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Effects of Near Fault and Far Fault Ground Motions on Nonlinear Dynamic Response and Seismic Improvement of Bridges

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Abstract

In this study, the dynamic response of bridges to earthquakes near and far from the fault has been investigated. With respect to available data and showing the effects of key factors and variables, we have examined the bridge's performance. Modeling a two-span concrete bridge in CSI Bridge software and ability of this bridge under strong ground motion to near and far from fault has been investigated. Nonlinear dynamic analysis of time history includes seven records of past earthquakes on models and it was observed that the amount of displacement in the near faults is much greater than the distances far from faults. Bridges designed by seismic separators provide an acceptable response to a far from fault. This means that in bridges using seismic separators, compared to bridges without seismic separators, Acceleration rate on deck, base shearing and the relative displacement of the deck are decrease. This issue is not seen in the response of the bridges to the near faults. By investigating earthquakes near faults, it was observed that near-fault earthquakes exhibit more displacements than faults that are far from faults. These conditions can make seismic separators critical, so to prevent this conditions FDGM should be used to correct the response of these bridges. Based on these results, it can be said that the displacement near faults with forward directivity ground motion is greater than far from faults. So that by reducing the distance from the faults, the maximum value of the shearing and displacement of the deck will be greater.

Keywords: Nonlinear Dynamic Response of Bridge; Seismic Improvement of Bridges; the Near and Far Fault; Forward Directivity Ground Motions.

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1. Introduction

Today, destructive effects of earthquakes near fault are well known. In the earthquakes near the fault, the destruction of structures has been well observed. In recent years, the destruction of bridges in near fault has shown that the impact of these earthquakes should be considered in the design of bridges. One of the most important features of this type of earthquake is forward directivity. In the records of acceleration in the near fault, in the records of PGV in near the fault, the meaning of PGV is that created from the PGA [1]. An image of these effects is creating large displacements and is seen in PGD records. The presence of these large values in the parameters of ground motion near the fault is a hallmark of earthquake records, such as the Northridge earthquake, Kobe earthquake, Chichi earthquake in Taiwan, and for near-fault earthquakes, or in other words, earthquakes with a low distance from faults. The purpose of this study is to use the value of recent ground motion data in order to improve the understanding of conventional reinforced concrete and to improve the understanding of the response of the precast concrete bridges to the ground movements. Increasing clarity about FDGM and structural response to this type Land movement leads to direct benefits to near fault, and as a result,

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reduction of the seismic risk and opportunities for improved resource allocation is achieved.

2. Research Background

One of the most important efforts that scientists and researchers have made to investigate the effect of near-fault earthquakes on the behavior of structures is the study of the behavior of buildings due to ground motion near the source of an earthquake with beats, which was developed by Anderson and Bertro [2], and also Lio et al. [3] studied the dynamical behavior of a five-hinged concrete bridge due to earthquakes near and far from the fault. Faghihinejad [4] explores a study entitled "Investigating the impact of the decks adjacent to the bridges under strong ground motion in the immediate vicinity of the fault", in which the main cause of the collapse of the bridges between the decks adjoining the bridge is expressed in extreme earthquakes near the fault. The three-dimensional models, based on the analysis of nonlinear time histories, classified the seventh earthquake record by the finite element method using SAP2000 software. According to the results of his research, the hypothesis of knocking between the decks adjacent to the bridge was the main cause of the bridge's destruction Raphael [5], in his study entitled "The Effect of Near Earth Fault on Long Bridges, yielded results that came to light on a long cable bridge, the results of which showed that the earthquake near the cause of the pulse in its record compared to distant earthquakes, it can result in more force and displacements. Cerqueira Silva [6] studied the application of the vertical component of the earthquake on the foundations through the supports in concrete bridges. In this study, to investigate the effect of vertical component of the earthquake on the seismic behavior of the concrete bridge bridges, four structures of three span concrete bridges with openings of 20, 30, 40 and 50 meters with a box deck and with the executive details of the country modeling and their behavior under the influence of vertical component of the earthquake, were assessed by applying 7 accelerations of different linear and nonlinear dynamics analysis. The results show that the axial force in the column is substantially increased by the vertical movement of the earthquake, so that the axial force of the bridge columns increases by an average of 41%. Also, the change in the plastic width of the maximum columns, which represents the change of permanent member of the member, has increased by an average of 35%. Cofer and Rodriguez [7] came up with findings on 405 and 520 bridges in Washington, DC, where a significant seismic damage could occur if the regular response to the pulse period is FDGM speed. This pulse speed is a result of the fault failure effects and occurs when the slip and propagation coincide.

3. Verification

The accuracy of the results on the Rodriguez research [7] model on bridge 520 and 405 in Washington, DC, was carried out. Bridge 405, 520, and 90 were modeled using CSI BRIDGE software and the results were verified by the results of Rodriguez tests. The concrete deck width is 11 meters and the bridge width is 8.5 meters. The deck system is a cross sectional concrete box with cast in place shafts. The height of the mid pillars is 8 m, and the columns are attached to the deck at the upper end, and on the lower end they are relied on rigid plugs and are assumed to be snug. The interaction of soil and structure is not considered.

