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A Comparative Study for Seismic Performance of RC Moment Resisting Frame with Steeland FRP Reinforcement

Ashraf. E. Morshed
Associate Professor of Civil Engineering, Housing and Building National Research Center, Cairo, Egypt

Abstract: Fiber reinforced polymer (FRP) reinforcement, in the form of longitudinal and transverse reinforcement,are currently being developed for use in new buildings and bridges. The major driving force behind thisdevelopment is the superior performance of FRPs in corrosive environments.In this study, an attempt has been done for investigating the seismic behavior of a 3D moment resisting frame performing static pushover analysis using either steel reinforced bars or FRP reinforced bars. The selectedmodel building represents all typical elements (beams and columns) with design guides according to Egyptian codefordesign and construction of concretestructures (2007). To investigate the possibility and effectiveness of the use of FRP bars, a comparative study was performed. The comparison has made between typical framed RC building reinforced by steel bars and the same building after reinforced with FRP. By using nonlinear static (pushover) analysis, the performance levels of structural members were evaluated for the two structures. According to the results of the structural analysis, significantly larger lateral displacement and slightly higher lateral strength with respect to original performance are possible using FRP reinforced bars than that when using steel bars.

Keywords:Fiber-reinforcement Polymer/plastic; Moment resisting RC frames; Pushover analysis.

I. Introduction

Concrete structures in the United States regardless of their purpose are disintegrating. Acommon link for this breakdown is that steel reinforcement is being used to strengthen the flexuralcapacity of the structures. Reinforcing steel will corrode when contact is made with humid orsaltyenvironments. When steel corrodes, it is expanding which creates tensile forces in theconcrete. As the concrete reaches its limit in tension it begins to crack and spall. This spallingcreates an even better environment for the corrosion to propagate even further (Bedardet. al.,1992).The deterioration of concrete bridges due primarily to corrosion of the reinforcing steel inthe concrete is a major concern today (Khalifa et. al., 1993). The cost to rehabilitate and repair thebridges in the United States is estimated at nearly fifty billion dollars. The cost to bring the entireinfrastructure up to par is many times the original bridge cost. The primary cause of thedeterioration is the corrosive action of steel on concrete cause by deicing chemicals and saltwaterharsh environment (Bedardet. al., 1992).Methods used to extend the longevity or protection of bridges are the use of sealers,increase cover depth, increase concrete density, and additives to retard the chemical process(Bedardet. al., 1992). A promising solution to the problem is the use of fiber reinforced plastics (FRP)as a replacement for reinforcing steel. The use of FRP as reinforcement has the followingadvantages of lightweight, high tensile strength, corrosion resistance, flexibility, andelectromagnetic resistance. FRP is comprised of high strength fibers bonded in a polymer matrix.It has been used by the aerospace and automotive industry for quite some time. FRPreinforcement can be used for marine and water exposed structures, piers, docks, suspension andcable-stayed bridges (Khalifaet. al., 1993).FRP reinforcing rods can be use to combat deicing salts in bridge decks, parapets,retaining walls,foundations, and curbs. FRP reinforcing can be use to combat saltwater for thesame type of structures or components. Other areas where FRP can be used are wastewater andchemicalcorrosion areas and low electrical conductivity areas. Projects that have FRP used inthem are bridges in Germany, Japan, China, and the United States (Bedardet. al., 1992).

Permanent plastic deformation of steel reinforcement in reinforced concrete (RC)moment resisting frames (MRFs) for example often results in residual drifts, which not onlycause overall capacity degradation but also pose life-threatening issues for the occupants evenunder gravity loads Zafaret. al., 2014).During Christchurch earthquake sequence (2010-2011), many RC structureswhose structural integrity was questionable after main shock event, collapsed during strongaftershock because of permanent damage to steel reinforcement (Weng et. al. 20111). Several recent studieshave focused on improving the post-earthquake functionality of RC structures throughintroducing the feature of re-centering, such as use of post-tensioned steel bars (Nakaharaet. al., 2008)andsuperelastic shape memory alloy (SMA) rebars because of their non-linear behavior(Saiidiet. al.,2007, Nehdi et. al., 2009). Although using SMA materials to provide RC structures with the ability to re-center isquite promising, it is faced with some challenges. For example, using large diameter SMA rebarsthat are not available commercially makes it cost prohibitive. In addition, research have shown that large diameter SMA rebars exhibit reduced hysteretic area and damping capability comparedto small diameter wires due to the accumulation of more distorted martensite crystalline structure (Saiidiet. al., 2007, Speicheret. al., 2011).

