International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 02, February-2017

Seismic Evaluation and Strengthening of RC Frames with FRP Composites

Mohamed Husain[1], Hilal Hassan[2], Mahmoud Abd Elhamid[3] and Eman Said Elgharbawy [4]
[1] Professor of Concrete Structures, [2] Associate Professor Structural Engineering,
[3] lecturer of structural Engineering,
[4] Structural Engineering, Faculty of Engineering,
Zagazig University, Egypt.

Abstract. **Existing structures designed and built before the current seismic codes need to be evaluated for its seismic safety. The nonlinear static pushover analysis has been a popular method for seismic performance evaluation of existing structures. The expectation is that the pushover analysis will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components. The primary aim of this research is the evaluation of the seismic performance of structures using nonlinear static pushover analysis method (displacement coefficient method) by SeismoStruct analysis program (Version7). Three building models are considered for evaluation, the first is a low-rise building (3-story), the second is medium-rise building (6-story) and the third is a high-rise building (10-story). These models resist seismic forces by moment resisting concrete frames, located in the high-seismically region of Egypt (ag = 0.2g). The results of evaluation are one of the following performance levels, immediate occupancy (IO), life safety (LS) and collapse prevention (CP). A number of columns in sex story building are found to be so deficient that needs strengthening and the ten story building are found to be near collapse. After strengthening of the deficient elements by using carbon fiber jacketing, the structure is seismically evaluated again. The study has shown that carbon fiber reinforced concrete jacketing (CFRP) is an efficient way for strengthening RC members to improve chord rotation as well as shear capacity.**

***Keywords:** Reinforced concrete frame, seismic performances, Non-linear static pushover analysis (NSPA), Displacement coefficient method, Strengthening, CFRP jacketing.*

INTRODUCTION

1.1 Background

The earthquake engineering is a sector of civil engineering that deals with the mitigation of earthquake-induced damage to structures and minimizing of loss of life during the earthquakes. Over the decades, researchers in performance-based earthquake engineering try to develop simple and precise approaches for predicting seismic capacity and demand on structures by taking into account their inelastic behavior, [11]. Although Egypt lies in low-to- medium seismic zone, but it has seen a lot of damage due to earthquakes throughout its history. So that, it is imperative to seismically evaluate the existing buildings with the present day seismic knowledge to avoid the major destruction in the future earthquakes. The buildings found to be seismically deficient should be retrofitted or strengthened.

The performance-based methodology necessitates the estimation of two quantities for assessment and design purposes. These are the seismic capacity and the seismic demand. Seismic capacity is the ability of the building to resist the seismic effects. Seismic demand is a description of the earthquake effects on the building. The performance is evaluated in a manner such that the capacity is greater than the demand (ATC-40, 1996), [1].

1.2 Pushover Analysis

According to FEMA (356) [2], the pushover analysis is one of the present day knowledge to evaluate the existing structures seismically. It is a static nonlinear analysis under permanent vertical loads and gradually increasing lateral loads that shows the inertial forces which would be experienced by the structure when subjected to ground motion, then obtain the capacity curve or the pushover curve. The capacity curve is a plot of total base shear versus top displacement in a structure. According to ATC (40) [1], there are two types of the conventional pushover analysis, Capacity Spectrum Method (CSM) and Displacement Coefficient Method (DCM).

The two methods are being used to make an evaluation for the building by calculating the performance point or the target displacement, then using the performance point to compare it with the available capacities for a performance check (immediate occupancy –life safety– collapse prevention), [7].

Immediate occupancy (IO), means post-earthquake damage should be at the level that the structure remains safe to occupy and stays harmless to inhabit and can be easily repaired, according to FEMA (356) [2].

Life safety (LS), shall be defined as the post-earthquake damage state in which significant damage to the structure has occurred damage and there is a risk of injury to life, but It should be possible to repair the structure and repairing may be less economical when compared to complete reconstruction, according to FEMA (356) [2].

Collapse prevention (CP), Substantial damage to the structure has occurred at this level, potentially included significant degradation in the strength and stiffness of the seismic load resisting system. Significant risk of injury due to falling hazards from structural debris may exist. The construction is not safe for re-occupancy and could not be technically practical to repair, according to FEMA (356) [2].

