



Seismic Behavior of Concrete Shear Walls in Structures Retrofitted by FRP Plates

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ABSTRACT

Earthquake is one of the natural phenomena that make more fatality, financial and environmental damages each year. Today, with the development of earthquake engineering, buildings in cities are somewhat resistant to lateral loads due to earthquakes. But unfortunately, still wide devastation, fatality and financial damage caused by the earthquake is announced. Since this event is due to the various specific parameters of each earthquake, identify forces and countered against them generally. So should effort that absorb energy due to it with appropriate materials; and design and make structures with good reliability, that to be confirmed of economic. In recent decades, many efforts have been made to the use of the appropriate field. Fiber reinforced polymers are such as these materials. In this study, has been tried to examine the effect of FRP plate on performance of concrete shear wall. Shear wall are the most important element in building resistance against lateral loads and access its suitability. In this study, to analyze the effect of polymer fibers, SEISMOSIGNAL and ABAQUS soft wares have been used.

Keywords: Earthquake, FRP, Stress, Accelerogram, Shear Wall, FRP plate.

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INTRODUCTION

Earthquake resistant structures should be provided with lateral and vertical seismic force resisting systems capable of transmitting forces to the foundations. Continuity and regular transitions are essential requirements to achieve adequate load path. Concrete shear walls are one of the main lateral resisting members in buildings because of their high in plane rigidity. In the last decade, the use of fiber reinforced polymers (FRP) to strengthen existing structures has increased due to their excellent characteristics such as high resistance, durability, ease of installation and high strength to weight ratio. Though a significant amount of research has been conducted on the use of fiber reinforced plastic for strengthening and rehabilitation of reinforced concrete elements, there is little information on the strengthening of shear walls. One of the first objects using FRP strengthening of RC shear walls was reported by Ehsani and Saadatmanesh (1997) (Ehsani and Saadatmanesh, 1997). They used FRP in order to retrofit a concrete building subjected to the Northridge earthquake. Another study on FRP strengthening of RC shear walls has been carried out by Lombard et al. The purpose was to investigate the feasibility of CFRP strengthening and rehabilitation of reinforced concrete shear walls (2008) (Asgary and et al, 2008). In this study the walls initially were subjected to seven average accelerograms loading without FRP plates and behavior of them is registered. Subsequently, the walls were strengthened with FRP plates and were subjected with the same loading again and behavior of them is registered also. The results showed that the wall strength increased and performance of that is improved. In this study, the effects of applying FRP plate on

the concrete shear wall were investigated by using the finite element analysis. In this paper, displacements, stresses and energy of concrete wall panels has been studied.

ACCELEROGRAMS USED

In this research, seven average accelerograms are used. Couple of accelerograms is related to BAM earthquake that happened in 2003 with Magnitude of 6.6 Richter in Iran (Asgary, Ali; Badri, Ali; Rafieian, Mojtaba; Hajinejad, Ali, 2008). Accelerograms related to BAM earthquake has been named BAM-1 and BAM-2 and shown in fig.1 and fig.2. Another accelerogram is related to ELCENTRO earthquake that happened in May1940 in Mexico. Magnitude of this earthquake was 6.9 Richter (Gunn, 2007). Accelerograms related to ELCENTRO shown in fig.3. Used other accelerogram is related to KAHAK earthquake that happened in 2007 in Iran. Magnitude of this earthquake was 5.6 Richter (Mohammadi and et al, 2014). Accelerograms related to KAHAK shown in fig.4. Another accelerogram is related to KOBE earthquake that happened in January 1995 in Japan. Magnitude of this earthquake was 6.9 Richter (Koketsu and et al, 1998). Accelerograms related to KOBE shown in fig.5. Another accelerogram is related to NORTHRIDGE earthquake that happened in January 1994 in California. Magnitude of this earthquake was 6.7 Richter (Petak and et al, 2001). Accelerograms related to NORTHRIDGE shown in fig.6. Used other accelerogram is related to SILAKHOR earthquake that happened in 2006 in Iran. Magnitude of this earthquake was 6.1 Richter (Ramazi and et al, 2006). Accelerograms related to SILAKHOR shown in fig.7.

