load details [13]

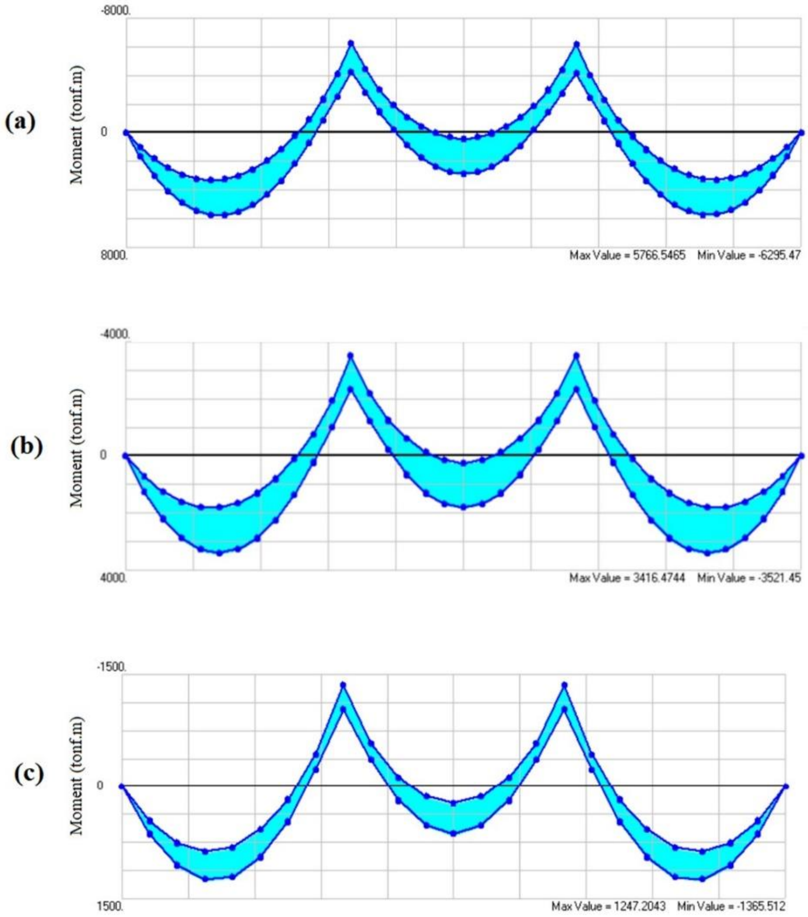


Fig. 7. Results of the maximum and minimum moments along the longitudinal axis of the S40 (a), S30 (b), and S20 (c) bridges

6. RESULTS OF LATERAL LOADING OF BRIDGES

The components forming bridges are divided into two parts of the substructure and superstructure. The main objective of using seismic bearings between the substructure and superstructure was to reduce the transfer of the substructure acceleration to the superstructure by absorbing the energy of strong movements of the earth by the seismic bearings. In fact, the smaller the ratio of acceleration of the superstructure to the substructure in the isolated bridges, the better the performance of the seismic bearings. After comparing the superstructure to substructure acceleration ratio of the bridges examined, it was observed that the maximum superstructure acceleration had a lower value in comparison to the maximum substructure acceleration for all cases, except for one case involving the S40 Bridge under the Kobe earthquake (Table 3). The difference between the values of the acceleration ratio in the bridges under study can be attributed to the dependence of performance of the seismic elastomeric bearing isolators reinforced with fibre on the frequency content of the selected earthquakes. It should be noted that the unexpected rise in the maximum superstructure to substructure acceleration ratio in the S40 structure under the Kobe earthquake was observed only in one pulse in the acceleration time history and, in overall, the bearing showed a suitable performance. Figure 8 illustrates a sample time history of the acceleration applied on the substructure and superstructure under the influence of the Big Bear earthquake on the S20 Bridge.

Tab. 3
Comparison of the values of the maximum superstructure to substructure acceleration ratio

Events	Superstructure to substructure acceleration ratio (%)		
	S40	S30	S20
Parkfield	88.69	90.35	96.17
Big Bear	61.30	61.87	62.81
Imperial Valley	51.06	52.54	55.33
Kobe	125.86	75.57	84.98
Duzce	74.11	73.27	73.45

