ISSN 2303-4521
Periodicals of Engineering and Natural Sciences *Original Research*
Vol. 10, No. 1, January 2022, pp.88-99

Seismic evaluation and strengthening of reinforced concrete buildings

Khnsaa Abdullhay Khlef [1], Fareed Hameed Majeed [2] and Abdullah Al-Hussein [3]
[1,2,3] Department of Civil Engineering, College of Engineering, Basrah University, Basra, Iraq

ABSTRACT

One of the best ways of achieving sustainability is to prolong the life span of existing structures instead of the “demolish and rebuild” option. Structure rehabilitation reduces construction waste, conserves natural resources, reduces negative environmental consequences, saves time, and saves cost, etc. Two main categories can be noticed in rehabilitation: repairing and strengthening. This study will focus on the strengthening category. The seismic analysis of existing reinforced concrete buildings before and after strengthening their columns is considered in this study. Three strengthening techniques (Ferro-cement jacket, steel jacket and Carbon fiber reinforced polymer jacket) are used to strengthen the reinforced concrete columns. The building is considered to be subjected to El Centro earthquake in two horizontal directions. The main objective is to investigate the optimum number and locations of the columns required to be strengthened so that the strengthened building satisfies the performance level. Four states of the building are considered; the original building and three strengthened buildings. The strengthening of a part of column height (only one meter along the potential plastic hinge) is considered. The results show that all three strengthening techniques are efficient to resist the seismic loads. This study helps engineers to select suitable, feasible and efficient strengthening techniques for structural members in existing buildings.

Keywords: Strengthening Technique, Steel Jacket, Ferro-Cement Jacket, Carbon Fiber Reinforced Polymer Jacket

Corresponding Author:

Khnsaa Abdullhay Khlef
Civil Engineering, Basrah University
Basra, Iraq
Email: Khansaa.alhelfy@gmail.com

1. Introduction

Strengthening is defined as the process undertaken to increase structural component strength. They are taken into account in cases when the expected load may override the member's capacity. Although various techniques can be utilized to improve the buildings seismic behavior, the most currently, used technique in earthquake engineering is actually to ensure that the building has sufficient ductility resources for dissipating the seismic energy and avoiding the brittle failure [1]. Appropriate improvement of the ductile behavior of reinforced concrete frames designed by pre-seismic-code can be done by confining the critical areas of the structural elements, wherein plastic hinges are expected to evolve through jacket techniques [2]. The most popular types of jackets are reinforced concrete jackets, steel jackets and FRP composite jackets.

Strengthening is required when the structural capacity assessment results in insufficient ability to withstand forces of expected intensity and acceptable damage limits. It is not just low quality materials and damage of structural components serves as the reasons for strengthening the building. The reasons for strengthening may also be changing the function of the building, changing environmental standards, and changing valid design codes [1]. Strengthening must be done by experts from every field. An engineer plays the principal role in most strengthening processes. The engineer must evaluate and analyze the structural capacity. The engineer must also design the best retrofit techniques to strengthen the structural deficiencies.

Because of the variety of structural conditions of a building, it is difficult to establish typical rules for strengthening. Each building has different methods depending on the deficiencies of the structure [1]. In order to determine whether to strengthen or not, some factors need to be considered: a) Technical aspects, which comprise materials testing and structural analysis; b) Cost intervention, in which cost and profit analysis has to be performed before a strengthening decision is made; c) Importance of building: Some buildings have additional values, such as historical values, which can greatly influence the final decision; d) Availability of appropriate technology: A "modern" technology may be needed to apply some of the strengthening techniques; (e) Professional workmanship for the application of the proposed measures; f) Duration of works: Some of the strengthening works may take less time to complete, while others may take more time to finish [1] .

The efficiency of steel, Ferro-cement and CFRP jacketing in strengthening of structural element has been confirmed in many studies. A method for retrofitting interior beam-column joints of reinforced concrete using Ferro-cement jackets with embedded diagonal reinforcements was proposed by Li et al. (2013) [3]. Under quasi-static cyclic loading, four 2/3 scale interior beam-column joints were prepared and tested, including one control specimen and three strengthened specimens. The results showed that the suggestion retrofitting technique could enhance the seismic performance of interior beam-column joints utilizing Ferro-cement with mortar of high strength. Ronagh and Eslami (2013) [4] studied the seismic performance of the RC structures rehabilitated with FRP composites. It was investigated for ductility, lateral resistance, and failure mechanism. The 8-story RC building compiled with the code specification was considered as a case study to represent midrise buildings. Nonlinear pushover analysis was performed in order to match the seismic response of the intended building with the glass fiber reinforced polymer (GFRP) and (CFRP) retrofitted buildings. Although the nonlinear results confirmed that the lateral carrying capacity utilizing (CFRP/GFRP) composite materials was significantly increased, the improvement of CFRP was twice that of GFRP. However, GFRP provides higher ductility. The efficiency and behavior of RC square columns retrofitted with steel angles and straps were studied by Tarabia and Albakry (2014) [5]. The experimental approach was performed on 10 specimens of axially loaded columns until failure. The use of this strengthening approach was found to be very efficient, resulting in an increase in the axial load capacity of the strengthened columns. The seismic behavior of a typical building located in Cairo city was verified by Ismail (2014) [6] utilizing nonlinear analysis (pushover). A typical RC building was compared to the same building after being retrofitted with CFRP jackets, concrete jackets, and steel elements. According to the results of the structural analysis, jacketing of the columns in the building with CFRP sheets allows for significantly greater lateral displacement and slightly greater lateral strength than the original performance. Steel jackets, on the other hand, resulted in a moderately greater lateral displacement with higher lateral strength.