Fig.1. BAM-1 Accelerogram

Fig.2. BAM-2 Accelerogram

Fig.3. ELCENTRO Accelerogram

Fig.4. KAHAK Accelerogram

Fig.5. KOBE Accelerogram

Fig.6. NORTHRIDGE Accelerogram

Fig.7. SILAKHOR Accelerogram

Walls Modeling

Shear walls modeling includes 35 models that it has been analyzed with FRP plates and without FRP plates.

3.1 Concrete Shear Wall modeling Without FRP Plates

In this study, it has been tried to be close to reality as possible in modeling. It has been used to panel a plate with 200 mm thickness and bars with 10 mm diameter in horizontal and vertical in distances 300 mm. Dimension of panel is intended 3 meters for height and 4 meters for length of plate. For columns it's been chosen dimension 400×400 mm with 8 bars with 18 mm diameter. Also, for beams it's been chosen dimension 400×400 mm with 6 bars with 14 mm diameter. Technical specifications of the concrete that it has been used in software models are shown in table1. Also, technical specifications of the bars that are used in software models have been shown in table2.

Table1. Concrete Technical specifications [3]

Density (kg/m ³)	Young's Modulus (GPa)	Poisson's Ratio	Yield Stress (MPa)	Plastic Strain
2400	28.6	0.20	20.68	0
			37.92	0.0015

Table2. Bars Technical specifications [3]

Density (kg/m ³)	Young's Modulus (GPa)	Poisson's Ratio	Yield Stress (MPa)	Plastic Strain
7850	200	0.14	400	0
			600	0.138

The connection between shear wall panel and column and beams it's been chosen rigid. Bars have been considered buried in concrete. Subsequently, model has been meshed. Loading has been applied under concrete frame and in the longitudinal direction. For loading, given accelerograms Multiplied by the 9.81m/s^2 . Meshing of concrete model has been shown in fig.8. After analysis, Stress values in concrete panel have been shown in fig.9.

Fig.8. Meshed model

Fig.9. Stress values in concrete panel

3.2 Concrete Shear Walls modeling with FRP Plates

For checking effect of FRP plates on concrete shear walls performance, created model in the previous step, has been reinforced with FRP plates, and analyzed. The FRP plate's that has been used in this study is carbon and glass. In models that have been used CFRP, in the first case in the

name of SCFRP-1 model, FRP plate's dimensions is equal concrete panel and thickness of FRP is 1 mm and both of side of panel. In the other case in the name of SCFRP-2 model, FRP plates used in vertical tapes and both of side of panel with 500 mm distances and thickness of them is 1 mm. This model has been shown in fig.10. In the other case in the name of SCFRP-3, FRP plates with 300 mm width and 0.5 mm thickness has been modeled crossed. This model has been shown in fig.11. In reinforced model with GFRP, reinforcing is similar SCFRP-3 model. The difference is that it has been used GFRP instead CFRP.

Fig.10. SCFRP-2 model

Fig.11. SCFRP-3 and SGFRP model

Specification of CFRP that used in analysis has been shown in table 3and 4. Specification of GFRP that used in analysis has been shown in table 5 also.

Table 3. Elastic Properties of CFRP [1], [2]

Density (kg/m ³)	Young's Modulus(x) (GPa)	Young's Modulus(y) (GPa)	Poisson's Ratio	Shear's Modulus(xy) (GPa)	Shear's Modulus(xz) (MPa)	Shear's Modulus(yz) (GPa)
1800 kg/m ³	373 GPa	10.1	0.22	5.70	3.40	1.86

Table 4. Hashin Damage Properties of CFRP [1], [2]

Longitudinal Tensile Strength (MPa)	Longitudinal Compressive Strength (MPa)	Transverse Tensile Strength (MPa)	Transverse Compressive Strength (MPa)	Longitudinal Shear Strength (MPa)	Transverse Shear Strength (MPa)
2280	1440	57	228	96	48

Table 5. Technical specification of GFRP [1], [2]

Density (kg/m ³)	Young's Modulus (GPa)	Poisson's Ratio	Yield Stress (MPa)	Plastic Strain
1900	70	0.20	1860	0
			2680	0.045

Since used resins for installation FRP plates on concrete panel, connection has been considered rigid. Connection between concrete panel and FRP plates at all levels is intended.

