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Research Article

Effect of bending and shear performance of steel coupling beams under near-field and far-field earthquakes

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ABSTRACT

This study examines the bending and shear performance of steel coupling beams under near-field and far-field earthquakes using ETABS Software. For this purpose, four sample 10-story buildings with coupled walls and coupling beams with different heights are modeled in 2D form, and the results of the analysis of the buildings are compared and investigated. These analyses compare shear forces, bending anchors, and lateral displacements resulting from lateral loads in the coupled shear walls in each sample building. Then the seismic behavior of coupling beams is examined. The analyzed 2D structures are 10-story, the length of the shear wall equals 600cm, and the length of the coupling beams is 180cm. The same height of 350cm was considered for each floor. The height of coupling beams was different in each structure, so it equaled 220cm, 180cm, 140cm, and 100cm in the first, second, third, and fourth structures, respectively. The results revealed the greater effect of near-field earthquakes on the displacement history response based on the average response graph of structure displacement history under the far- and near-field earthquake records. In the case of a near-field earthquake, the average history of base shear would be about 0.182ton, so this rate would be about 0.086ton in the far-field earthquake. In the near-field earthquake, the average displacement history is around 0.124 of the earth's gravity acceleration.

Keywords: Steel Coupling Beams, Bending performance of Beam, Shear Performance of Beam, Near-Field Earthquake, Far-Field Earthquake

INTRODUCTION

Reinforced concrete shear walls are one of the most secure techniques to cope with lateral forces. A shear wall is a wall designed to resist the simultaneous effect of axial, bending, and shear forces caused by vertical loads and earthquake loads. Shear walls usually bear the highest base shear force, which leads to a considerable increase in the building's stiffness and a dramatic decline in non-structural elements. Shear walls can be deployed in different areas of a building's plan regarding architectural considerations. However, it should be considered that the deployment of this wall in the plan must be symmetric as much as possible, and the gravity center of each floor should be near the rigidity center of the shear wall.

In most cases, the erection of regular openings for the windows or doors on shear walls is inevitable. The location of openings must be determined in a way that shear wall structures' behavior is optimum for bearing the imposed loads. The designer ought to ensure that the general and bending behavior of walls does not face any problems when there is a significant decrease in its cross-section. Otherwise, the wall behavior becomes brittle and collapses under the shear failure before reaching its maximum bending capacity. In the majority of cases, shear walls can bear the largest share of base shear force, and this phenomenon results in a considerable increase in the building's stiffness and a significant reduction in non-structure elements. In the shear walls having an opening, when the wall has one or more openings in its lowest area then each member of the wall in the sides of the opening is called the shea wall base, and a part of the wall between the upper and lower opening is named coupling beam. In earthquake energy absorption by shear walls with openings, their coupling beams are the most responsible elements. In the design of shear walls, therefore, plastic hinges or joints in the bending behavior must be projected in a way that no diagonal failure or destruction occurs in both coupling beams and walls. Among critical surfaces in coupled walls, the surfaces of cracks between openings can be mentioned, which results in wall shear failure [1 & 2].

In general, earthquake force is distributed among the structure's elements based on their stiffness rate; thus, the stiffer the structure, the more earthquake force will be absorbed. Because the shear wall system is stiffer than the beam and column bending frame, it absorbs more force from the earthquake, so bending frames bear less force. Therefore, beams and columns bear lower force, and one can consider a smaller size for them in the structure design compared to the case of shear wall absence [4]. If the structure is not highly tall, the wall is designed against shear and is controlled against bending, and reinforced if required. Like deep beams, shear reinforcements are composed of two series of rebars perpendicular to each other that act as stirrups in beams [4].