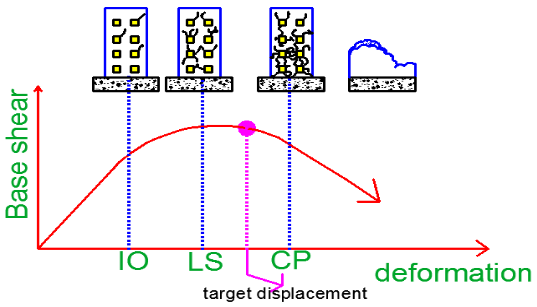

Fig1: performance levels FEMA [356].

Damage Control Structural Performance Range

Damage Control range, Shall be defined as the continuous range of damage states between the Life Safety Structural Performance Level and the Immediate Occupancy Structural Performance Level, [2].

Limited Safety Structural Performance Range

Limited Safety range, shall be defined as the continuous range of damage states between the Life Safety Structural Performance Level and the Collapse Prevention Structural Performance Level, [2].

Prabhu, A. (May, 2013) [9] studied the pushover analysis method and calculated the target displacement to evaluate a 50-year old four story reinforced concrete structure, which lies in Zone II, according to IS 1893:2000 classification of seismic zones in India. Masonry infills have been considered as non-structural members during his study. The Push over analysis reveals the structure is safe and hence the building does not need to be retrofitted serviceability and maximum earthquakes.

Ahmed, S. Y. (June 2013) [10] analyzed Ten stories–five bays reinforced concrete frame_subjected to seismic hazard of the Mosul city/Iraq. Plastic hinge is used to represent the failure mode in the beams and columns when the member yields. The pushover analysis is performed on the present building frame using SAP2000 software (V.14) to verify the code's underlying intent of Life Safety performance under seismic effects. All the plastic hinges formed in the beams are positioned in the dangerous branch (collapse prevention CP) of Acceptance Criteria of plastic hinge, this demands strengthening the beams. Through the comparison between different options of the plastic hinge behavior during the pushover analysis, the plastic hinge formed due to its brittle behavior put it in the greater severity level.

Tayyebi, S. M. (October 2014) [11] Studied the difference between nonlinear analysis method, Incremental Dynamics Analysis (IDA), The Displacement-based Adaptive Pushover Analysis (DAP), and static pushover analysis (SPA) for evaluating the seismic performances of three models, which are considered to represent low-rise (3-story frame), medium-rise (8-story frame) and high-rise structures (12-story frame). This consists of a moment resisting reinforced concrete structures with no shear walls, located in a high-seismically region of Turkey. They are designed according to Turkish Earthquake Code 2007 and TS 500-2000 codes, considering both seismic and gravity loads. The conventional pushover analysis represents an easier and more practical method with respect to nonlinear dynamic analyses. The procedure avoids the major pitfalls in time-history analyses, which require simulation of time history ground motion records compatible with a target response spectrum. Displacement- based adaptive pushover analysis represents an improvement regarding to other static procedure, although the method could not provide the optimal solution. In fact, the capacity curves clearly demonstrate that DAP provides better estimates, particularly for high-rise structures in which the effects of vibration higher modes are significant. Hence, DAP represents simplified and practical procedure that able to predict the response of high-rise RC structures with appropriate accuracy, the current research uses the DAP method.

Proposed work and objectives.

This research project aims at conducting a seismic evaluation of existing buildings using nonlinear static analysis method (displacement coefficient method) to identify the failing members and strengthening it by following these steps:

1) Analyze the seismic performance of the existing structure with more degree of accuracy by using the Non-linear Static Analysis Method.
2) Simulate the structure in SeismoStruct Version 7 and run the Pushover analysis for the limiting case of the structure to generate a pushover curve.
3) Find the target displacement of the structure by using Idealized Force-Displacement Curve and Displacement Coefficient Method in accordance with ATC 40.
4) Studying the behavior of the structure when subjected to the Pushover Analysis by limiting the maximum displacement of the top node to the calculated target displacement.
5) Strengthening the failing member by FRP Jacket.
6) Re- evaluate the strengthening structure.
7) Comment on the result after and before strengthening.