From previous studies, it can be noticed that there are many studies conducted experiments to find the responses of RC members confined by steel, Ferro-cement and CFRP jackets and they were compared with the numerical analysis using the finite element methods. They also show that repairing and strengthening of structural elements with steel, Ferro-cement and CFRP jacket has been proven to be efficient in providing additional strength and ductility. However, there are a few studies have examined the overall behavior of (steel, Ferro-cement and CFRP) strengthening RC structures.

The objective of this study is to compare performance and the cost of strengthening a multi-story building with different strengthening techniques, specifically steel jacketing, Ferro-cement jacketing and CFRP jacketing. Finite element analyses are carried out to determine the performance level, stiffness, and ductility of different strengthening schemes and the results are compared to choose the best possible option among the three techniques. Nonlinear dynamic time history analyses are carried out using SAP 2000 software to determine the capacity demand ratio in terms of story drift and base shear.

2. Seismic analysis

The seismic analysis is part of the structural analysis, which is the calculation of a building's response to earthquakes. In earthquake prone areas, it is a part of the structural design, earthquake engineering, or structural evaluation and retrofit process. According to the types of external actions and structural behaviors, the analysis can be distributed as follows:

a- Linear Static Analysis, b- Nonlinear Static (pushover) Analysis, c- Linear Dynamic Analysis, and d- Nonlinear Dynamic Analysis

Linear static analysis (or equivalent static analysis) can be utilized for regular building with finite height; Linear dynamic analysis can be carried out by the response spectrum method. The main differences between the static and dynamic linear analysis are the level of forces and their distribution along the height of the structure. A nonlinear dynamic analysis, which is also known as nonlinear time history analysis, is the most effective and rational method for assessing the dynamic response of a structure subjected to an earthquake **[7]**.

3. Strengthening techniques

It is important to identify the key performance objectives and related structural inconsistencies before starting the process. All relevant options and methods of strengthening techniques should be assessed. After a detailed comparison, the most practical and economically appropriate option capable of addressing the identified discrepancies is chosen. Various analysis techniques are available to quantitatively determine the most appropriate measure that produces the best performance at a relatively lower cost **[8]**. The aim of this study is to compare three different strengthening techniques (Ferro-cement, steel, CFRP) jackets. Before applying these techniques to the building, they are applied to a single column and linear static analysis is conducted to choose the appropriate dimensions and characteristics of each technique so that all strengthened columns are having the same stiffness.

The analysis of the column strengthened by steel jacketing with various thicknesses of (2, 3, 4 and 5) mm and subjected to a lateral load of 100 kN is shown in Figure 1. Then, the same procedure is followed for the analysis of the column strengthened by Ferro-cement with thicknesses of (15, 20, 30 and 40) mm and for CFRP jacket with (1, 2, 3 and 4) ply. The results of static analysis for strengthened columns are shown in Figure 2.

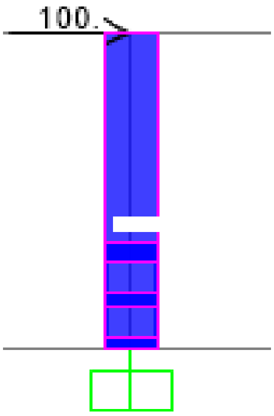


Figure 1. Representation of strengthened column subjected to lateral load in SAP 2000

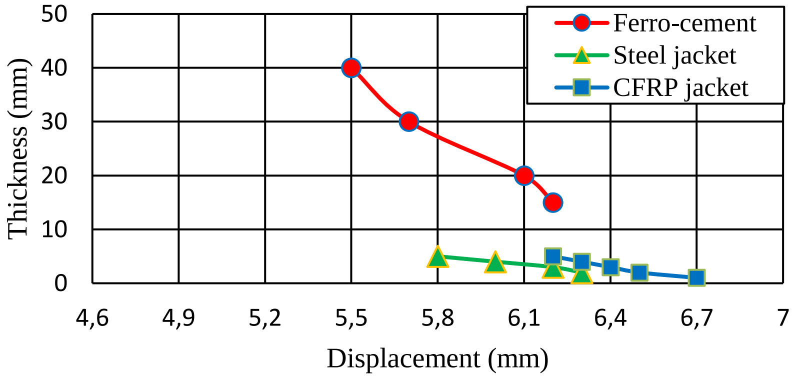


Figure 2. Results of static analysis of strengthened columns

From the obtained results, the used thicknesses of steel, Ferro-cement, and CFRP jackets are 3mm, 15mm and 1 ply, respectively. The properties of the three strengthening techniques considered in this study are briefly presented below.

3.1 Ferro-cement jacket

Ferro-cement is a type of reinforced concrete utilizing closely spaced multilayers of mesh and/or small diameter bars fully encapsulated in mortar. The most common type of reinforcement is wire mesh. The matrix utilized in Ferro-cement comprises of mortar made with Portland cement, aggregate and water **[9]**. Strengthening RC columns with Ferro-cement is a commonly used technique because the material costs are low, it is durable, and no special protection for corrosion or fire is required. The process of making it is simple and does not require advanced technical skills [13].

In this study, the thickness of Ferro-cement jacket is 15 mm reinforced with four layers of square welded-wire mesh (13×13) mm. Each layer is 1 mm in diameter (common types and sizes of steel meshes used in Ferro-cement in ACI Committee 549) **[9]**. The Ferro-cement jacket is modeled in SAP2000 using section designer.

3.2 Steel plate jacket

One such strategy is a steel cage, which comprises of steel angles at the corners of reinforced concrete sections and steel straps at a specific position along the length **[10]**. In this study, the column is strengthened utilizing four longitudinal steel angles (30×30×3) mm and horizontal straps of (460×180×3) mm that are welded to the longitudinal angles at a particular spacing (300) mm along the height. The steel jacket is modeled in SAP2000 program utilizing section designer and non-prismatic section.