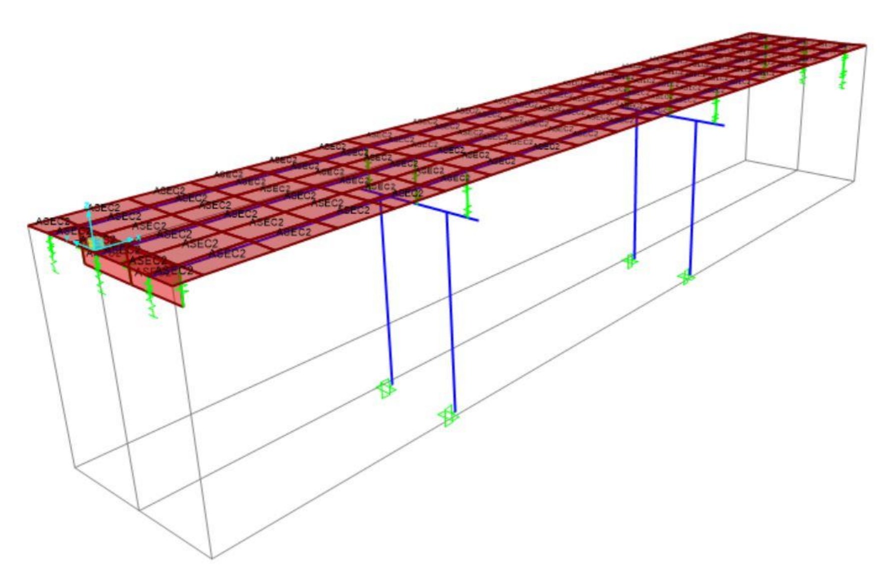

Figure 1. SR520 concrete bridges with box beam deck (prefabricated)

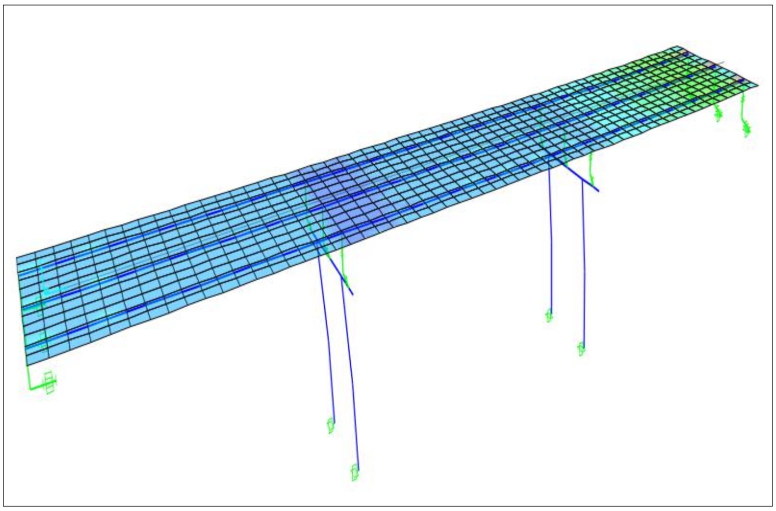

Figure 2. N405 concrete bridges with box beam deck (prefabricated)

According to the results of Cofer and Rodriguez research [7], we check the accuracy of our results. In their study, they selected 520 bridge and the answers in their research were compared with their results in order to prove the correctness of the software's answers.

Table 1. Results of the frequency of the bridge 520 in the Rodriguez study [7]

Eigenvalue Output					
Mode No	Eigenvalue	Frequency		Generalized Mass	Governing DOF
		(Rad/Time)	(Cycles/Time)		
1	61.88	7.8664	1.252	4.36E+05	X-Component
2	869.69	29.491	4.6936	1.01E+07	X,Z-Rotation
3	1237.8	35.182	5.5994	9.92E+05	X,Z-Rotation
4	1434.8	37.879	6.0287	2.46E+05	Y-Component
5	1844.5	42.984	6.8354	1.28E+07	
6	3163.8	56.248	8.9522	97266	

Table 2 .Results of the frequency of the bridge 520 in the CSI Bridge software

Eigenvalue Output					
Mode No	Eigenvalue	Frequency		Generalized Mass	Governing DOF
		(Rad/Time)	(Cycles/Time)		
1	61.87956823	7.856785792	1.250675382	4.36E+05	X-Component
2	869.6893574	29.48984545	4.693564259	1.01E+07	X,Z-Rotation
3	1237.784328	35.09757523	5.585619951	9.92E+05	X,Z-Rotation
4	1434.781138	37.8789365	6.012956351	2.46E+05	Y-Component
5	1844.46034	42.98505857	6.854311111	1.28E+07	
6	3163.778132	56.23697036	8.946752098	97266	

According to the results of the current research for Bridge 520 in Washington, DC, using the Moquegua accelerometer, the analysis and validity of the results of modeling in the CSI Bridge program, are consistent with Rodriguez's research charts, analyzed by ABAQUS software. Table (2) is also the result of 520 bridge analysis, which at T = 0.8sec is a frequency of 1.25 in both software that proves to be consistent with the results of the accuracy of the results of CSI BRIDGE software analysis.