Check the Models Parameters

On issues related to the earthquake and structures subjected to earthquakes, several parameters are very significant. Including these parameters can be noted to displacements and stresses in structure. Another very important parameter that is effective in the design is the energy dissipated by the system, and in this study, to identify and analyze the effects of polymer plates that has been added to the shear walls are examined.

4.1 The Tension Builds

Stress in concrete models due to cracking and inelastic behavior of concrete and reduce the amount of concrete endure. Low technical specifications concrete in front of FRP fibers and steel also and the concrete reaches to maximum tension in all over the models due to the force of earthquake, so, the tension in bars has been checked. In this study, the maximum stress generated in selected elements has been studied. Maximum tension stress in bars models

has been shown in table 6. Changes in stress in steel bars without FRP plates and with FRP plates has been shown in fig.12 also.

Table 6. Maximum tension stress in bars (MPa)

Model Name	BAM-1	BAM-2	ELCENTRO	KAHAK	KOBE	NORTHRIDGE	SILAKHOR
Concrete panel	338.869	330.359	352.197	311.611	402.197	380.611	321.397
CCFRP-1	264.991	253.882	273.958	241.998	316.985	303.798	251.333
CCFRP-2	286.263	273.658	293.894	258.596	336.634	324.374	267.096
CCFRP-3	309.049	295.406	318.875	280.532	371.633	352.215	294.096
CGFRP	306.286	299.780	317.111	279.634	368.729	351.163	293.740

Fig.12. reducing tension stress in bars with FRP (%)

As can be seen stress amounts in steel bars in models that reinforced with FRP plates, in all earthquakes has been reduced. Amount of stress reducing has been shown in table7.

Table 7. Reducing tension stress in bars with FRP (%)

Model Name	BAM-1	BAM-2	ELCENTRO	KAHAK	KOBE	NORTHRIDGE	SILAKHOR
CCFRP-1	21.801	23.150	22.215	22.340	21.187	20.182	21.800
CCFRP-2	15.524	17.163	16.554	17.013	16.301	14.775	16.895
CCFRP-3	8.800	10.580	9.461	9.974	7.599	7.461	8.495
CGFRP	9.615	9.256	9.962	10.262	8.321	7.737	8.605

As can be seen, maximum stress amount is related to reinforced models with SCFRP-1, and minimum amount is related to reinforced models with GFRP. Stress changes have been shown in fig.13.

Fig.13. Maximum tension stress in bars (MPa)

4.2 The Created Displacements

Displacements in loads direction or, in other words, created axial displacement in shear walls is one important case of structures exposed to earthquake. So, it is so significant and has been examined. Axial displacements in models under analysis have been shown in table 8 and 9.

Table 8. Axial displacements in concrete models (mm)

Model Name	BAM-1	BAM-2	ELCENTRO	KAHAK	KOBE	NORTHRIDGE	SILAKHOR
Concrete panel	75.873	71.859	131.734	106.238	88.373	85.958	82.020
CCFRP-1	56.854	54.531	99.004	78.177	69.246	66.599	63.139
CCFRP-2	60.886	59.525	108.924	87.037	74.341	70.984	67.344
CCFRP-3	67.493	65.286	121.501	95.185	81.415	79.019	75.003
CGFRP	66.878	64.051	120.143	94.758	81.601	78.250	73.867

Table 9. Reducing axial displacement in concrete frames with FRP (%)

Model Name	BAM-1	BAM-2	ELCENTRO	KAHAK	KOBE	NORTHRIDGE	SILAKHOR
CCFRP-1	25.067	24.113	24.845	26.413	21.644	22.521	23.020
CCFRP-2	19.753	17.163	17.315	18.074	15.878	17.421	17.893
CCFRP-3	11.045	9.146	7.768	10.404	7.874	8.073	8.555
CGFRP	11.856	10.865	8.799	10.806	7.663	8.967	9.941

As can be seen, amount of displacements in reinforced models has been reduced. Variations are difference between models. The percentage of reducing displacements has been shown in fig.14.