Pushover Analysis

Pushover analysis is a staticn on-line arproced ure in which them agnitude of the later alload is in crementally in creased maintaining predefined distribution paternal on gthe heigh to fthebuilding. With the in crease in the magnitude of loads, weak link sand failure modes of the building an be found. Pushover analysisc and etermine the behaviour of a building, including the ultimatel oadit can carry and the maximuminelasticdeflectionitundergoes.Localnonlineareffectsaremodelledandthestructureispusheduntil a collapse mechanism is developed. Ateach step, Base shear and pushover curve are developed. The graphs are plotted with base sheara long the vertical axis and roof displacement along the horizontal axis. Figure1 presents the generalized push over curve consist in go fspectral accelerational on gvertical ax is and spectral is placement along horizon talax is. It has two component snamely, capacity curve and demand curve. Capacity curvere presents the capacity of a structural system in terms of baseshearandroofdisplacement. Demand curve represents the demand under a given seismic force for known damp in gand soil conditions. Here, the capacity curve is represented by A, B ,C, D and E which suggests different stages in a building studied under in creased horizontal earth quake force. Based on structural and functional requirements, three different demarcations are represented, namely, Immediate Occupancy (IO),Life Safety (LS) and Collapse Prevention (CP). Accordingly, the following are the four level sastructure can experience in terms of in crease in vulnerability. They are Operational level Damage control level, Limited Safety level and Hazard level. Normally, the structure experience selastic line ardeformation from A to B beyond which the in crease in load carrying capacity is non-linear an dultimate load is reached at C. Atthisstage ,there will be a drop in the load carrying capacity and every structure has minimum strength call edresidual strength to which it will settle. Pushover analysis will indicate to what state the given structure reaches under as signed load ,it is represented by push over hinges of different stages .Further ,the point of intersection between capacity curve and demand curve is called the performancepointwhoseco-ordinatesprovideinformationabouttheseismicperformanceofagiven structure under a design earthquake load.