3.3 CFRP jacket

Carbon fiber reinforced polymer (CFRP) is a very light and strong material that has very high tensile strength and strength-to-weight ratio. CFRP are composites that comprise of carbon fibers and matrix **[11]**.

Fibers are the components that carry the applied loads. The matrix ensures the consistency of the fibers, protection of fiber from external environment and re-transition of applied loads to the fiber. In this study, the column was fully warped by one layer of CFRP (1mm thickness).

4. Description of the building

A symmetric six-story reinforced concrete frame building is considered in this study. It consists of four bays in the X-direction and three bays in the Y-direction. The length of each bay along the X-direction and the Y-direction is 5 m. The height of the ground story is 3.5 m; however, the height of the other stories is 3 m. Thus, the total dimensions of the structure are 20×15×18.5m. The support conditions of the structure are considered to be fixed at the foundation level. The structure comprises of RC slab of 15 cm thick laying on the RC beam of 50 cm depth and 30 cm width, which is supported by RC column (50×50) cm. The details of the column and beam sections are illustrated in Figure 3.

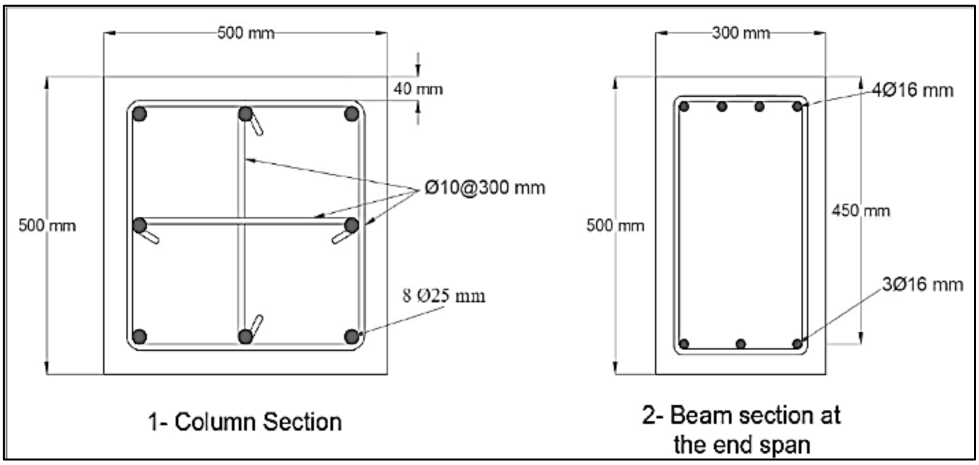


Figure 3. Details of column and beam sections

The damping ratio is considered to be 5%. The loadings on the structure are a dead load, which consists of self-weight, plus a uniform load of (2 kN) and a live load of (4 kN) for each story. In addition, the structure is considered to be subjected the El-Centro earthquake. The nonlinear time history method is employed to analyze the structure subjected to earthquake excitations in either X or Y-direction.

In this study, the plastic hinges are assigned at each end of beam element with uncoupled moment M3 and also assigned at both ends of column element but with coupled P-M2-M3 hinge. Table **1**. Show the properties of the materials utilized in this study.

Table 1. Properties of material

Material	**Property**	**Symbol**	**Unit**	**Value**
Concrete	Compressive strength	f_c'	MPa	30
	Modulus of elasticity	E	GPa	25.74
	Poisson's ratio	ν_c	----	0.2
Steel	Yield stress	f_y	MPa	420
	Ultimate stress capacity	f_u	MPa	620
	Modulus of elasticity	E	GPa	200
	Poisson's ratio	ν_s	----	0.3
Ferro-cement (mortar)	Compressive strength	f_c'	MPa	40
	Modulus of elasticity	E	GPa	29.72
	Poisson's ratio	ν_c	----	0.2
Steel plate	Yield stress	f_y	MPa	344.73
	Ultimate stress capacity	f_u	MPa	448
	Yield strain	ε_y	----	1.75×10^{-3}
	Modulus of elasticity	E	GPa	200
CFRP	Modulus of elasticity	E_x	MPa	62000
		E_y	MPa	4800
		E_z	MPa	4800
	Poisson's ratio	ν_{xy}	----	0.22
		ν_{xz}	----	0.22
		ν_{yz}	----	0.3

The study deals with the analysis of four buildings. One of them is without any strengthening technique and the remaining buildings are with different strengthening techniques. Initially, the original building under earthquake excitation is analyzed and the weak columns that developed plastic hinges are specified. Then, the region of the plastic hinge is strengthened as shown in Figure 4 by one of the following techniques:

(a) Steel jacket, or
(b) Ferro-cement jacket, or
(c) CFRP jacket.