4. Materials and Methods

The acceleration maps used for analysis in the software were presented in the following forms. There are also two ways to improve the bridge:

1- Use of extension dampers in bridges
2- Using seismic separators on bridges

Table 3. Properties of the selected earthquakes

V/H	PGA (g)			Distance from the fault (KM)	Magnitude (Mw)	Station	Time (s)	Chosen record	Number
	Vertical	Horizontal	Longitudinal						
1.605	0.522	0.3	0.34	10.05	6.7	Northridge	1994.01.17	Sun Valley	1
1.237	1.008	0.64	0.81	...	6.6	Bam	2003.12.26	Bam	2
1.045	0.538	0.49	0.51	12.56	7.37	Bam	1979.06.20	imperial valley	3
0.748	0.724	0.9	0.96	20.95	7.6	CHY080	1999.09.20	Chichi	4
1.042	0.696	0.58	0.66	21.22	8.4	PERU	1998.11.04	Moquegu	5
1.450	0.515	0.31	0.35	25.12	6.7	Artela	1994.01.17	Northridge	6

5. Modeling

In this research, the seismic performance of three bridge models with similar specimens with different conditions was investigated in CSI BRIDGE software. The first bridge is 66 meters long, consisting of an intermediate tripod and eight supports on the hull. The second bridge has the same characteristics as the first bridge, except that the supports and its base are separated by seismic separators (LRBs). In addition to the profile of the second bridge, the third bridge has additional extension dams on the rollers. Each of these bridges was subjected to six earthquakes near and near the fault of nonlinear time analysis (3 earthquakes in soft soil conditions and 3 earthquakes in hard soil). The first bridge was simple and without a seismic separator and an extension mirror, the second bridge was based on the first bridge, with the change that seismic separators on top of each base (between the base and the deck), as well as in the elementary backbone and the end of the bridge, in which a total of 10 separators were used in the model. And the third bridge was based on the second bridge, which in its original and end points, in addition to the seismic separators, included extension dams, which were supplemented by a total of six dampers. In Table 4, the bridge information studied is fully described.

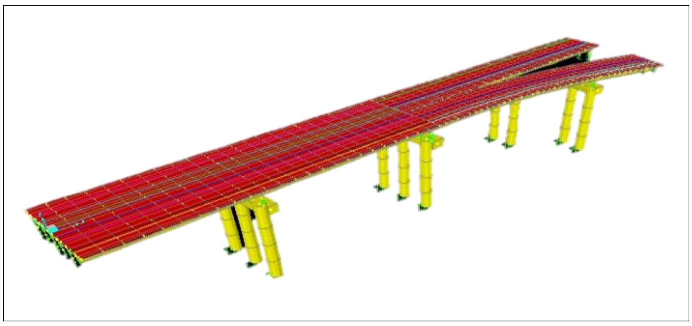

Figure 3. Simple concrete bridges with box beam deck (prefabricated)

Table 4. Specifications of the bridge studied

concrete with Two-span	General specifications
61 (m)	Total length
30.5 (m)	Span length
11(m)	Deck width
Variable as a Parabola from 3 meters on the support to 1.2 meters	Deck depth
3 piers and 8 meter	Number and depth of each pier
Rectangular pier with a length of 1.5 (m) and a width of 1.2 (m)	Dimensions of the pier
9 (m)	capital of a column Length
Rigid	Details of the supports
articulated coupling	Connect the deck to the abutment
Rigid	Connect the deck to the pier
300 (kg/cm^2)	f'_c (beam)
250 (kg/cm^2)	f'_c (pier)
250 (kg/cm^2)	f'_c (Superstructure)
AIII	bar

6. Results

In the assessment of the main subject of the study, which is the effect of near-and-far earthquakes on the bridges, the results of the dynamic analysis of the time history for the displacement of the bridge in the near area is illustrated in Figure 10.