Fig.14. Reducing axial displacements in concrete frames with FRP (%)

Another drift that it's happened in shear walls is buckling. The amount of builds displacement under loads has been shown in table 10 and table 11.

Table 10. Buckling concrete frames (mm)

Model Name	BAM-1	BAM-2	ELCENTRO	KAHAK	KOBE	NORTHRIDGE	SILAKHOR
Concrete panel	14.760	4.032	4.064	1.336	2.278	2.281	7.999
SCFRP-1	9.738	2.651	2.726	0.847	1.599	1.600	5.349
SCFRP-2	10.921	2.928	3.028	0.974	1.794	1.800	6.084
SCFRP-3	12.823	3.461	3.601	1.156	2.024	1.998	7.040
SGFRP	12.619	3.390	3.559	1.148	2.014	1.994	7.003

Table 11. Reducing Buckling concrete frames with FRP (%)

Model Name	BAM-1	BAM-2	ELCENTRO	KAHAK	KOBE	NORTHRIDGE	SILAKHOR
CCFRP-1	34.024	34.246	32.919	36.620	29.822	29.847	33.133
CCFRP-2	26.012	27.379	25.487	27.097	21.257	21.060	23.940
CCFRP-3	13.124	14.162	11.395	13.495	11.155	12.376	11.994
CGFRP	14.506	15.908	12.423	14.091	11.596	12.575	12.459

As axial displacements, buckling displacements has been reduced also. Reducing in bucking as a percentage has been shown in fig.15.

Fig.15. Reducing Buckling concrete frames with FRP(%)

4.2 The Energy Values

Another significant parameter in shear walls is energy dissipating. Amount of energy dissipating for models has been shown in table 12 and table 13.

Table 12. Amount of dissipative energy in frames (Joule)

Model Name	BAM-1	BAM-2	ELCENTRO	KAHAK	KOBE	NORTHRIDGE	SILAKHOR
Concrete panel	4.45E+12	4.45E+12	4.58E+12	3.39E+12	4.88E+12	4.72E+12	4.42E+12
SCFRP-1	5.58E+12	5.58E+12	5.67E+12	4.30E+12	6.09E+12	5.94E+12	5.54E+12
SCFRP-2	5.29E+12	5.29E+12	5.42E+12	4.08E+12	5.79E+12	5.60E+12	5.33E+12
SCFRP-3	4.82E+12	4.82E+12	4.98E+12	3.75E+12	5.24E+12	5.12E+12	4.91E+12
SGFRP	4.83E+12	4.82E+12	5.01E+12	3.77E+12	5.27E+12	5.15E+12	4.94E+12

Table 13. Increasing of dissipative energy in concrete frames with FRP (%)

Model Name	BAM-1	BAM-2	ELCENTRO	KAHAK	KOBE	NORTHRIDGE	SILAKHOR
SCFRP-1	25.497	25.497	23.844	26.610	24.661	25.912	25.392
SCFRP-2	19.026	19.026	18.417	20.294	18.592	18.587	20.524
SCFRP-3	8.454	8.454	8.773	10.449	7.292	8.451	11.170
SGFRP	8.703	8.478	9.408	11.113	7.899	9.123	11.838

As can be seen, amount of dissipative energy has been raised in reinforced models that this raising has been shown in fig.16.

Fig.16. Increasing of dissipative energy in concrete frames with FRP (%)

CONCLUSION

As can be seen, in this study, concrete shear walls reinforced with FRP plates and has been analyzed and important parameters in shear walls that are an important segment of structures against earthquake has been checked.

According to the previous sections, amount of stress in steel bars that buried in concrete panel has been reduced with reinforcing with FRP plates. It shows that, FRP plates take part in to endure earthquake loads. The amount of axial displacements in concrete frame is decreased due to using FRP plates that is caused by increased stiffness. Because of using FRP plates on panels, amount of buckling has been significantly reduced. The reason for this decline can be increase the hardness and confinement of concrete panels. Absorption and dissipation of energy in concrete frames is improved by using FRP plates. It shows better performance of structures that reinforced by FRP plates against earthquake.