Those structures having interlocked shear walls created by connecting two separate shear walls using connecting beams are effective lateral load-resisting systems that bring a high lateral resistance and stiffness if wall openings are deployed regularly in the building's height, and these connecting beams are designed appropriately. The tensile and compressive axial force created in the walls resulting from coupling beams' stiffness contributes to bearing a large part of the total overturning anchor through coupling rather than the case of single walls without any connection that dissipates the energy caused by earthquake only through bending deformations. Thus, a stiffer and more resistant system appears [1]. These axial forces are transferred through the cut created in the coupling beam. In systems having interlocked shear walls, the coupling beams must be stiff and powerful enough, and yield before the surrounding walls behave more formable and show significant energy absorption characteristics for achieving the optimum behavior [2]. High potential for considerable reduction of bending anchor to shear type in beams' walls and energy loss capacity are essential structure elements in a seismic plan. Therefore, Hysteresis characteristics of coupling beams are mainly seen in the overall response of a system in the design of coupling beams based on some studies conducted in the past. The coupling beam is designed with this purpose the beam's flanges remain elastic, and the beam's web is yielded in the shear. Hence, the web's effect is neglected in the calculation of bending resistance when the size of the flange is measured. Ultimately, a suitable depth-to-thickness ratio must be determined for the flange and web to prevent local bulking of the flange or web, which is similar to the case exist about the coupling beams in bracing frames. Finally, the buried length of the beam inside the wall is measured based on the available equations. Researchers have tried to achieve a coupling beam with higher resistance, stiffness, and formability characteristics rather than similar samples. Some of the steel coupling beams suggested and used include ordinary and composite steel coupling beams [2], beams with shear sheet, web [1], beams with fuse section [1], and coupling beams with prestressed rebars.

Since the coupling beam transmits a considerable shear force from a shear wall with cantilever function to another shear wall, a significant shear deformation occurs in it. Hence, this beam will be rapidly destroyed during the earthquake. The placement of diagonal longitudinal and transverse rebars in the coupling beam highly improves the behavior of this beam under intermittent loads. The connecting beams with high formability called coupling beams are used to create a unit structural performance for two adjacent and separate structural walls, and or for components at two sides of opening in the walls having large openings. In this case, the walls connected are called coupling walls. The mentioned rules are considered for those coupling beams in that their final shear forces exceed the double shear capacity of the section, and their free opening length-to-height ratio is less than 3. Otherwise, coupling beam steeling is done based on the common bending rules.

The walls must be designed in a way to ensure the formation of the plastic hinge (flow of reinforcements) so that no diagonal tensile failure that is brittle occurs in the wall or the coupling beams. In general, walls behave in a way that the pulp joint is shaped first in the coupling beams and then in the walls.

In the bending failure, the plastic hinge is shaped at the wall's cross-section where shear force also indicates maximum rate. The main area of the plastic hinge is at the height that is called the length of the plastic hinge. The length of this area is usually considered a rate 1-1.5 times greater than the wall's thickness to control shear. In the failure caused by shear, the cracks resulting from bending in the area of the plastic hinge are increased in thickness and length and then are combined with cracks resulting from diagonal stretch, so that the concrete cannot finally resist shear after several periods and the whole shear must be supported by the reinforcements. In the slip failure, the wall moves horizontally, and construction joints occur in the place. The failure caused by foundation rotation leads to foundation rise, which considerably decreases the depreciation power of energy and causes other destructions in the structure.

Since most areas of Iran are seismic, it is highly important to consider proper design for structures and make them earthquake-resistant. For this purpose, shear walls are among the most substantial energy waste systems that are now used in most structures. Architectural reasons sometimes make architects create openings in the shear wall, and two shear walls are connected through coupling beams this member plays a key role in the seismic behavior of the structure, and its formability has a considerable effect on the failure of main walls and other structure members. This research examines the seismic behavior of the structure and its effects with a specific emphasis on this member and the use of steel and concrete coupling beams.

Coupling shear walls are one of the lateral resistance systems that are widely used in concrete structures and sometimes in steel structures. The important point in these shear walls is seen in the design of the coupling beam, which is designed in terms of bending and shear capacity to be the first damaged member and be changeable during severe earthquakes. Most cross-sections used in these beams are of concrete or steel types. In this research, concrete and steel beams are used as coupling beams in the concrete shear walls under the near-field and far-field earthquakes.