1.3 SeismoStruct:

SeismoStruct is a Finite Element package capable of predicting the large displacement behavior of space frames under static or dynamic loading, taking into account both geometric nonlinearities and material inelasticity. Concrete, steel, FRP and SMA material models are available together with a large library of 3D elements that may be used with a wide variety of pre-defined steel, concrete and composite section configurations, [11,12].

Building description:
Three RC structures, with different elevation, are considered to represent low-rise, medium- rise and high-rise RC structures for this work. The structures have a moment resisting RC elements without any shear walls and are supposed to be located in a high-seismically region of Egypt zone (ag =0.2g). The ground floor height is 4m and all the typical floors are the same height of 3.2 meters. Structures are designed according to Egyptian building code by using (M20/25) as concrete and (Fe400) to be the reinforcement steel. The structure was designed for only dead and live loads.

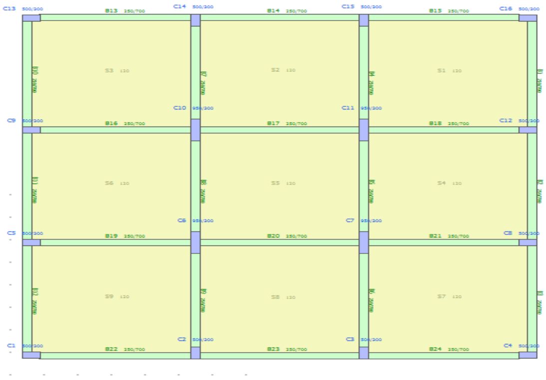

Fig 2: The frame has three bays with 5 meter span length in two directions.

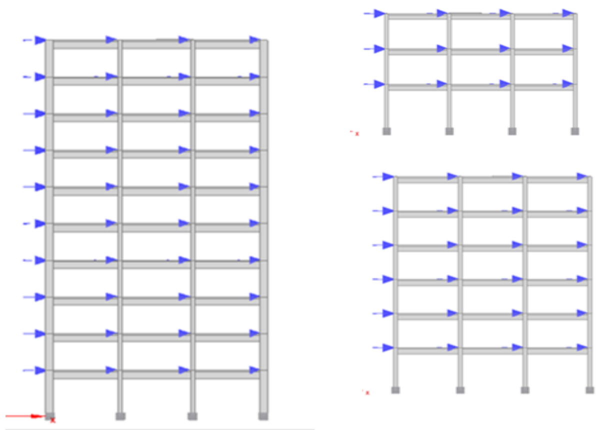

Fig 3: 3 story frame, 6 storey frame, 10 story frame.

Table (1). The 3story dimension, 10.4m in elevation

Col dimension		
Dimension (Cm)	Reinforcement	Stirrups
30*30	8ϕ12	Φ8/20

Beam dimension			
Dimension (Cm)	Top	Bottom	Stirrups
25*60	4ϕ16	4ϕ16	Φ8/20

Table (2). The 6story dimension, 20m in elevation.

Col dimension		
Dimension (Cm)	Reinforcement	Stirrups
Exterior col 30*30	8ϕ12	Φ8/20
Interior col 30*60	10ϕ16	Φ8/20

Beam dimension			
Dimension (Cm)	Top	Bottom	Stirrups
25*60	4ϕ16	4ϕ16	Φ8/20

Table (3). The 10 story dimension, 32.8m in elevation.

Col dimension		
Dimension (Cm)	Reinforcement	Stirrups
Exterior col 40*50	8ϕ18	Φ8/20
Interior col 40*95	12ϕ20	Φ8/20

Beam dimension			
Dimension(Cm)	Top	Bottom	Stirrups
25*60	4ϕ16	4ϕ16	Φ8/20

Target Displacement calculation
According to ATC (40) [1], The target displacement is intended to represent the maximum displacement likely to be experienced during the design earthquake, Equation (1) represents a basic relation that is used to calculate the target displacement, U_t.

$$U_t = C_o\ C_1\ C_2\ C_3\ S_a\ \frac{T_e^{\,2}}{4\pi^2} \qquad \{1\}$$

Where:

- The coefficient C_o: modification factor to relate spectral displacement of an equivalent SDOF system to the roof displacement of the building MDOF system. From table(8-8) at ATC (40), we can get C0 according to a number of stories.