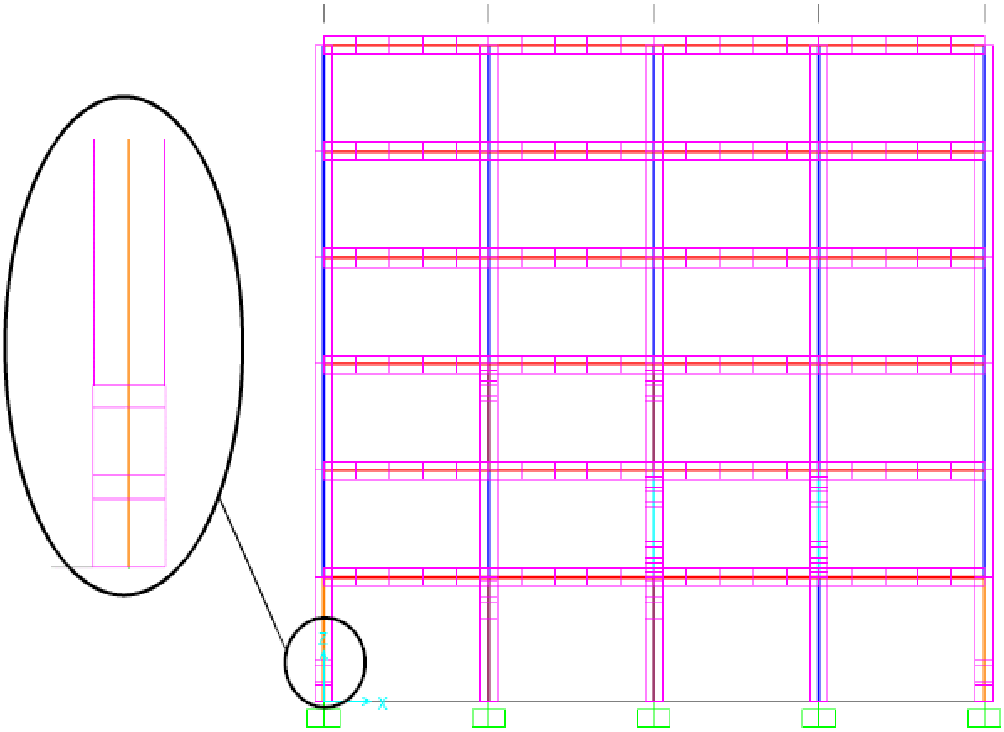


Figure 4. A building with strengthening of the plastic hinge regions developed in columns

5. Plastic hinge performance levels

The performance points were specified by FEMA 365 and ASCE 41 to represent the structural performance at different stages as follows **[12]**:

- Immediate occupancy performance (IO) level indicates that, the structural damages after an earthquake are very limited, and the main lateral and vertical force resisting system of the structure retains its pre-earthquake stiffness and strength. The risk of life-threatening injury because of structural damages is very low and minor repairs in the structure may be appropriate but generally, it is not be required before re-occupancy **[12]**.
- Life safety performance (LS) level refers to a condition where the structural damages after an earthquake are significant, but some resistance against either total or partial collapse of the structure is remained. Several structural components and elements are severely damaged but this has not led to falling large debris inside or outside the building. Injuries may happen; however, the risk of life-threatening injury due to damage of the structure may be low. The structure should be repaired after earthquake but this will be uneconomical. Although the structure is not susceptible to collapse risk, repairs in the structure should be conducted prior to re-occupancy.
- Collapse prevention performance (CP) level means that, the damages after an earthquake drove the structure to the verge of total or partial collapse. Severe damages in the structure have occurred potentially, including significant decreasing in the strength and stiffness of the structural system which resists lateral force, significant permanent lateral deformation of the structure and deterioration in the capacity of the vertical-load carrying system. However, all main structural elements, which resist gravity loads, retain (to

a more limited extent) their strength to carry gravity load. The risk of injury is very big because of falling of structural debris. The structure will be unsafe and cannot be practically repaired **[12]**.

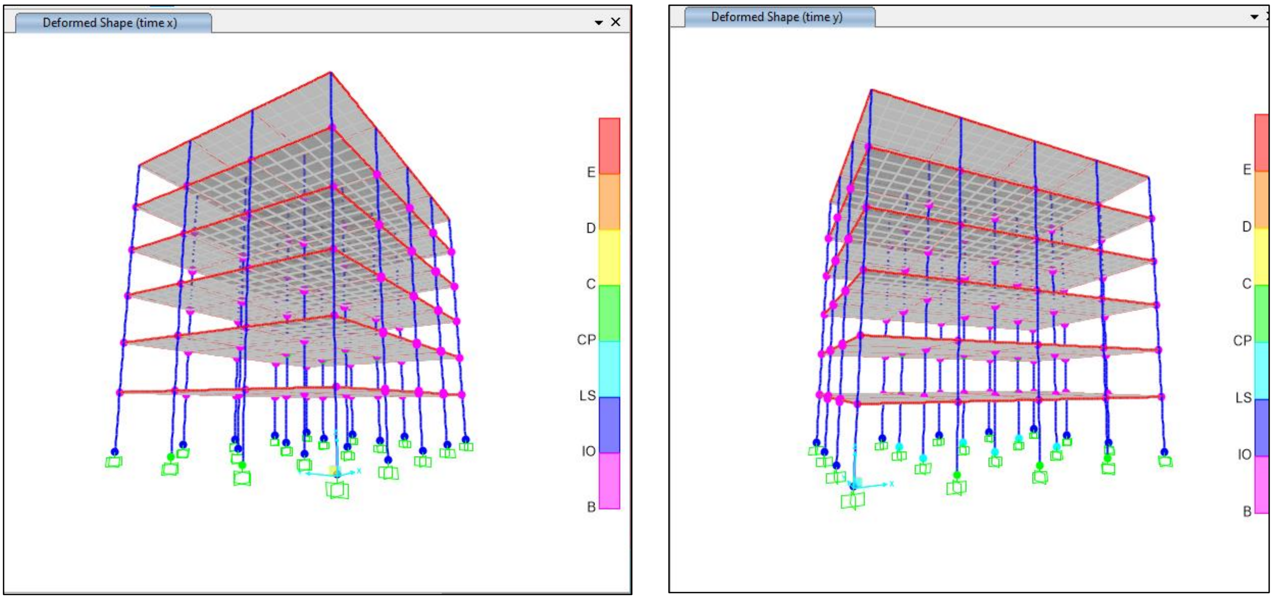
6. Results of cases studies

The factors considered in this study are:

1- Direction of earthquake.