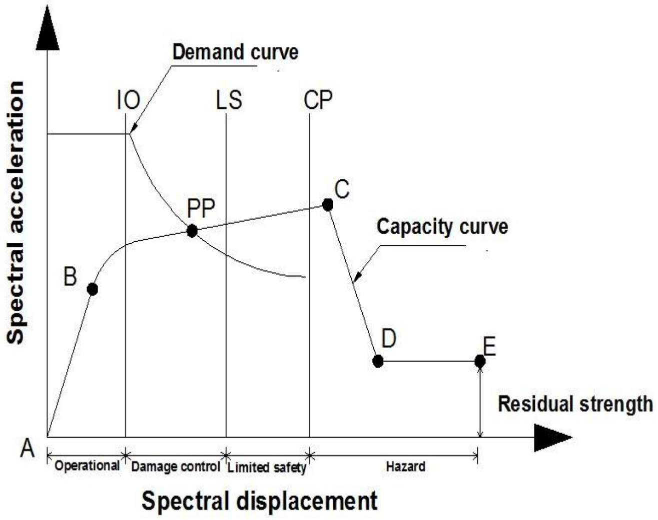


Figure1. Force – Deformation curves for Pushover Hinges

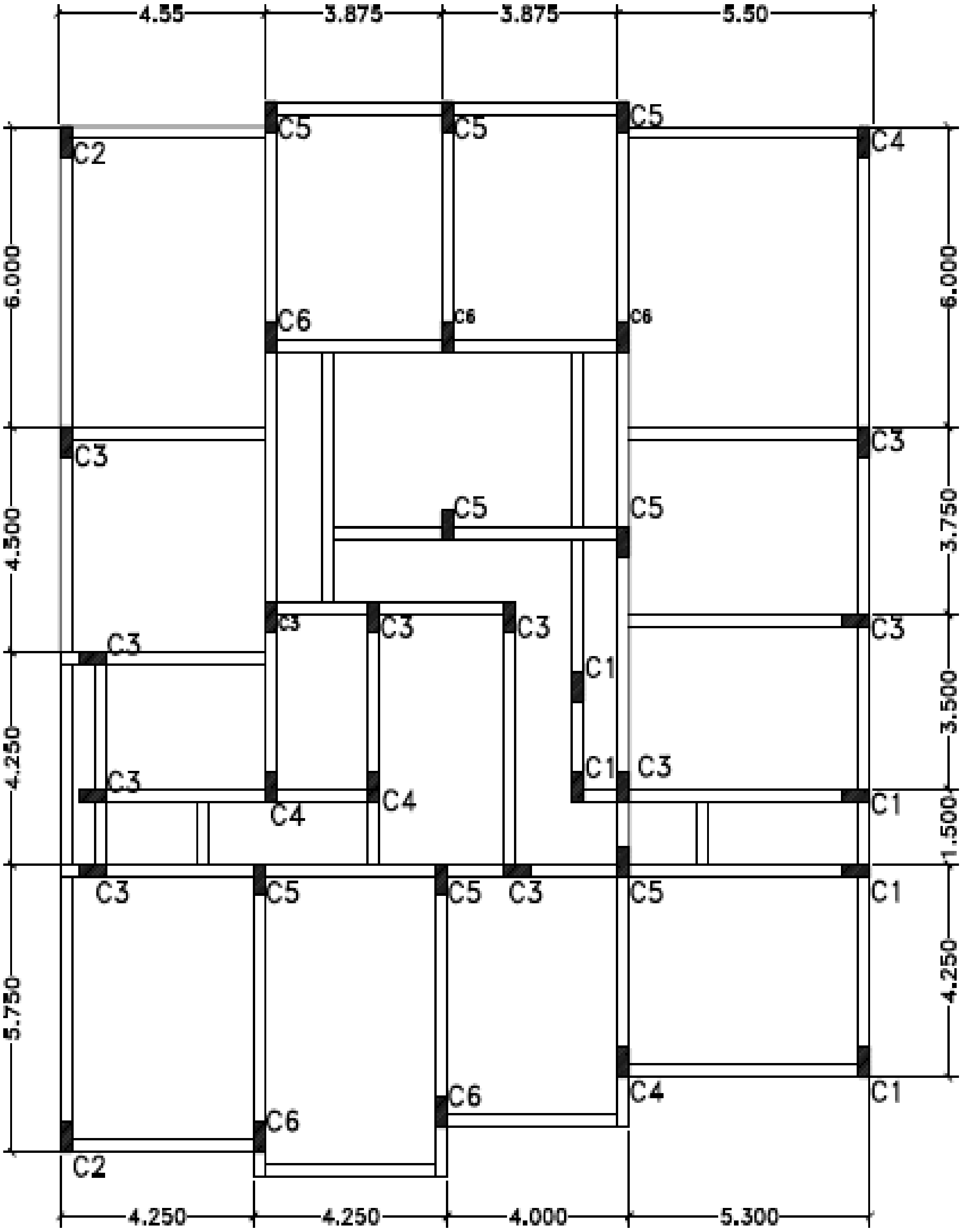
Present Analysis

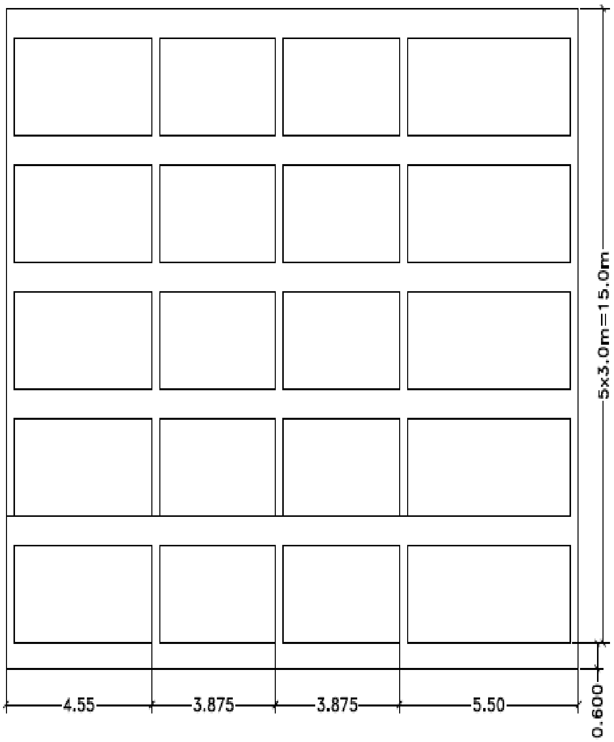
This paper studies seismic performance of building using a new type of reinforcing bars made of fiber-reinforced polymer (FRP). Thisnew type of composite material is characterized with both ductility and pseudo-elasticity, whichare two important characteristics that are sought in this study to enhance the seismic behaviorand damage mitigation of MRFs under multiple strong seismic events. A study of five storey, multi bay prototype RC MRFs,reinforced with steel and fiber reinforced polymer (FRP)reinforcements, are analyzed using nonlinear static analysis (pushover) to study theirnonlinear behavior and seismic performance of such buildings. Sap2000, finite element software was used for analysis, design and generation of pushover curves of reinforced concrete frame system. Further, to understand the effects of 3D idealizations on structural frame system, comparison is made for both frame systems using the two types of reinforced bars (steel, FRP).