- C_1 = modification factor to relate expected maximum inelastic displacements to displacements calculated for linear elastic response.
  $C_1 = 1 \qquad T_e \geq T_0$
  $C_1 = (1 + \frac{(R-1)*T_0}{T_e})/R \qquad T_e < T_0$
  C_1 =need not exceed 2.00 for $T_e < 0.1$ second

- R = the ratio of inelastic strength calculated as,
  $$R = \frac{S_a/g}{V_y/W} * \frac{1}{C_o}$$
- W= total dead load and 25 percent of the floor live load.

- C_2 = Modification factor differs according to the framing type system and performance levels, the values listed in table (8-9) in ATC (40).

  - $C_2 = 1.10$ for frame type 1, life safety, $T_o \leq$ T

- C_3 =modification factor

  - For buildings with positive post-yield $C_3 = 1.0$

- For buildings with negative post-yield $C_3 = 1 + \frac{\alpha(R-1)^{3/2}}{T_e}$
- T_e : Effective fundamental period of the building in the direction under consideration, in Second.

$$T_e = T_i\sqrt{\frac{K_i}{K_e}}$$

- T_i : Elastic fundamental period (in second) in the direction under consideration.

$$T = T_i = C * h_n^{\beta}$$

- β = 0.90 for concrete moment-resisting frame systems, according to ASCE (41-06) [4].
- C = 0.018 for concrete moment-resisting frame systems, according to ASCE (41-06) [4].
- h_n = height (in ft) above the base to the roof level.
- K_i : Elastic lateral stiffness of the building in the direction under consideration.
- K_e : Effective lateral stiffness of the building in the direction under consideration.

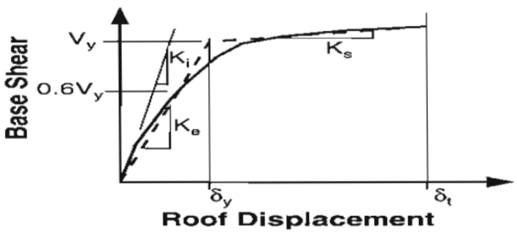

Fig 4: Bilinear representation of the capacity spectrum ATC [40].

Sa: spectral response acceleration, according to ATC (40), the generalized value of Sa can be found using either.

Sa = 2.5*C_A *For* $T_o \leq T_1 \leq T_s$

Sa = C_A / T *For* $T_s < T_1$

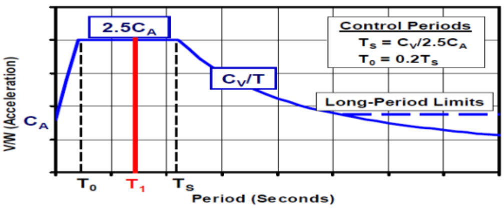

Fig 5: 5% damped elastic response spectrum ATC [40], [1].

C_v , C_A= seismic coefficient depending on the seismic zone and the soil type according to the table (4-8) and table (4-9) in ATC [40], [1].

- For seismic zone (a_g= 0.2g)
- Soil type (D)
- C_v = 0.4
- C_A = 0.28

3-story structure:

Table (4). ATC (40) parameters for 3-story frame model

Item	Value	Item	Value
C_o	1.3	T_i	0.42
C_1	1.00	K_i	13400
C_2	1.1	K_e	9600
C_3	1.00	V_y	480
S_a	0.7	W	4028.06

- $U_t = 1.3 * 1 * 1.1 * 1 * (.7 * 9.81) * \frac{0.49^2}{4\pi^2} =$ .059m

Capacity curve of conventional pushover analysis:

Figure (6), shows the structure's pushover capacity curve and the performance levels derived by performing pushover analysis using the SeismoSoft analysis program.

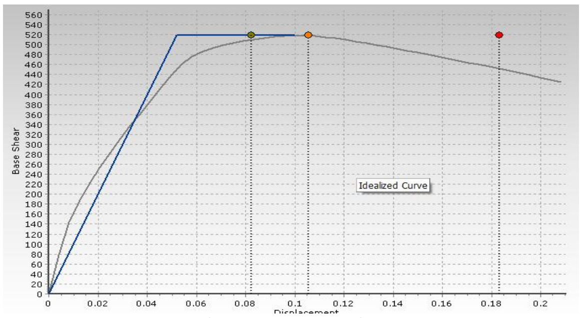

Fig 6: the performance levels of 3-Story Frame

Table (5). The performance levels of 3-Story Frame.