METHODOLOGY

Structure analysis has been done through time history dynamics using El Centro Earthquake Record. Fig 1 depicts the studied plan. Table 1 reports the characteristics of used cross-sections.

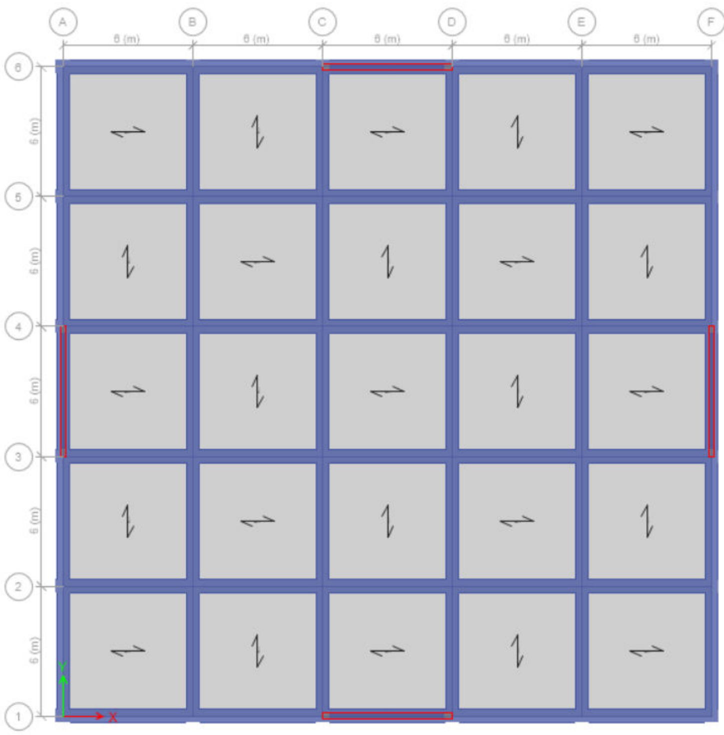

Fig 1. Schematic of structure plan geometry of dual bending frame with shear wall

Table 1.Characteristics of sections' size

Floor number	Column's characteristics	Beams' characteristics
Floors 1-2	45348-18F16	45345-18F18
Floors 3-4	45315-16F116	40340-16F16
Floors 4-5	40340-16F16	35335-14F16

Step 1: selection of models' geometry, including:

1. Plate (2D) frames are regular without irregularity in the height
2. Number of floors: 5-story
3. Number of openings: 5 openings
4. Height of floors: 3.2m

5. Width of opening: 5m

Step 2: Design of models based on the following points:

1. A specific formability level is selected.
2. The mass of all floors is considered equal.
3. To measure seismic mass, the recommendations available in seismic acts are used, so that seismic dead mass is considered as the sum of total dead mass plus a percentage of live mass of the floor. The involvement percentage of live load equals 20% assuming the residential use for all models and by the values suggested in the 2800 Standard 4th edition.
4. A dead load of floors is assumed to be 3000Kg/m, and a live load equals 1250Kg/m.
5. It is assumed that all models of the thesis are located in an area with very high seismic risk based on the classification of 2800 Standard 4th edition.
6. The soil of the construction place is of soil type II based on the classification of 2800 Standard 4th edition.
7. The 2800 Standard 4th edition will be used for loading and seismic analysis.
8. Analysis of models will be done before design based on the linear static and dynamic method based on the 2800 Standard 4th edition.
9. After the analysis is done, concrete frames are designed based on the design rules under Topic 9 and ACI.
10. The ETABS2016 Software is used for the professional design of buildings.

Step 3: selection of accelerogram

1. Seven earthquake acceleration records in the fault near-field and 7 earthquake acceleration records in the fault far-field and in soil type II are chosen for the study.
2. The metrics recommended in the 2800 Standard 4th edition are observed to select the accelerograms.
3. All accelerograms are chosen from the PEER website.
4. All accelerograms are entered into the scaling process with the initial PGA.

Step 4: Nonlinear dynamic analysis based on the following points:

1. OPENSEES Software is used for nonlinear dynamic analysis.
2. For nonlinear time history dynamic analyses, seven accelerograms of fault near-field and 7 earthquake acceleration records in fault far-field, and in soil type II are selected.