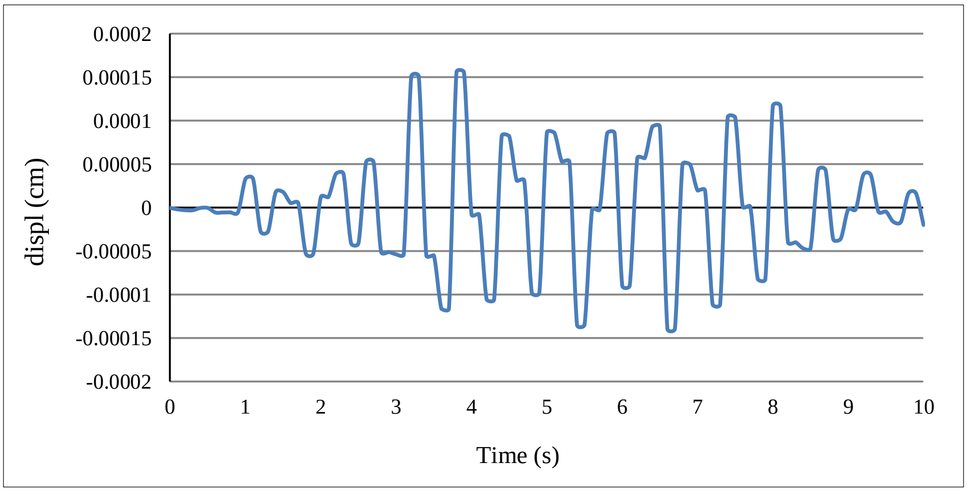

Figure 4. Time-displacement graph for the earthquake near the fault

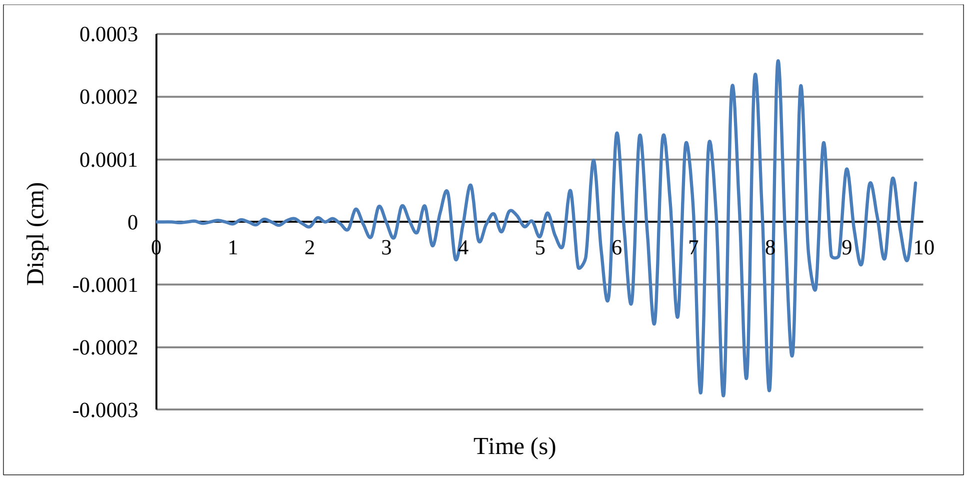

Figure 5. Time displacement graph for the earthquake far from the fault

To calculate the acceleration on the deck, we select the point on the top of the deck, which is exactly on the separator (Joint 345). We examined the acceleration at this point in both horizontal directions (Ux, Uy).

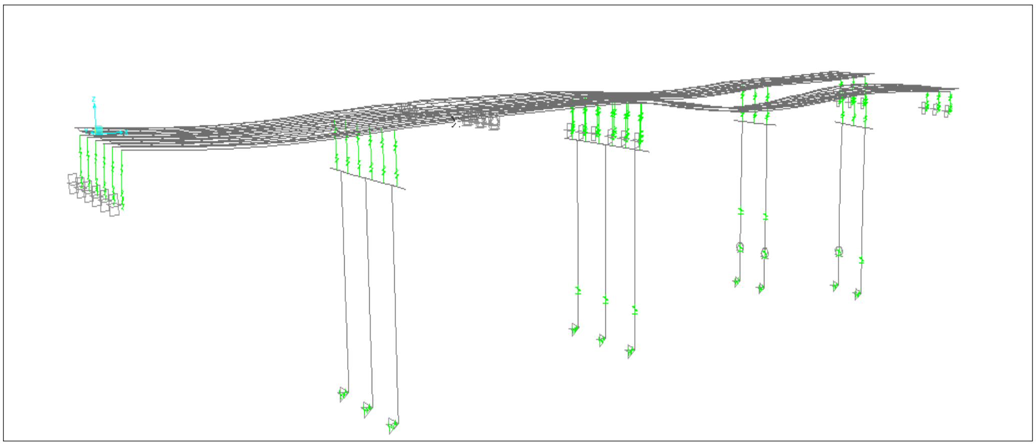

Figure 6. Deformation created in modeling bridge has a damper (in soft soil)

Table 5. Results of near and far earthquakes in terms of horizontal and vertical displacements in a simple bridge

Soft Soil			Stiff soil		
	UX(cm)	**UY(cm)**		**UX(cm)**	**UY(cm)**
NR	21.2	57.3	NR	68.8	57.2
SN	72.4	97.9	SN	66.4	67
CHI	38.7	59	CHI	18.8	44.6
MOQ	104	206	MOQ	97.3	134
IV	92.5	103	IV	69.3	130
BAM	99.3	150	BAM	137	185