Performance limit	At Displacement (m)	Base shear (KN)
Yield	.056	459.97
IO	0.082	510.3
LS	0.106	517.93
CP	0.183	451.4

According to FEMA (356) procedure, the target displacement is equal to 0.059 m in 3-story RC frame. The frame yields at 0.056m and obtained top drift ratio 0.57%. Based on the target displacement the 3-story RC frame under uniform lateral load expected to be safe and does not need to be strengthened.

For 6-story building:

Table (6). ATC (40) parameters for 6-story frame model

Item	Value	Item	Value
C_o	1.42	T_i	0.78
C_1	1.00	K_i	16000
C_2	1.1	K_e	13000
C_3	1.00	V_y	700
S_a	.51	W	8056.125

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 02, February-2017

- $U_t = 1.42 * 1 * 1.1 * 1 * (.51 * 9.81) * \frac{0.86^2}{4\pi^2} = .146\text{m}$

Capacity curve of conventional pushover analysis:

Figure 7, shows the structure's pushover capacity curve and the performance levels derived by performing pushover analysis, using SeismoSoft program.

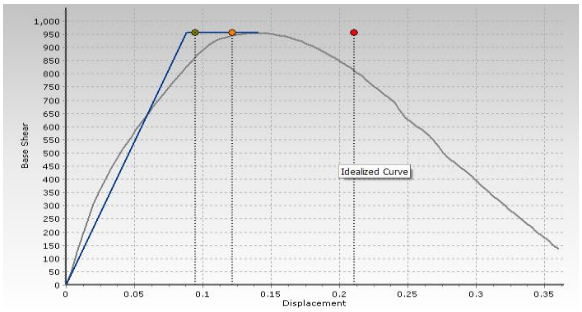

Fig 7: the performance levels of 6-Story Frame

Table (7). The performance levels of 6-Story Frame.

Performance limit	At Displacement (m)	Base shear (KN)
Yield	.069	676.78
IO	.0946	870.7
LS	0.1214	943.03
CP	0.210	821.14

According to FEMA (356) procedure, the target displacement is equal to 0.126 m in 6-story RC frame. The frame yields at 0.069 m and obtained top drift ratio 0.63%. Based on the target displacement the largest plastic hinges in limited safety range. Thus, 6-story RC frame under uniform lateral load have significant damage and there is a risk of injury to life but it could be strengthened.

For 10-story building

Table (8): ATC (40) parameters for 10-story frame model.

Item	Value	Item	Value
C_o	1.5	T_i	1.21
C_1	1.00	K_i	27000
C_2	1.1	K_e	23000
C_3	1.00	V_y	2400
S_a	.33	W	13426.875

- $U_t = 1.5 * 1 * 1.1 * 1 * (.33 * 9.81) * \frac{1.3^2}{4\pi^2} = .23\text{m}$

Capacity curve of conventional pushover analysis:

Figure (8), shows the structure's pushover capacity curve and the performance levels derived by performing pushover analysis, using SeismoSoft program.

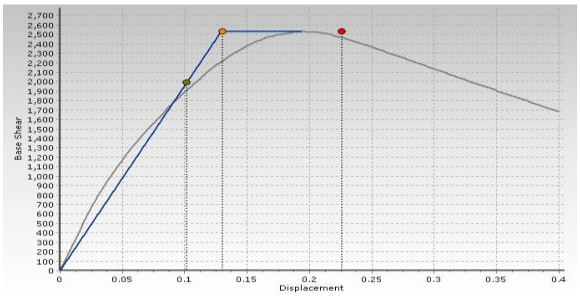

Fig 8: The performance levels of 10-Story Frame

Table (9): The performance levels of 10 - story frame.

Performance limit	At Displacement (m)	Base shear (KN)
Yield	.075	1569.18
IO	0.1	1911.535
LS	0.13	2228.495
CP	0.2226	2465.519

According to FEMA 356 procedure, the target displacement is equal to 0.23 m in 10-story RC frame. The frame yields at 0.075 m and obtained top drift ratio 0.70%. Based on the target displacement, total collapse occurred. Thus, 10-story RC frame under uniform lateral load have Substantial damage. So that, the construction is not safe for re- occupancy and could not be technically practical to repair or strengthen.