Time history analysis

Step 1: selection of accelerogram: according to 2800Standar, those accelerograms used in determining the effect of ground motion must indicate the actual ground motion as much as possible in the building construction place during the earthquake.

Step 2: scaling accelerograms: various methods have been presented for scaling the record of earthquakes:

A) Use of suitable seismic index, direct method

In this technique, all earthquake maps are scaled in a way that all of them take the same index. To do so, different indexes have been presented in previous years, which include some parameters such as Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV), which are among the most important ones.

B) Spectral matching

This technique is a common strategy for using earthquake accelerograms within spectral and time history analyses, which is also used in the 2800 Standard (3rd edition). It is tried in this technique that the spectrum obtained from earthquake mapping within a certain period is not to be less than its corresponding plan spectrum.

C) Accelerogram generation based on the target spectrum

Another technique for earthquake map scaling is the use of mappings that all are matched with a target spectrum in the design step, which is mainly an ideal spectrum. This technique can be called a generalized method of spectral matching.

D) Fema 440 scaling method

This technique is done in a way that the maximum displacement of the roof center of mass equals the target displacement obtained from overload analysis. In this technique, the maximum displacement caused by an earthquake is determined based on the nonlinear dynamic analysis at the roof level, and the target displacement of the structure is determined by using nonlinear static analysis methods and techniques presented in the relevant standards.

Step 3: definition of accelerograms scaled through software and creation of respective load cases

There are various methods to do time history analysis based on direct differentiation. It is recommended to use the H-H-T technique. The H-H-T technique uses a simple parameter called α. This parameter may vary between 0 and -1.3. When α=0, this technique becomes Newmark method equivalent with γ= 0.5 and β= 0.25. This method is similar to the average acceleration method. The use of α=0 presents a higher accuracy rather than available techniques.

Table 2. Characteristics of far-field earthquake records

Type of accelerogram	Name of accelerogram	Station	Occurrence year	Magnitude (Richter)	Distance from sault (Km)
Far-field	Kobe, Japan	Nishi-Akashi	1995	6.9	28.7
	Superstition Hills	EL Centro Imp. Co.	1987	6.5	35.8
	Hector Mine	Hector	1999	7.1	26.5
	San Fernando	LA - Hollywood Stor	1971	6.6	39.5
	Friuli, Italy	Tolmezzo	1976	6.5	20.2
	Manjil, Iran	Abbar	1990	7.4	40.4
	Landers	Yermo Fire Station	1992	7.3	23.6

Table 3. Characteristics of near-field earthquake records

Type of accelerogram	Name of accelerogram	Station	Occurrence year	Magnitude (Richter)	Distance from sault (Km)
Near-field	Loma Prieta	Saratoga-Aloha	1989	6.9	17.2
	Cape Mendocino	Petrolia	1992	7	4.5
	Northridge-01	Sylmar-Olive View	1994	6.7	16.8
	Kocaeli, Turkey	Izmit	1999	7.5	5.3
	Gazli, USSR	Karakyr	1976	6.8	12.8
	Chi-Chi, Taiwan	TCU084	1999	7.6	8.9
	Nahanni, Canada	Site2	1985	6.8	6.5

This study has been conducted to analyze and examine the seismic behavior of coupling beams against different lateral loads caused by earthquakes by using ETABS Software. For this purpose, four 10-story sample buildings having coupled walls with coupling beams and different heights are modeled based on the 2D technique, and the results obtained from analysis in each sample are compared and investigated. In this analysis, shear forces, bending anchors, and lateral displacements caused by lateral loads in coupled shear walls in each sample building are compared, and the seismic behavior of coupling beams is examined. The analyzed 2D structures are 10-story buildings with a shear wall length of 600m and coupling beam length of 180cm. The height of all floors equaled 350cm. The height of coupling beans was different in each structure, which equaled 220cm, 180cm, 140cm, and 100cm in the first, second, third, and fourth structures, respectively.