2- Type of strengthening technique.

Nonlinear time-history method is utilized for the analysis of structural systems subjected to earthquake excitation. Different structural models are simulated using SAP2000 V22 software. The performance level of all members in the building is assessed before and after strengthening. In this study, Life safety (LS) level for sever earthquake is selected to represent the target performance level. A trial and error method is used to specify the minimum number of columns that needed to be strengthened to reach the building to the desired performance level considering the earthquake excitation in X and Y-direction. The distribution of plastic hinges and the level of performance for non-strengthened building under design earthquake in X and Y-direction are shown in Figure 5.

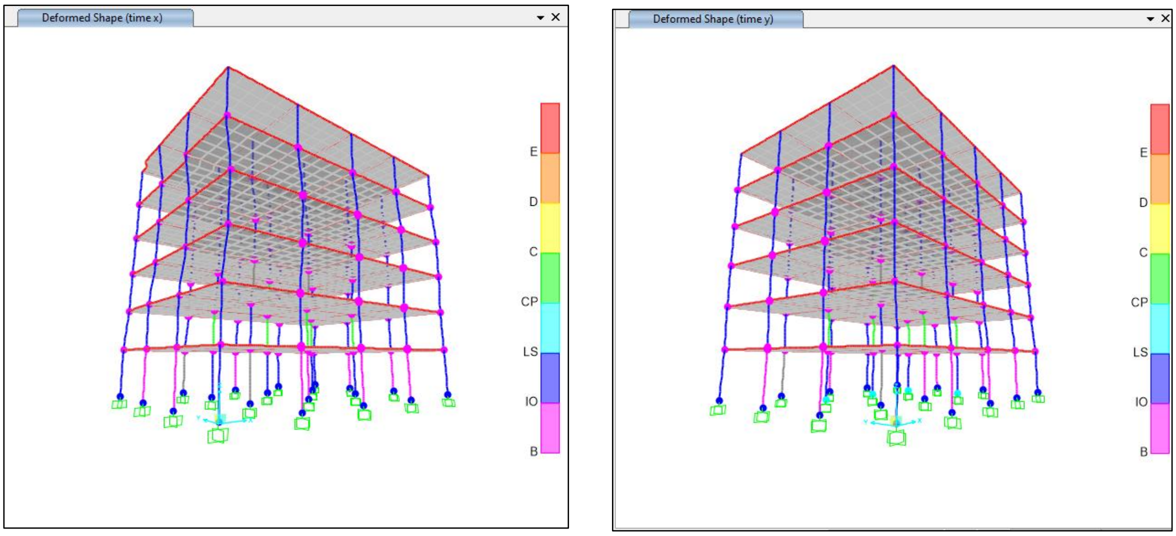


(a) For earthquake in X-direction (b) For earthquake in Y-direction

Figure 5. Plastic hinges distribution and their performance level for non-strengthened building

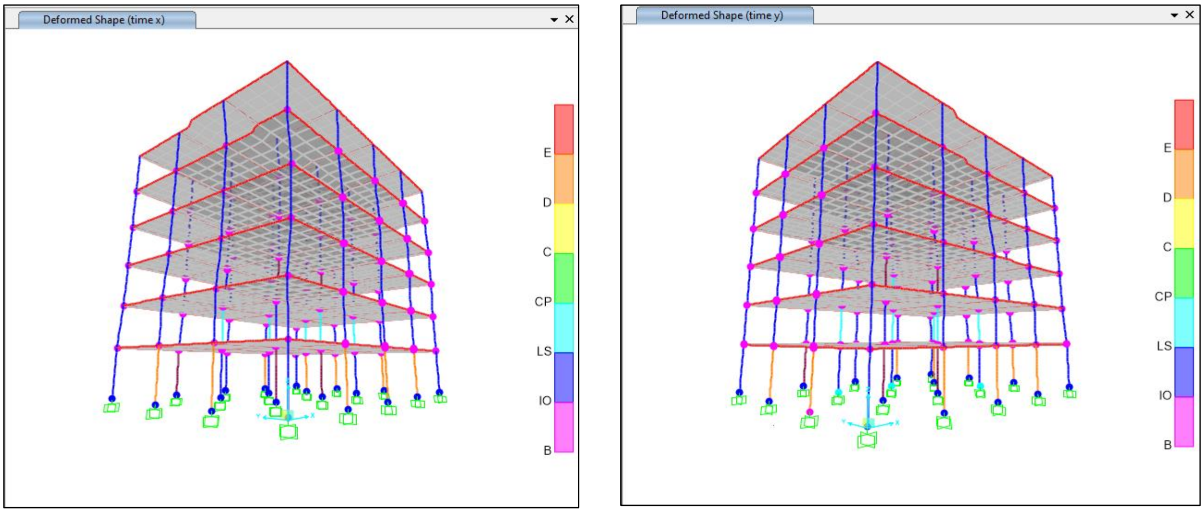
From Figure 5, it can be seen that the collapse prevention (CP) level of performance has developed at 14 locations in five columns at the ground floor and nine columns at the first floor. In the first trial, all these columns are strengthened with the three strengthening techniques and these columns reached to the performance of LS or IO level. However, the perormance of CP level has developed in other columns. Therefore, in the second trial the failed columns are strengthened.

After completing the second trial, the analysis shows that the CP levels transferred to other columns including the strengthened columns that needed to be strengthened to the opposite direction of the earthquake. In other words, when some of the failed columns are strengthened because of the earthquake applied in the X-direction, the strengthened columns may fail again due to the earthquake applied in Y-direction and vice versa. Therefore, a trial and error procedure has been taken into account to determine the minimum numbers and locations of the columns that required to be strengthened to reach to the required level for both earthquake in X and Y-direction. The hinges with collapse prevention levels are developed sometimes at one end of the column or at both ends of the column. Accordingly, one end or both ends of failed columns are strengthened .The final trials are shown in Figures 6, 7 and 8 for Ferro-cement, steel and CFRP jacket, respectively. The number of strengthened region in columns at each story for the three strengthening techniques is summarized in Table 2.