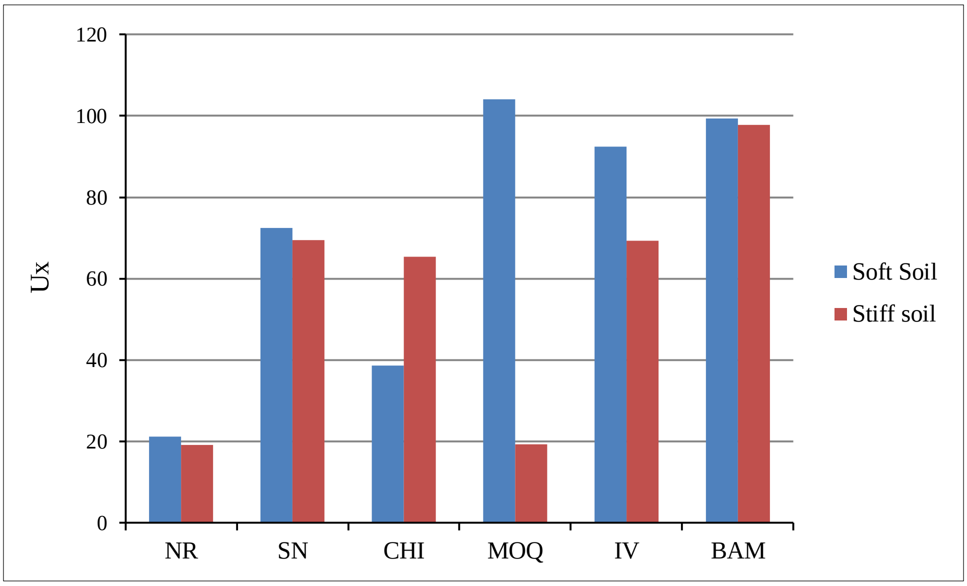

Figure 7. Comparison of horizontal displacement on a simple bridge in hard and soft soils

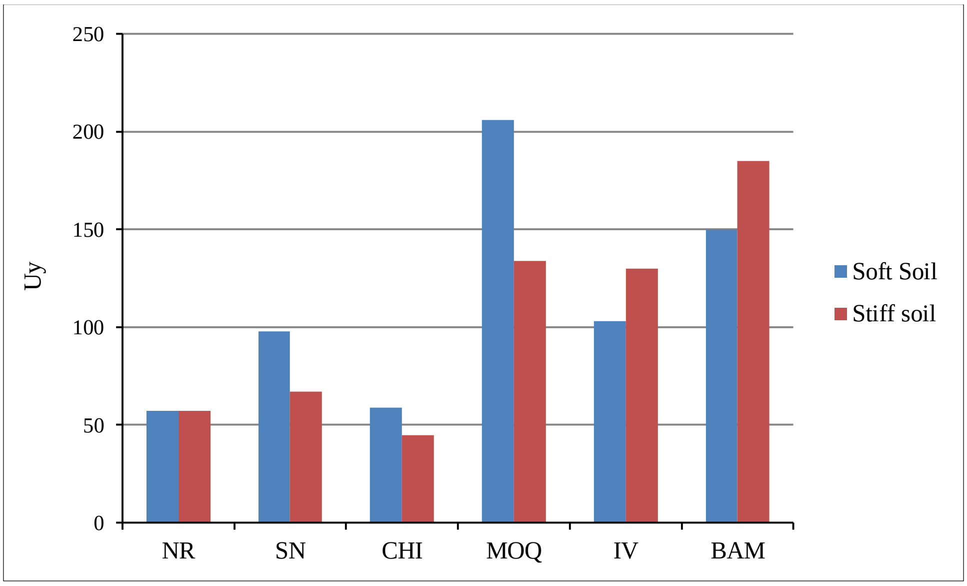

Figure 8. Comparison of vertical displacement on a simple bridge in hard and soft soils

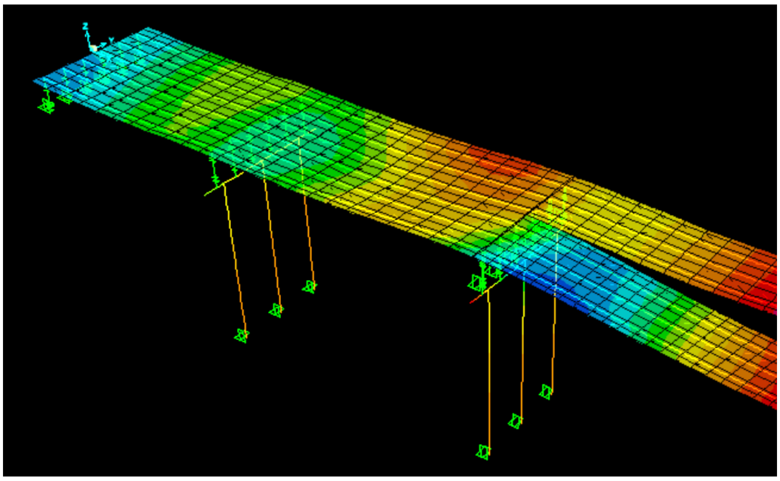

Figure 9. **The deformation generated in the modeling of the bridge has a separator (in soft soil)**

Table 6. Results of distant and near earthquakes in terms of horizontal and vertical displacements on a bridge with a separator

	Soft Soil			Stiff soil	
	UX(cm)	**UY(cm)**		**UX(cm)**	**UY(cm)**
NR	29.5	37.6	NR	41	28.1
SN	34.2	35.3	SN	36	39
CHI	36.1	43.5	CHI	35	52.1
MOQ	52.2	52	MOQ	47.4	41.8
IV	43.4	42.5	IV	44.4	23
BAM	74	74.8	BAM	84.2	91.2