Fig 2. Depicts the geometry of the coupling beam of shear wall deployment.

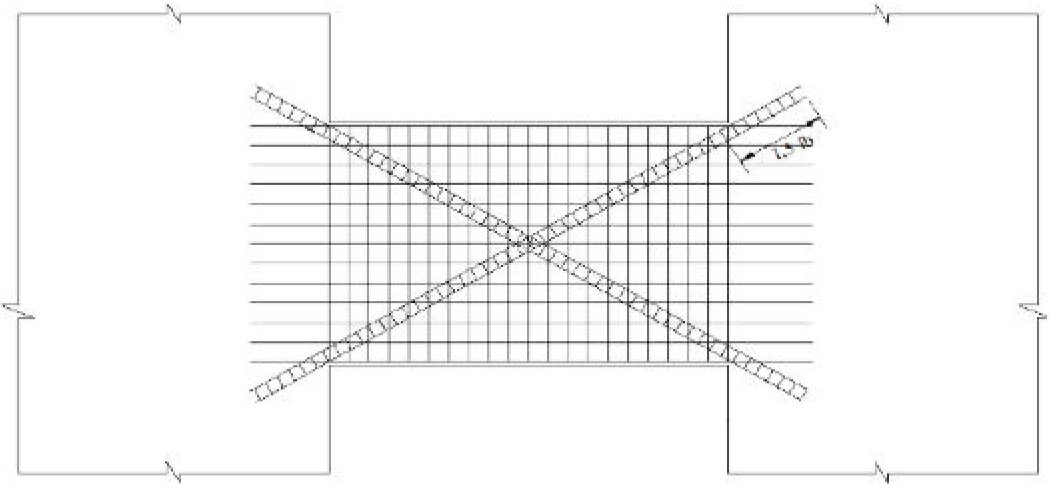

Fig 2.Coupling beam of shear wall

Fig 3. Shows the geometry of coupled shear walls and lateral forces imposed on the structure.