Generally, it can be said that, the FRP plate has been caused better performance of concrete shear walls against earthquake with increasing in hardness and confinement of concrete panel. So, FRP reinforcing increased capacity endure of frame and prevention of fraction of concrete panel. In the other word, with decrease of structures drifts, the design on structures is improved. Of course, the amount of improving of shear walls is related to, plate's type, plate's arrangement and plate's thickness that should be considered in design.

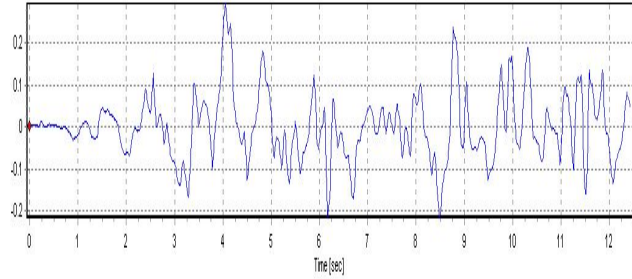


Fig.1. BAM-1 Accelerogram

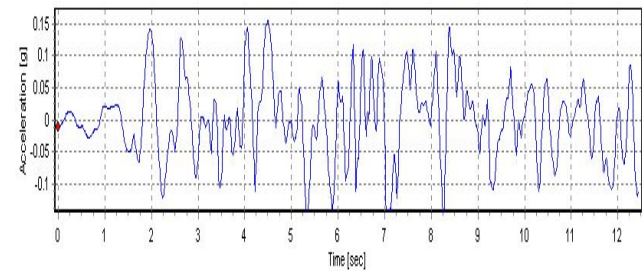


Fig.2. BAM-2 Accelerogram

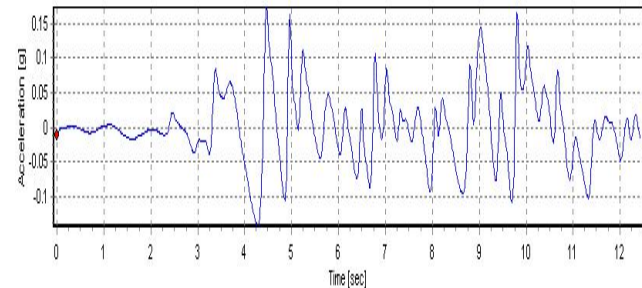


Fig.3. ELCENTRO Accelerogram

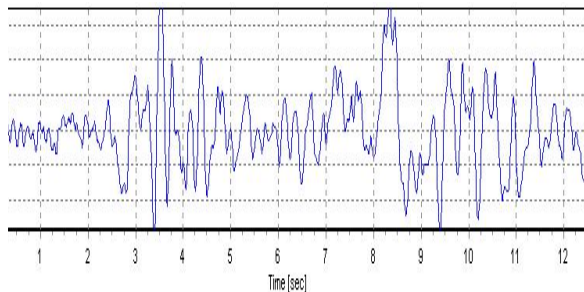


Fig.4. KAHAK Accelerogram

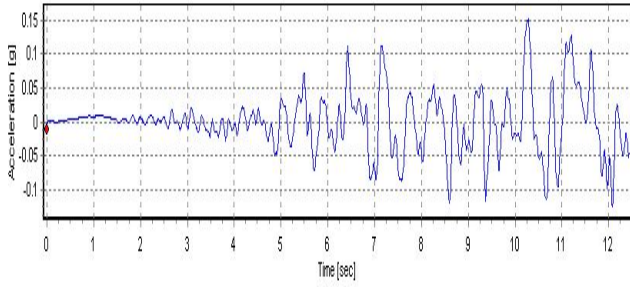


Fig.5. KOBE Accelerogram

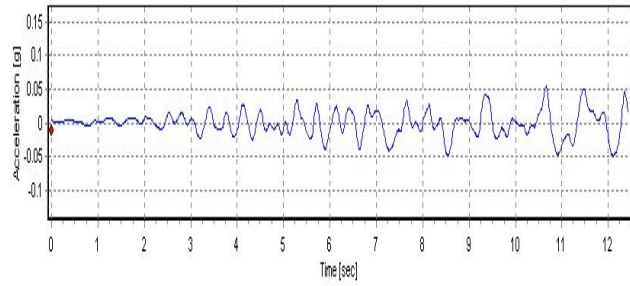


Fig.6. NORTHRIDGE Accelerogram

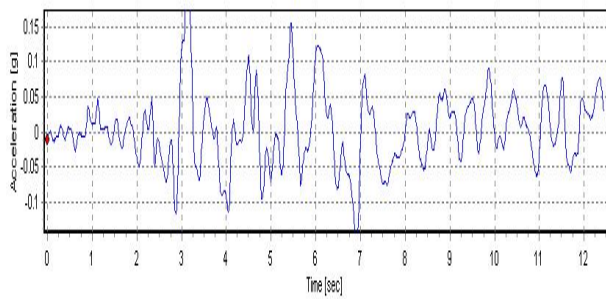


Fig.7. SILAKHOR Accelerogram

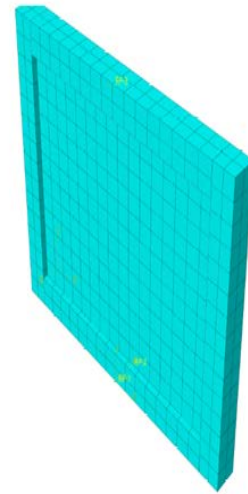


Fig.8. Meshed model

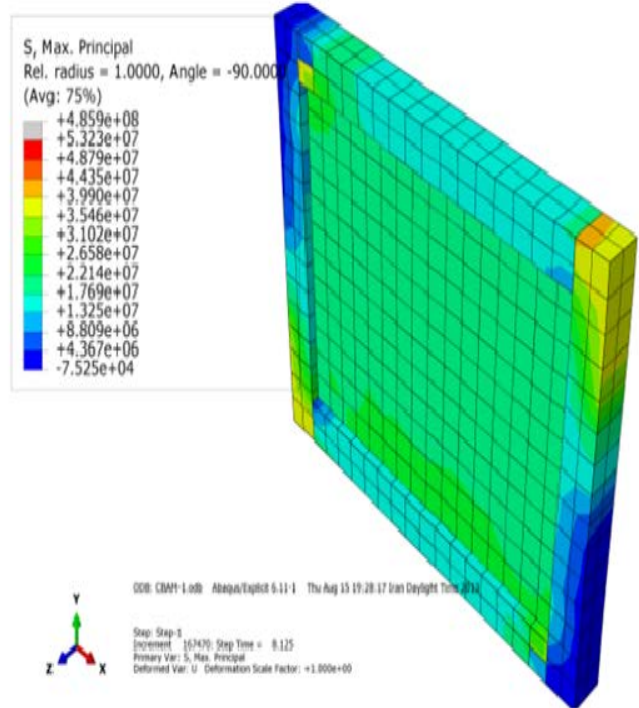