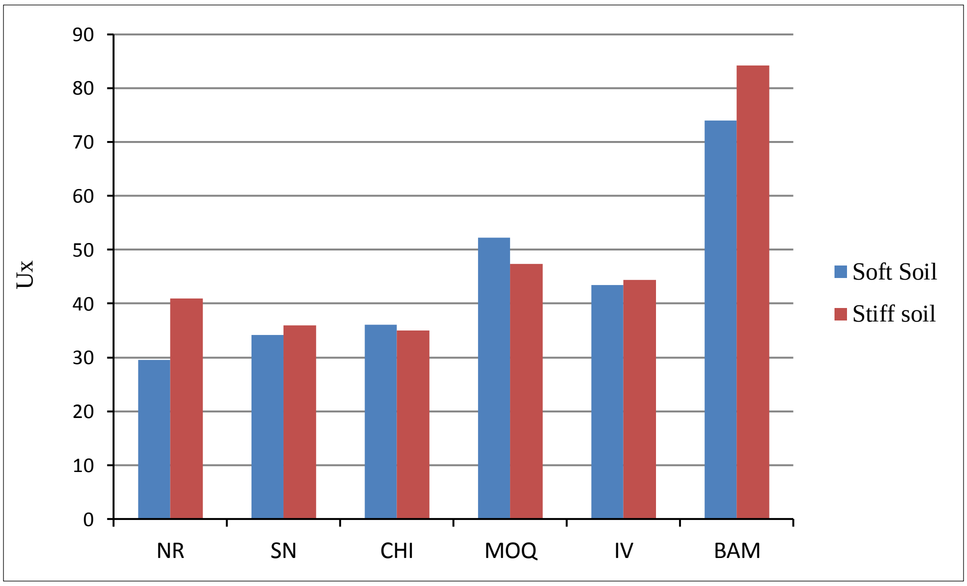

Figure 10. Comparison of horizontal displacement in a bridge with a separator in hard and soft soils

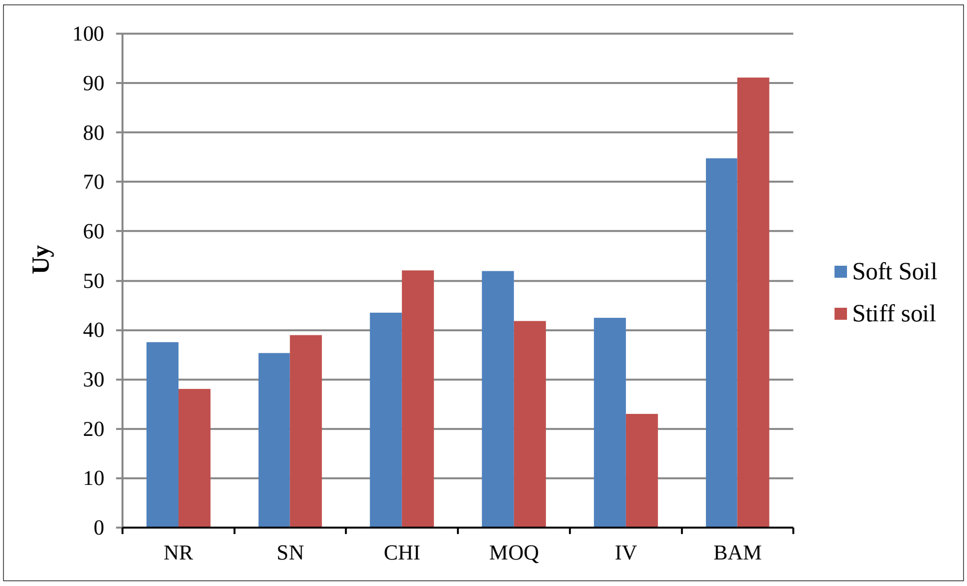

Figure 11. Comparison of horizontal displacement in a bridge with a separator in hard and soft soils

Table 7. Results of distant and near earthquakes in terms of horizontal and vertical displacements in the bridge with separators and dampers

	Soft Soil			**Stiff soil**	
	UX(cm)	**UY(cm)**		**UX(cm)**	**UY(cm)**
NR	23.1	60.1	NR	56.9	82.5
SN	26	158	SN	40.7	165
CHI	69.6	199	CHI	22.3	62.3
MOQ	82.9	28	MOQ	153	200
IV	76	153	IV	96.7	144
BAM	87.8	70.3	BAM	56.3	113