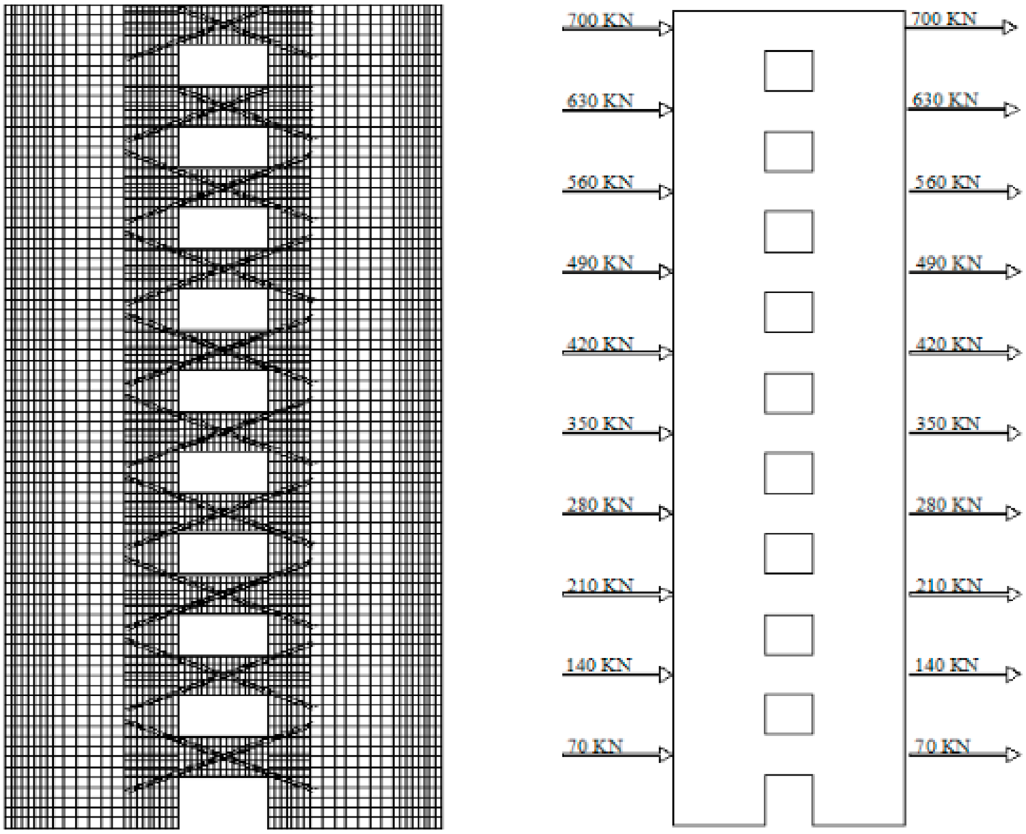

Fig 3. Geometry of coupled shear wall and lateral forces imposed on the structure

RESULTSAND DISCUSSION

The model underwent the 5 far-field records (sanfernado01, sanfernado01, manjil, Taiwan, Nhanni) and 5 near-field records of earthquakes (sanfernado01, Coyote Lake, Morgan hill, cape Mendocino, Northridge-01). The results of the time history analysis were considered under the earthquake records mentioned above to structure average response as a metric and structure response assessment. The figure below indicates the average response of results obtained from the far- and near-field earthquake displacement history under the far and near earthquake records.

In this part of the study, the model of the concrete shear wall coupled with the steel coupling beam is stimulated and analyzed under the 10 far- and near-field earthquake records. This model is modeled at this step within two modes: far-field earthquakes and near-field earthquakes. This model is stimulated and analyzed under the effect of the mentioned 10 earthquake records, and analysis is finished when the highest positive effect occurs on the dynamic response decline. After the time history was analyzed, the average structure response caused by 7 earthquake records was used as the base for the analysis of results because 7 earthquake accelerograms were used in this study. The results of the analysis consisting of model displacement history are reported in Fig 4.

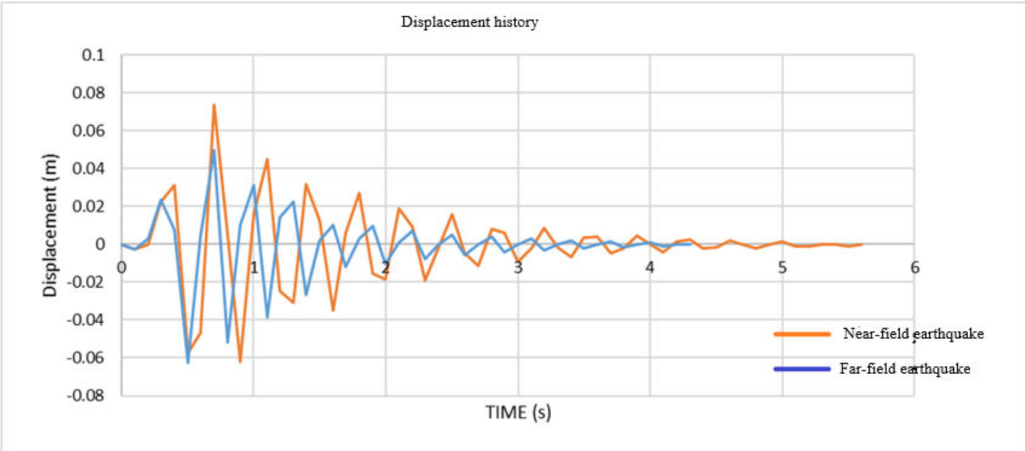

Fig 4. Comparative graph of average response of structure displacement under the near- and far-field earthquake

According to the graph of the average response of structure displacement history under the far- and near-field earthquakes, the effect of near-field earthquakes on the displacement history response is higher, and the average displacement history rate is around 7.87cm in the case of the far-field earthquake while this rate equals 5.67cm within a far-field earthquake. More assessment of the base shear history graph reveals that the effect of near-field earthquakes on the base shear history response is higher so that the average base shear history in near-field earthquakes is around 0.182ton while this rate equals 0.086ton in the far-field earthquake.