Fig.9. Stress values in concrete panel



Fig.10. SCFRP-2 model

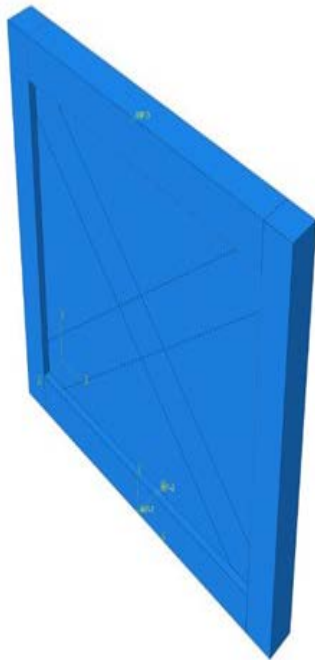


Fig.11. SCFRP-3 and SGFRP model

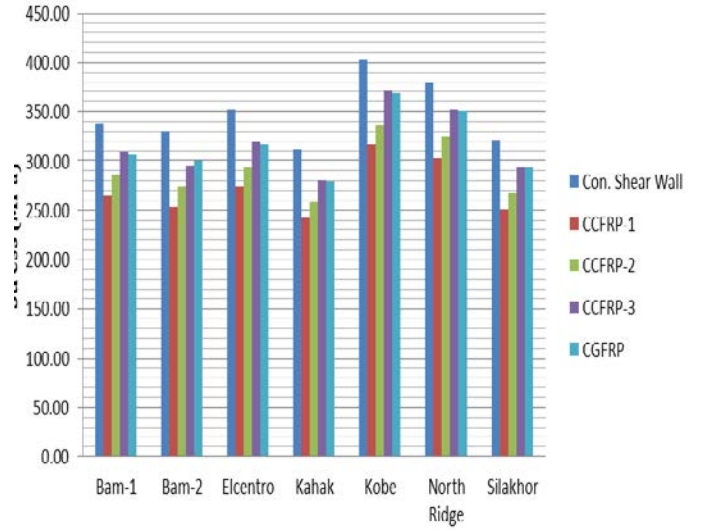


Fig.12. Reducing tension stress in bars with FRP (%)

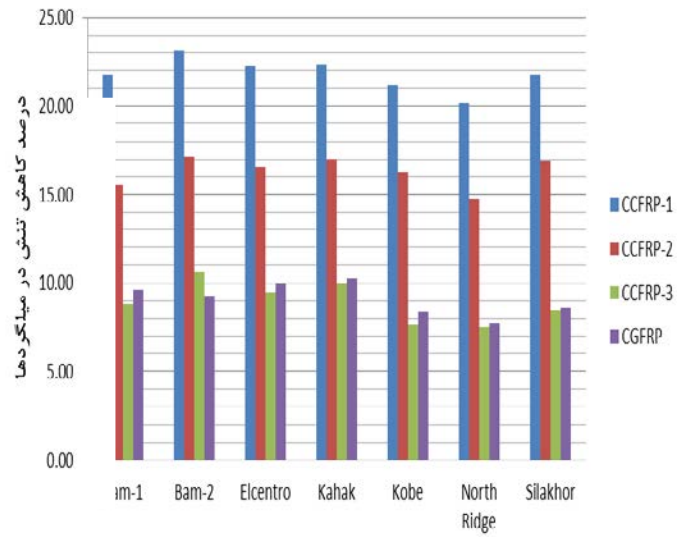


Fig.13. Maximum tension stress in bars (MPa)

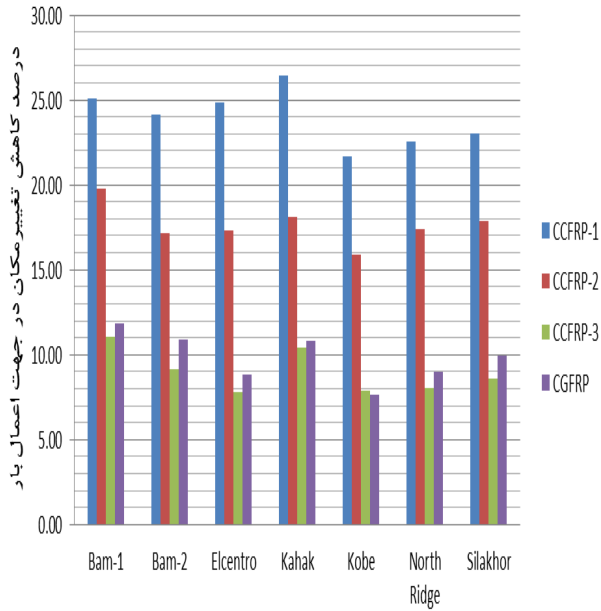


Fig.14. Reducing axial displacements in concrete frames with FRP (%)

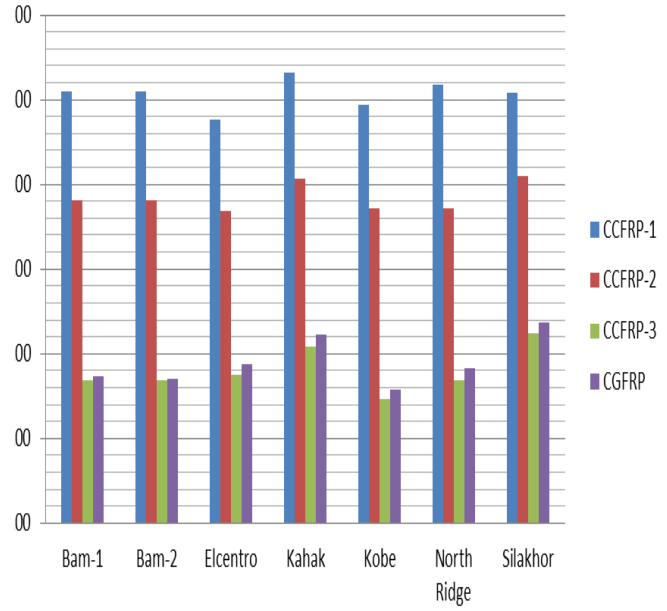


Fig.16. Increasing of dissipative energy in concrete frames with FRP (%)