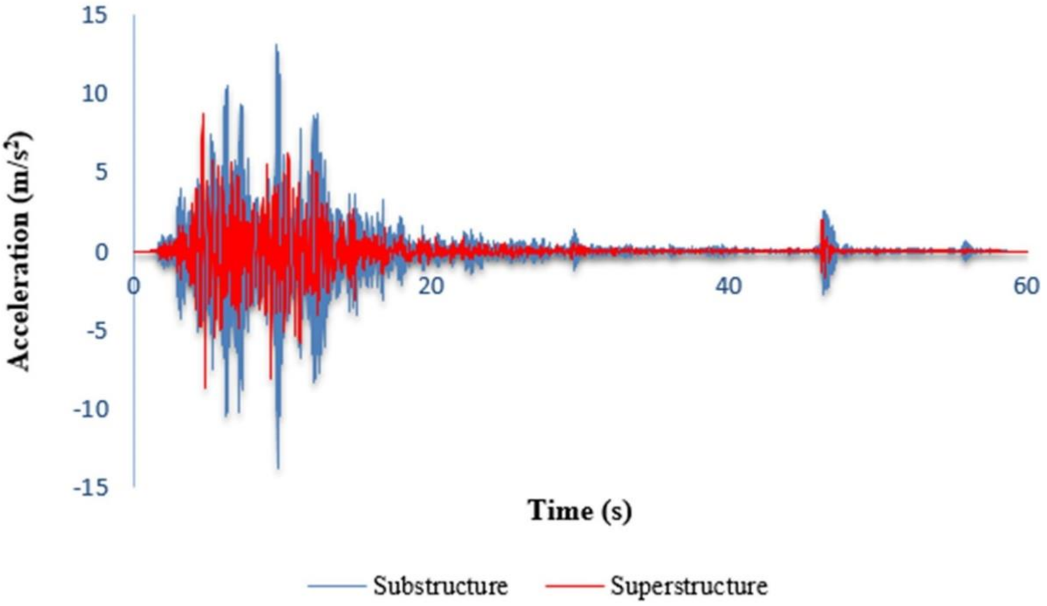


Fig. 8. Time history of the bridge superstructure and substructure accelerations under the Big Bear earthquake on the S20 Bridge

7. CONCLUSION

In this study, the performance of three reinforced concrete box girder bridges isolated with elastomeric bearings reinforced with fibre, which is a novel issue in civil engineering, was investigated. Given the moment envelope diagrams under gravity load, the bridge with a longer span, hence, with more mass compared to the other two bridges, tolerated a higher moment. Due to the continuity of the bridge deck, the maximum moment due to dead and traffic loads occurred in the middle supports. In general, seismic isolation reduced the superstructure to the substructure acceleration ratio, indicating the suitable behaviour of the elastomeric bearing reinforced with fibres in considered bridges. This acceleration reduction ranged from 4 to 50% under near-field earthquakes, suggesting the dependence of the seismic elastomeric bearing reinforced with fibres on the frequency content of the earthquake. The use of this type of bearing in the industry as a substitute for other conventional tools is still being discussed, while civil engineers presently regard this type of bearing with conservative vision. Conclusively, to spread the investigations in this area, the authors recommend generalising studies in the future to other types of bridges and comparing the behavior of fibre bearings with other conventional devices.

References

1. Li Xinle, Hui Jiang, Dan Shen. 2012. „Study on seismic safety performance for continuous girder bridge based on near-fault strong ground motions”. In *2012 International Symposium on Safety Science and Technology*: 916-922. Nanjing, China. ISBN 9781627486156. DOI: https://doi.org/10.1016/j.proeng.2012.08.259.
2. Housner George W., Donald E. Hudson. 1958. „The Port Hueneme earthquake of March 18, 1957”. *Bulletin of the seismological society of America* 48: 163-168. ISSN 0037-1106.
3. Hall John F., Thomas H. Heaton, Marvin W. Halling, David J. Wald. 1995. „Near- source ground motion and its effects on flexible buildings”. *Earthquake Spectra* 11(4): 569-605. ISSN 8755-2930. DOI: https://doi.org/10.1193/1.1585828.
4. Liao Wen I., Chin Hsiung Loh, Shiuan Wan, Wen Yu Jean, Juin Fu Chai. 2000. „Dynamic responses of bridges subjected to near- fault ground motions”. *Journal of the Chinese Institute of Engineers* 23(4): 455-464. DOI: https://doi.org/10.1080/02533839.2000.9670566.
5. Hudson Donald E., George W. Housner. 1958. „An analysis of strong-motion accelerometer data from the San Francisco earthquake of March 22, 1957”. *Bulletin of the seismological society of America* 48: 253-268. ISSN 0037-1106.
6. Bolt Bruce A. 1971. „The San Fernando, California earthquake of February 9, 1971: Data on Seismic Hazards”. *Bulletin of the seismological society of America* 61: 501-510. ISSN 0037-1106.
7. Bertero Vitelmo V., Stephen A. Mahin, Ricardo A. Herrera. 1978. „Aseismic design implications of near-fault San Fernando earthquake records”. *Earthquake Engineering and Structural Dynamics* 6(1): 31-42. ISSN 1096-9845. DOI: https://doi.org/10.1002/eqe.4290060105.
8. Toopchi-Nezhad Hamid, Michael J. Tait, Robert G. Drysdale. 2008. „Testing and modeling of square carbon fiber-reinforced elastomeric seismic isolators”. *Structural Control and Health Monitoring* 15: 876-900. ISSN 1545-2263. DOI: https://doi.org/10.1002/stc.225.
9. Kelly James M. 1997. *Earthquake-resistant design with rubber. 2nd ed*. Springer-Verlag London. ISBN 978-1-4471-0971-6.
10. Karimzadeh Naghshineh Ali, Ugurhan Akyuz, Alp Caner. 2015. „Lateral response comparison of unbonded elastomeric bearings reinforced with carbon fiber mesh and steel”. *Journal of Shock and Vibration,* ISSN 1875-9203. DOI: http://dx.doi.org/10.1155/2015/208045.
11. Vatanshenas Ali, Davood Sharif Bajestany, Arian Aghelfard. 2018. *Guidelines to select and scale earthquake records for time history analysis of structures*. Salehian Publications. ISBN: 978-622-214-003-8.

12. Iranian Standards No. 139. 2000. *Standard Loads for Bridges*. Tehran: Office of the Deputy for Technical Affairs, Bureau of Technical Affairs and Standards, Management and Planning Organization.
13. Vatanshenas Ali, Davood Sharif Bajestany, Arian Aghelfard. 2018. ,,The effect of seismic isolation on the response of bridges". *International Journal of Bridge Engineering (IJBE)* 6(3): 61-74. ISSN 2241-7443.

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