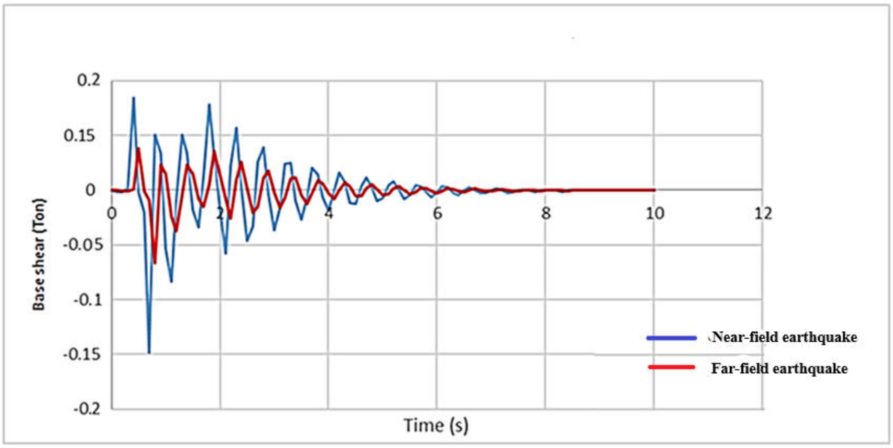

Fig 5. Comparative graph of average response of base shear history under the near- and far-field earthquake

Also, the structure acceleration history graph indicates the higher effect of near-field earthquakes on the acceleration history response, so the average displacement history is around 0.124 peak gravity acceleration in the near-field earthquake, while this rate equaled 0.059 peak gravity acceleration in the far-field earthquake (Fig 6).

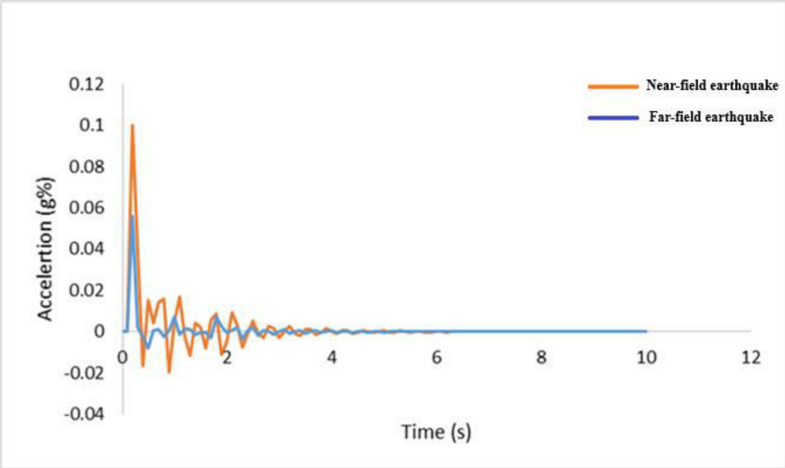

Fig 6. Comparative graph of average response of structure acceleration under the near- and far-field earthquake

CONCLUSION

According to the graph of the average response of structure displacement history under the far- and near-field earthquake records, near-field earthquakes have a higher effect on the displacement history response, so the average displacement history in the near-field earthquake is around 7.84cm, while this rate equals 5.67cm within a far-field earthquake. The assessment of the base shear history graph indicates the higher effect of near-field earthquakes on the base shear history response so that the average base shear history in near-field earthquakes is around 0.182ton, while this rate equals 0.086ton in the far-field earthquake. The structure acceleration history graph also indicates the higher effect of near-field earthquakes on the acceleration history response, so the average displacement history is around 0.124 peak gravity acceleration in the near-field earthquake, while this rate equaled 0.059 peak gravity acceleration in the far-field earthquake. According to the comparison between time history graphs of the effect of coupling beam material on the seismic behavior of the structure of concrete coupling shear wall with steel coupling beam, when the concrete coupling beam is changed to steel then the displacement rate will be decreased around 24.31%.

According to the obtained results, it is recommended to measure the seismic parameters of the proposed system and compare the behavior of the proposed system when using coupling beams with bending or shear behaviors.

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