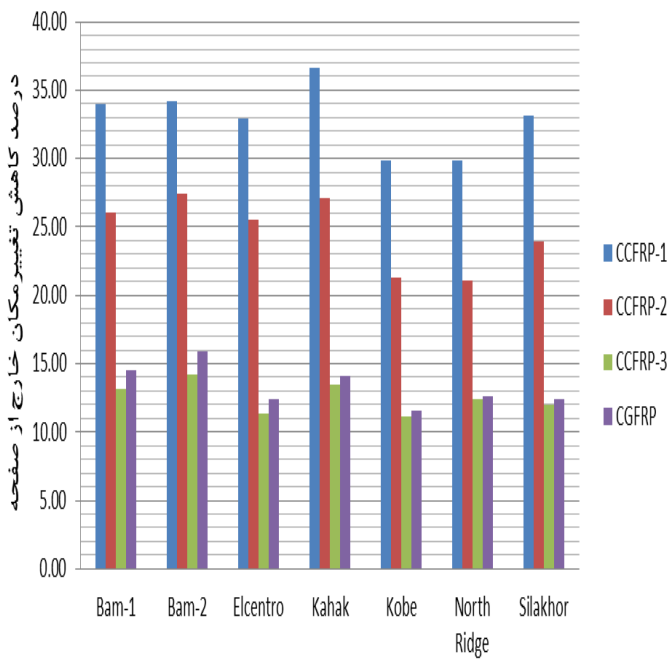


Fig.15. Reducing buckling concrete frames with FRP (%)

REFERENCES

1. ACI Committee 440, 2008, "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures (440.2R-08)", American Concrete Institute, Farmington Hills, MI.
2. Razaqpur, A.G.; Kashef, A.H. "State-of-Art on Fiber Reinforced Plastics for Buildings", Submitted to: Institute for Construction - National Research Council of Canada, Carleton University, Ottawa, 1993.
3. ACI 318R-14, "Building Code Requirements for Structural Concrete", American Concrete Institute, Farmington Hills, MI, September 2014.
4. Asgary, Ali; Badri, Ali; Rafieian, Mojtaba; Hajinejad, Ali. "Lost and Used Post-Disaster Development Opportunities in Bam Earthquake and the Role of Stakeholders". University of Montreal. Retrieved October 26, 2008.
5. Ehsani, MM; Saadatmanesh, M. "Fiber composites: an economical alternative for retrofitting earthquake-damaged precast-concrete walls". Earthquake Spectra, No. 2, 13(1997) 25-41.
6. Gunn, A.M. (2007). "Imperial Valley, California. earthquake". Encyclopedia of Disasters: Environmental Catastrophes and Human Tragedies, Volume 1. Greenwood Publishing Group. pp. 364-365, 2008.
7. Koketsu, Kazuki; Yoshida, Shingo; Higashihara, Hiromichi (1998). "A fault model of the 1995 Kobe earthquake

derived from the GPS data on the Akashi Kaikyo Bridge and other datasets". University of Tokyo. August 3, 1998.

8. Mohammadi, Hesaneh; Gheitanchi. Mohammad Reza; "Seismotectonics of Qom Region with Emphasis on 2007 Kahak Earthquake". Azad university of Tehran North Branch. May 12, 2014.
9. Petak, William; Elahi, Shirin (2001). The Northridge Earthquake, USA and its Economic and Social Impacts. Euro Conference on Global Change and Catastrophe Risk.
10. Ramazi, Hamidreza; Hosseinnejad, Mohammadreza. "The Silakhor (Iran) Earthquake of 31 March 2006, from an Engineering and Seismological Point of View". Published on March 2009 in Seismological Research Letters.