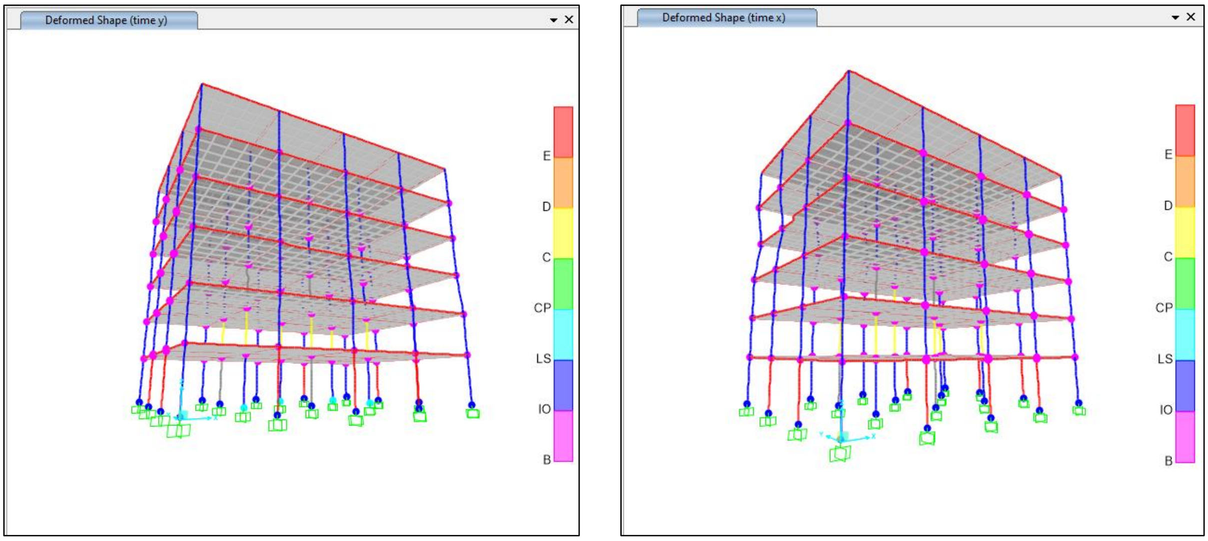
(a) For earthquake in X-direction (b) For earthquake in Y-direction

Figure 6. Plastic hinges distribution and their performance level for strengthened building with Ferro-cement jacket



(a) For earthquake in X-direction (b) For earthquake in Y-direction

Figure 7. Plastic hinges distribution and their performance level for strengthened building with steel jacket



(a) For earthquake in X-direction (b) For earthquake in Y-direction

Figure 8. Plastic hinges distribution and their performance level for strengthened building with CFRP jacket

Table 2. Number of strengthened regions of columns in the building

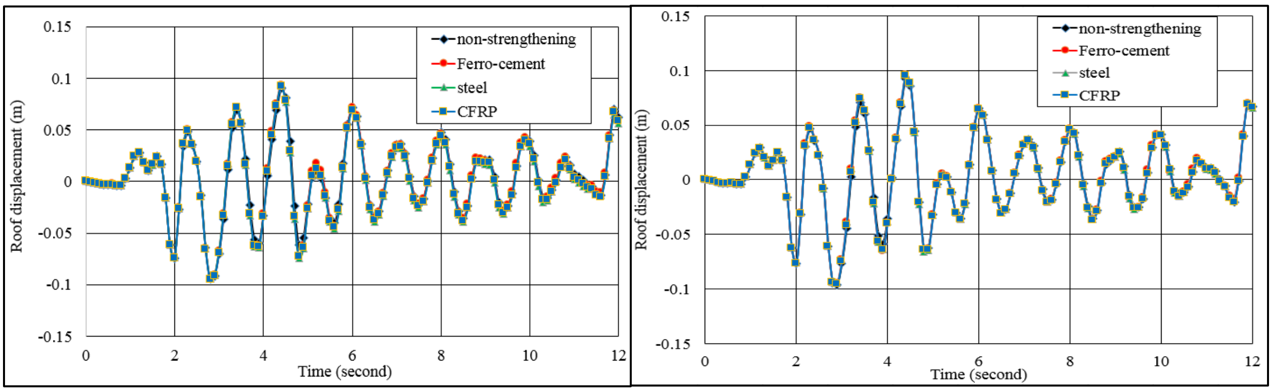
Story No.	No. of columns		
	Steel jacket	Ferro-cement	CFRP jacket
1	10	11	10
2	12	10	12
3	4	4	4
Total	26	25	26

It is clear from the results that the numbers and locations of the strengthened columns required to satisfy the performance level of the building depend on the used strengthening method. The numbers of strengthened columns are the same for all three techniques. The steel jacket and CFRP jacket have the same number and locations of the strengthened columns required to satisfy the performance level of the building. Table 3 shows numbers of plastic hinges and their performance levels for each building.