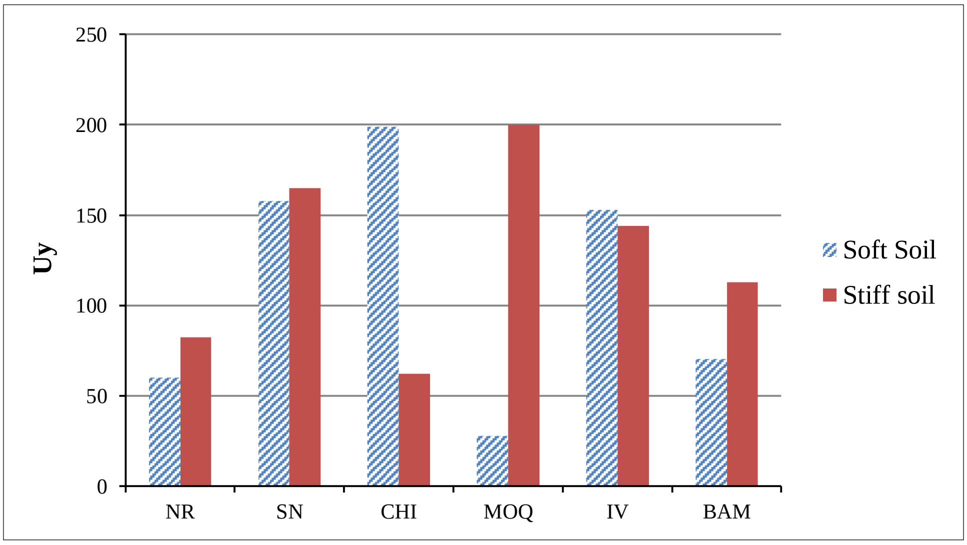

Figure 12. Comparison of vertical displacement

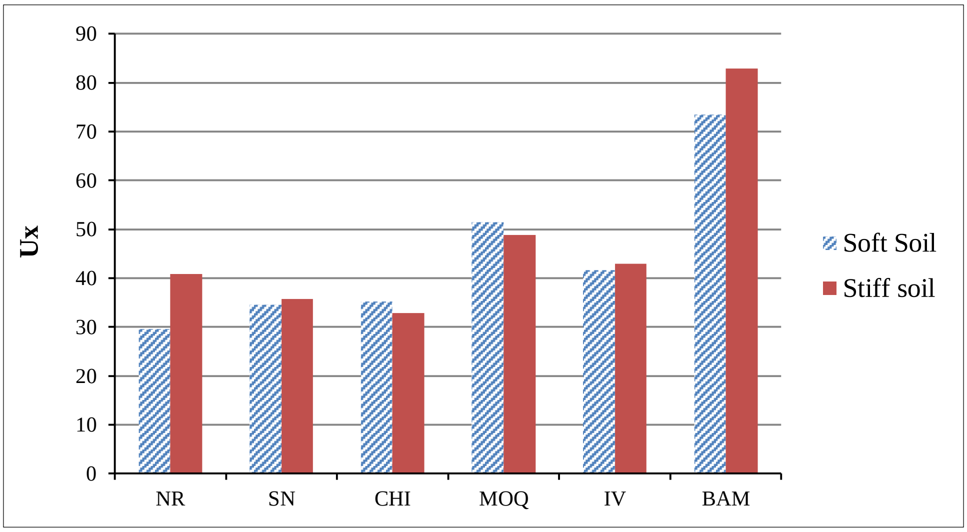

Figure 13. Comparison of horizontal displacement

Using the obtained tables and figures, it is inferred that the use of seismic mirageous separators, with stiff soil under the bridge, has no adequate result in terms of horizontal and vertical displacement and further investigation is needed, but in soft soils, the use of dampers and separators has, on average, has had a good result in terms of reduced displacement.

7. Results and Discussion

By applying seismic separators, the total displacement responses of the entire structure increase due to non-elastic displacements of separators, but the relative lateral displacement in the middle of the deck and the crowns in the midsole in the separation mode decreases significantly, depending on the type of bridge and type of acceleration. The reduction rate will be lower if the base is taller.

In the case of a conventional or unseparated bridge, the main shape of the bridge vibration is primarily the vertical movement of the deck. The greater the side deck (lateral) stiffness of the bridge, the greater the shape of the bridge vibration. In a bridge of a short crater with deep metal shafts, the main vibrational shape is the same as the lateral transmission mode, but in longer and more flexible bridges, the lateral transmission of the bridge occurs in higher modes. Seismic separation transforms the vibrational mode of the lateral transmission of the bridge into the main vibrational mode of the bridge, due to the damaging effects of the earthquake on the plume.

With increasing initial stiffness of the separators, the principal period of the structure, which in the isolated state is the same as the lateral transmission mode, decreases; therefore, the base cut of the structure increases and closes in on the cut of the base of the unseparated state; this is seen in more resilient bridges and the effect of reducing forces is felt by more seismic separation. In fact, as it was said, the more resilient the bridge, the effect of seismic separation is greater in reducing the force responses and displacements.

By increasing the period of the structure, the amount of waste between the responses of the near and far reaching areas increases sharply. In the case of bridges, it can be said that if the bridge has legs with high deflection and built in the vicinity of the fault, the length of the bridge deck should be sufficiently large for displacements. In buildings and at distances more than 15 km from the earthquake center, there isn’t much difference between the maximum degree of class deformation, but near the fault there is a great difference between the maximum degree of deformation. Tall dams with long periods (dams with a height of 60 m) are more accelerated in near-fault earthquakes than distal earthquakes. In other words, with long distances from the earthquake energy release area (Earthquake surface center), tall dams have a maximum crown acceleration. This issue can be seen in clay dams and sand dams, which can be due to the long period of dams, as well as the long period of earthquake acceleration near the fault, which decreases as time passes from the center of the earthquake. And its effect on dams with a long period of time is lower, and vice versa, the effect of earthquakes far from fault on longer dams increases.