Strengthening

Strengthening of existing reinforced concrete structures is a very important target to avoid the development of plastic hinges in columns at the seismic zones. Strengthening is increasing bending and shear capacity. FRP systems are suitable for strengthening of RC structures due to their technical and economic advantages. Classic strengthening solutions may lead to some inconveniences as such methods are costly and disruptive to operate. A typical approach is increasing the dimensions of the elements with consequent mass increasing and leading to seismic problems. Furthermore, if reinforcement corrosion is present and its causes are not carefully removed the corrosion will continue, [5], [8].

Fiber reinforced concrete jacketing (FRP) is a member-level strengthening technique. It is increasing concrete confinement, shear capacity and flexural strength of the members. There are three types of fiber reinforced polymer glass fiber, aramid fiber and carbon fiber, but the Carbon fibers are the best choice when it comes to use FRP because of the high tensile stiffness and strength, stability under high temperatures and resistance to acidic/alkali/organic environments, [3, 6, 8].

According to ACI (440.2 R-02) [3], the material properties reported by manufacturers, such as the ultimate tensile strength and fiber strain. Typically, these properties do not consider long-term exposure to environmental conditions and should be considered as initial properties because long term exposure to various types of environments can reduce the tensile and strain properties so that the material properties used in design equations should be reduced based on the environmental exposure condition.

Product name: Sika wrap-300C

Sika Wrap®-300 C is a unidirectional woven carbon fiber fabric for the dry application process.

Table (10): physical and mechanical properties of (CFRP) Sika wrap 300C.

Fiber stiffness	Fiber strain	Fiber density	Thickness
230 GPA	1.5%	1.79 g/cm3	0.166 mm

Tensile strength	Tensile E-modulus
3900 N/mm2	230000 N/mm2

- According to ACI (440.2 R-02) table (8-1), Environmental Reduction Factor Ce for carbon fibers = 0.95

The uses, according to manufacturers:
Structural strengthening of reinforced concrete, masonry, brickwork and timber elements or structures, to increase flexural and shear loading capacity for:

1) Replacing missing steel reinforcement
2) Increasing the strength and ductility of columns
3) Increasing the loading capacity of structural elements
4) Correcting structural design and / or construction defects
5) Increasing resistance to seismic movement
6) Improving service life and durability
7) Structural upgrading to comply with current standards

- After strengthening the unsafe member by using CFRP, The result showing that.

For 6 story building:

Table (11). For chord rotation failing member (6 -story building, first floor).

Col. NO	Demand	Capacity before CFRP	Statue	Capacity After CFRP	Statue
C1	0.0184	0.0171	Unsafe	0.0232	Safe
C2	0.0184	0.0139	Unsafe	0.0188	Safe
C3	0.0184	0.0140	Unsafe	0.0189	Safe
C4	0.0184	0.0151	Unsafe	0.020	Safe
C5	0.0184	0.0160	Unsafe	0.021	Safe
C6	0.0184	0.0160	Unsafe	0.019	Safe
C7	0.0184	0.0158	Unsafe	0.0190	Safe
C8	0.0184	0.0139	Unsafe	0.0189	Safe
C9	0.0184	0.0160	Unsafe	0.0219	Safe
C10	0.0184	0.0160	Unsafe	0.0194	Safe
C11	0.0184	0.0157	Unsafe	0.0191	Safe
C12	0.0184	0.0139	Unsafe	0.0189	Safe
C13	0.0184	0.0171	Unsafe	0.0232	Safe
C14	0.0184	0.0139	Unsafe	0.0188	Safe
C15	0.0184	0.0139	Unsafe	0.0188	Safe
C16	0.0184	0.0151	Unsafe	0.020	Safe

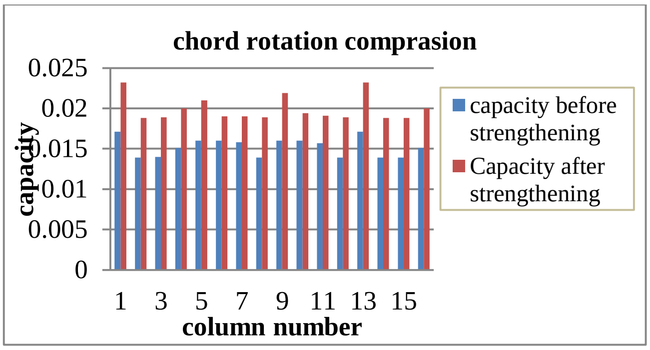

Fig (9). Chart for chord rotation comparison before and after CFRP 6-story building.