Table 3. Numbers of plastic hinges and their performance levels

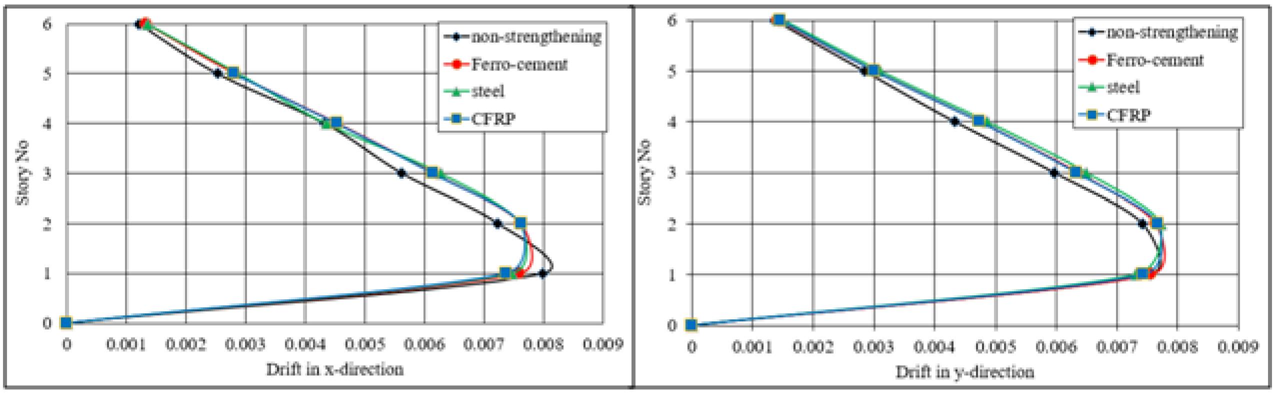
Strengthening Method		Non-strengthening		Ferro-cement jacket		Steel jacket		CFRP jacket	
Earthquake Direction		(X)	(Y)	(X)	(Y)	(X)	(Y)	(X)	(Y)
No. of Hinges	B	207	195	210	199	199	185	214	200
	IO	18	11	20	16	20	16	20	16
	LS	0	6	0	4	0	3	0	4
	CP	6	8	0	0	0	0	0	0

The maximum roof displacements, maximum story drift ratios and base shear force chart are shown in Figures 9, 10 and 11, respectively.



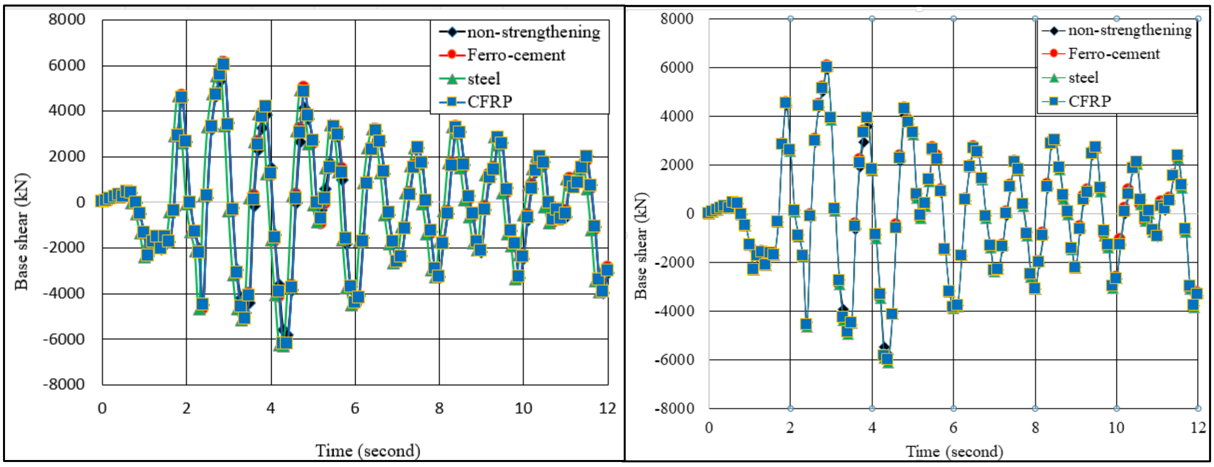
(a) For earthquake in X-direction (b) For earthquake in Y-direction

Figure 9. Max roof displacement for non-strengthened and strengthened buildings



(a) For earthquake in X-direction (b) For earthquake in Y-direction

Figure 10. Max story drift ratio for non-strengthened and strengthened buildings



(a) For earthquake in X-direction (b) For earthquake in Y-direction

Figure 11. Base shear chart in Y-direction for non-strengthened and strengthened buildings

The maximum displacement of the roof, shown in Figures 9, is very close for all the three methods. The displacement of strengthened buildings with steel, Ferro-cement and CFRP jackets is increased with an average ratio of 3.3%, 3.3%, and 2.75% respectively in comparison with the original building. From Figure 10 it can be noticed that there is a very small difference in story drift among all the strengthening techniques in the two directions. The base shear force of strengthened buildings with steel, Ferro-cement and CFRP jackets increases with an average ratio of 2.6%, 2.5% and 1%, respectively in comparison with the non-strengthened building as shown in Figures 11.

7. Cost and time analysis

For the purpose of comparison of cost and time among the presented strengthening techniques, all other parameters must be fixed. The most important parameter is that the strength or stiffness of all techniques must be the same. If this parameter is not specified, the comparison of the cost and time among the techniques will be meaningless. The change in characteristics of the strengthening (material properties or dimensions) will lead to increase in the cost and/or the required time. In this study, the cost and time comparison among these three techniques is investigated by using the same static stiffness for them. The use of the same static stiffness is more practical and also the results showed that the seismic behavior of the strengthened buildings with these three techniques is similar.

In this comparison, the local cost for strengthened materials is considered. The unit price is selected USD as a common practice. The estimated price for three strengthening techniques is converted per square meter of surface column area by calculating the total cost of strengthening column and dividing the total cost on the strengthened surface area for each item of activities. The total cost includes cost of materials and labors for installation. The total estimated local cost of the three strengthening techniques is shown in Tables 4.