Near-fault mappings have a shorter duration of time than distant faults, and in speed maps near the fault, there are one or more pulses of high amplitude and percussion pulses that increase the need of rigid structures in near faults earthquakes. Also, the increase in the ratio of pseudo-momentum to the natural period of the structure, as well as the increase in the ratio of acceleration of the earth to the structural absorption resistance, increases the nonlinear response and damage to the structure, and the concentration of the deformations in the lower classes of the building results in the lowered effect of P-Δ in the classes.

In bridges, with increasing distance from the fault, the maximum displacement varies and similarly, in homogeneous clay dams with a high elevation, decreases with increasing distance from the maximum acceleration fault on the dam crest. But in homogeneous clay dams with shorter heights or with a low natural period, the opposite is observed, so that, at distances away from the fault, an increase in maximum acceleration occurs at the dam's crown. The behavior of this type of dams is similar to that of a natural periodic bridges that, as far as the seismic fault is concerned, the maximum displacement of the bridges increases. This could be due to the long period of structures and also the long period of earthquake acceleration near the fault, which, as far away from the earthquake release point, accelerates and reduces the effect on long structures. On the contrary, the effect of earthquakes far from fault on more short structures is seen.

Engineering structures with similar natural period of time exhibit similar behavior due to earthquakes near the fault zone and far from the faults. One of the factors affecting the behavior of structures in the earthquake is the proximity of the period of the structure and the period of earthquake acceleration. Therefore, because the near-field earthquakes have a longer period than the period of acceleration of earthquakes, engineering structures such as buildings, bridges, and earth dam are homogeneous with a longer period in the near-fault zone and short clay structures show a more critical behavior in areas far away from the fault. Therefore, it is optimal to consider special measures for designing high-rise structures that are built near the fault.

8. Conclusion

In general, the results indicate that the effects of near-field earthquakes on the displacement of the structure are greater than the distal earthquake, and it is a considerable and significant difference, that the effects of near-fault zone earthquakes on seismic parameters is more destructive than the distal area.

With the increase of the initial stiffness and separating force, the effective stiffness of the entire structure increases and the effective period of the bridge decreases. Thus, with the same geometry, it is possible to reduce the number or thickness of the rubber layers, and the displacement of the design, both from the uniform load method and from the time history analysis, is reduced, but the dimensions of the separator in the plan also increases. It can be concluded that this reduces the shear strain of the separator.

In bridges where the lateral stiffness of the base members is relatively low (the height of the columns is high), the amount of shear force reduction in the midsole in the isolated conditions is less than that of the conventional bridge. Another reason for this is that the role of seismic separation in these bridges is the balance of the power response between the various components of the substructure, so in these bridges, with a significant reduction in the shear force in the crates, there is a significant reduction in the base cut. Therefore, in bridges with more flexible intermediate bases, the role of seismic separation is mainly the reduction of forces in the crates and, consequently, the balance between the response forces in the components of the infrastructure (the crates and the middle base).

With the increase of the stiffness of the separators, the shear force generated in them increases and as a result, their maximum displacement increases, which leads to an increase in the lateral displacement of the deck. Due to the limitation of the maximum deck displacement, it should be used with a suitable initial severity. By increasing the force of the separators (flow limit), a greater shear force is produced in the separators, and as a result, the cutting force is transferred to the midpoints and the shells and the lateral displacement of the base of the head the maximum displacement of the deck is increased.

As the ratio of the secondary hardness to the initial increases, with the same initial hardness, the maximum displacement of the separators often decreases; therefore, it can control the displacements, but increases against the shear force produced in the separators. The result is that the shearing force is increased in the components of the auxiliary and consequently in the base cut. The higher the severity of the separation, the increment will be higher.

By increasing the separation force, the viscous slip ratio is increased according to the uniform Ashtou load method, but with increasing initial separation difficulty, this ratio does not necessarily increase, but in lower yielding forces, if the initial hardness increases, this reduces ratio but in high yielding forces, with the increase of the initial hardness, the damping ratio also increases. The harder the separator moves after rising, the total effective thickness of the bridge is increased, but the effective period of the bridge and the viscous ratio of the separator is reduced; so, if the bi-directional behavior of the separator reaches the full elastoplastic state, its efficiency will be greater. Based on the division-rule of the Eurocode, the designed separators are part of a high-damping rubber separator group. Since the viscosity reduction ratio is generally between 0.15 and 0.2 (15% to 20%).

By increasing the number of separators, the forces and loads applied to each separating unit decrease, so its geometric dimensions decrease, but it is noteworthy that with increasing the number of separators on the bridge, the total effective stiffness also increases and this reduces the effective period of the isolated bridge, so (in terms of limits imposed by the bridge structure and also the cost of each unit) an optimal mode for the number of separators used in bridges should be calculated.

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