CONCLUSION

This paper discusses the non-linear static pushover analysis of 3-story, 6-story and 10- story reinforced concrete structure in seismic zone ($a_g = 0.2g$). The target displacement is calculated using the displacement coefficient method in accordance with ATC (40). The simulation of the structure analyzed in Seismostruct Version (7). The structure was designed for only dead and live loads, since earthquake loads would not have been a part of the original design, and then strengthening the failing member by using CFRP material.

- The target displacement is equal to 0.059 m in 3-story RC frame. The frame yields at 0.056m and obtained top drift ratio 0.57%. Based on the target displacement the 3-story RC frame under uniform lateral load expected to be safe and does not need to be strengthened.

- According to FEMA (356) procedure, the target displacement is equal to 0.126 m in 6-story RC frame. The frame yields at 0.069 m and obtained top drift ratio 0.63%. Based on the target displacement the largest plastic hinges in limited safety range. Thus, 6-story RC frame under uniform lateral load have significant damage like the chord rotation damage and there is a risk of injury to life but it could be strengthened.

- According to FEMA 356 procedure, the target displacement is equal to 0.23 m in 10-story RC frame. The frame yields at 0.075 m and obtained top drift ratio 0.70%. Based on the target displacement, total collapse occurred. Thus, 10-story RC frame under uniform lateral load have Substantial damage. So that, the construction is not safe for re-occupancy and could not be technically practical to repair or strengthen.

- CFRP jacket (one layer) increasing the capacity for chord rotation in the range of 35 %

- Finally the pushover analysis combined with the performance levels is able to evaluate the seismic damage of buildings to examine the state of the structure during earthquakes and thus provide information on the damage and the members in need of strengthening.

Recommendation for future work:

There are various areas of future work that should be investigated in regards to this study like various soil types and other zones of earthquake. Other configurations obtained by varying the number of bays and storys.

REFERENCES:

[1] Applied Technology Council, ATC-40: "Seismic Evaluation and Retrofit of Concrete Buildings", Vols. 1 and 2, 1996, California.

[2] American Society of Civil Engineers, & United States. Federal Emergency Management Agency (FEMA 356). (2000). Global topics report on the pre standard and commentary for the seismic rehabilitation of buildings. The Agency.

[3] ACI Committee, ACI 440.2R-02, (2002). Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures- Code of Practice, American Concrete Institute.

[4] Seismic Rehabilitation of Existing Buildings, ASCE (41-06), (2006). American Society of Civil Engineers.

[5] DAN, SORIN, et al. Strengthening of reinforced concrete framed structures in seismic zones by using CFRP. In: WSEAS International Conference on Engineering Mechanics, Structures, Engineering Geology (EMESEG, 08), Heraklion, Crete Island, Greece. (2008). p. 67-72.

[6] AL ALAILY, H. S. (2011). Retrofit of reinforced concrete columns by composite jacketing (Doctoral dissertation, Cairo University).

[7] Bhosale, A. (2012). Seismic evaluation of R/C framed building using shear failure model (Doctoral dissertation, National Institute of Technology Rourkela).

[8] Bhaumik, M. (2013). Seismic Analysis and FRP Jacketing of 4-storey RC Building (Doctoral dissertation).

[9] PRABHU, A. (2013). Seismic evaluation of 4-story reinforced concrete structure by non-linear static pushover analysis (Doctoral dissertation, NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA).

[10] Ahmed, S. Y. (2013). Seismic Evaluation of Reinforced Concrete Frames Using Pushover Analysis. Al-Rafadain Engineering Journal, 21(3).

[11] Tayyebi, S. M. (2014). Nonlinear Analysis Methods for Evaluating Seismic Performance of Multistory RC Buildings (Doctoral dissertation, Eastern Mediterranean University (EMU) -Doğu Akdeniz Üniversitesi (DAÜ)).

[12] SeismoStruct user manual (2016), is a registered trademark of Seismosoft Ltd. Copyright law protects the software and all associated documentation.