Table 4. Cost calculation for strengthening column

No	Descriptions	Unit	Steel jacket			Ferro-cement jacket			CFRP jacket		
			Quantity	Unit Cost "USD"	Total Cost "USD"	Quantity	Unit Cost "USD"	Total Cost "USD"	Quantity	Unit Cost "USD"	Total Cost "USD"
1	Mobilization , storing equipment's	LS	---	---	250	---	---	125	---	---	50
2	Pre-Curing	m^2	50	25	1250	50	35	1750	58	20	1160

No	Descriptions	Unit	Steel jacket			Ferro-cement jacket			CFRP jacket		
			Quantity	Unit Cost "USD"	Total Cost "USD"	Quantity	Unit Cost "USD"	Total Cost "USD"	Quantity	Unit Cost "USD"	Total Cost "USD"
3	Adhesive (epoxy)	m^2	50	10	500	---	---		58	10	580
4	strengthening material	m^2	50	5.5	275	50	25	1250	58	85	4930
5	Demobilization and site cleaning	LS	---	---	750	---	---	750	---	---	100
	Total Cost	USD			3025			3875			6820

Note: LS stands for Lump sum

The time required for each strengthening techniques is estimated according to each item activities per square meter of surface column area. Table 5 shows the estimated time for strengthening square meter of column area by one team work.

Table 5. Time required for strengthening 1m^2 (one team work)

No	Descriptions	Unit	Steel jacket	Ferro-cement jacket	CFRP jacket
			Quantity	Quantity	Quantity
1	Pre-Curing	Hours	1.5	4	1.5
2	Adhesive (epoxy)	Hours	0.3	----	0.3
3	strengthening material	Hours	0.8	1.25	0.5
4	Demobilization and site cleaning	Hours	0.2	0.3	0.05
	Total Required Time	Hours	2.8	5.55	2.35

It is clear that the CFRP jacket has the highest cost among the three techniques but lower installation time. However, the steel jacket has the lowest cost and the Ferro-cement jacket has the highest installation time.

8. Conclusions

The following conclusions are obtained after the seismic analysis of the building before and after strengthening it.

- The three strengthening techniques improve the performance level and the ductility characteristics of the building.
- The three strengthening techniques are very useful to reduce the number and level of the plastic hinges in the building and they reduce the risk of building collapse.
- In seismic analysis, the three techniques which have the same static stiffness show similar dynamic behavior with approximately same numbers of strengthened columns to reach to the required level of performance for each type.
- The static stiffness for these three strengthening techniques can be adopted to know the cost of each technique to obtain the same protection for building under the seismic loads.
- The CFRP jacket has the highest cost but lower installation time compared to steel and Ferro-cement jacket. However, the steel jacket has the lowest cost and the Ferro-cement jacket has the highest installation time.

- Each strengthening technique has its own advantages and it cannot be said that one technique is absolutely better than the other techniques.

9. References

[1] H. Shrestha, K. Pribadi, D. Kusumastuti, and E. Lim, “Manual on Retrofitting of Existing Vulnerable School Building-Assessment to Retrofitting”, Part I, *Construction Quality and Technical Assistance, Center for Disaster Mitigation-Institution of Technology Bandung*, 2009.

[2] M. Porcu, J. Vielma, F. Panu, C. Aguilar, and G. Curreli, “Seismic Retrofit of Existing Buildings Led by Non-linear Dynamic Analyses” , *International Journal of Safety and Security Engineering*, vol. 9, no. 3, p.201-212, 2019.

[3] B. Li, E. Lam, B. Wu, and Y.Wang, “Experimental Investigation on Reinforced Concrete Interior Beam–Column Joints Rehabilitated by Ferro-cement Jackets”, *Engineering Structures*, vol. 56, p. 897-909, 2013.

[4] H. Ronagh and A. Eslami, “Flexural Retrofitting of RC Buildings Using GFRP/CFRP – A Comparative Study”, *Composites*: Part B, vol. 46, p. 188-196, 2013.

[5] A. Tarabia, and H. Albakry, “Strengthening of RC Columns by Steel Angles and Strips”, *Alexandria Engineering Journal*, p. 1-12, 2014.

[6] A. Ismail, “Nonlinear Static Analysis of A Retrofitted Reinforced Concrete Building*”, Housing and Building National Research Center HBRC Journal*, vol. 10, p. 100-107, 2013.

[7] K. Rathod, and S. Gupta, “A Nonlinear Time History Analysis of Ten Storey RCC Building”, *International Research Journal of Engineering and Technology*, vol. 7, p. 7153-7160, 2020.

[8] N. Anwar, and F. Najam, “Structural Cross-Section Analysis and Design”, *Elsevier Science & Technology Books*, 2017.

[9] ACI Committee 549. “Guide for the Design, Construction and Repair of Ferrocement”. American Concrete Institute, Re-approved, 1999.

[10] P. Nagaprasad, D. Sahoo, and D. Rai, “Seismic Strengthening of RC Columns Using External Steel Cage”, *Earthquake Engineering and Structural Dynamics,* vol. 38, p. 1563-1586, 2009.

[11] Y. Amran, R. Alyousef, R. Rashid, H. Alabduljabbar, and C. Hung, “Properties and Applications of FRP in Strengthening RC Structures: A Review”, *Structures Journal*, vol. 16, p. 208-238, 2018.

[12] S. Sapkota, “Seismic Capacity Evaluation of Reinforced Concrete Buildings Using Pushover Analysis”, MSc Thesis, The University of Toledo, 2018.

[13] F. Majeed, “Estimating the behavior of Ferrocement strengthened RC columns using artificial neural networks”, *International Journal of Applied Engineering Research*, vol.13, no.1, pp. 732-736, 2018.