Features of the Building

Building is a reinforced concrete frame building with multi bays in X-direction or Y-direction. Egyptian Loading Code (ECP201-2012) states that the design horizontal acceleration as 0.15g for this building zone. The footings of the fivestorey building are located on soil layer, which can be classified as class type "C" according to the Egyptian loading code. Note that, a seismic load reduction factor of 5.0 is taken into account as mostly done in practice for this type of RC frame structures. A typical floor plan of the building, which is used for housing purposes, is given in Fig.2. According to Fig.3, it can be seen that all columns are rectangular. Characteristic compressive strength of concrete is taken as 25 MPa. Both longitudinal and transverse reinforcement are deformed bars with characteristic yield strength of 360 MPa. The columns schedules of the building are shown in Fig.3. The longitudinal reinforcement of the building, consist of 16 mm or 12 mm bars at 150 mm spacing as shown in Fig.4. All beams with dimensions25x70cm and were reinforced with 4□16 as bottom reinforcement and 4□16 as top reinforcement over columns.

Figure2.Typical floor plan of the building





model		Bas.+ Gr.	1^{st}+ 2^{nd} +3^{rd}.
C1	Dim.	25x50	25x40
	Rft.	8□ □ □	8□ □ □
C2	Dim.	25x55	25x45
	Rft.	8□ □ □	8□ □ □
C3	Dim.	25x60	25x50
	Rft.	8□ □ □	8□ □ □
C4	Dim.	25x65	25x65
	Rft.	8□ □ □	8□ □ □
C5	Dim.	25x70	25x60
	Rft.	10□ □ □	8□ □ □
C6	Dim.	25x90	25x80
	Rft.	12□ □ □	10□ □ □

Figure3Typical frame & Columns schedule

The steel reinforcement bars are calculated according to Egyptian codefordesign and construction of concretestructures (2007). For the FRP reinforced bars the Egyptian code of practice for the use of fiber reinforced polymer (FRP) in the construction fields (2005) is used. Arelatively low percentage of reinforcement of 0.7 % was used as compared to steel reinforced columns,because of the higher strength of FRP reinforcement. The effects of FRP reinforcement in compressionwere incorporated in design with due considerations given to their stress-strain characteristics establishedexperimentallySharbatdar (2004).An important aspect of design was concrete confinement since column deformability could only beintroduced through concrete confinement due to the brittle behaviour FRP bars. Carbon FRP grids wereused as column confinement reinforcement. The displacement based design approach developed bySaatcioglu and Razvi (2002) and also adopted by the Canadian Standard CSA S806-02 (2002) was used forconfinement design. The mechanical properties of the two types of reinforcements are given in Tables 1, 2.

Table 1 Steel Reinforcement Properties

Material	F_y MPa	F_{ult} MPa	E MPa
Rebar	400	600	203900

Table 2 FRP Reinforcement Properties

Material	F_y MPa	F_{ult} MPa	E MPa
Rebar (Curtis 1997)	480	890	46200

II. Results And Discussion

The deformed shapes and plastic hinges of the frame indicated in Fig. 2 and Fig. 3 are presented in Fig. 4 and Fig. 5 for reinforced steel bars and FRP bars respectively.These two Figs. show that the number of hinges and hinges status increase with for frame reinforced by FRP bars than that reinforced by steel bars.Also, it is clear from these Figs., that the distribution of vertical element inertia on the plan have a big effect on the hinge distribution, capacity and drift limits of the buildings.

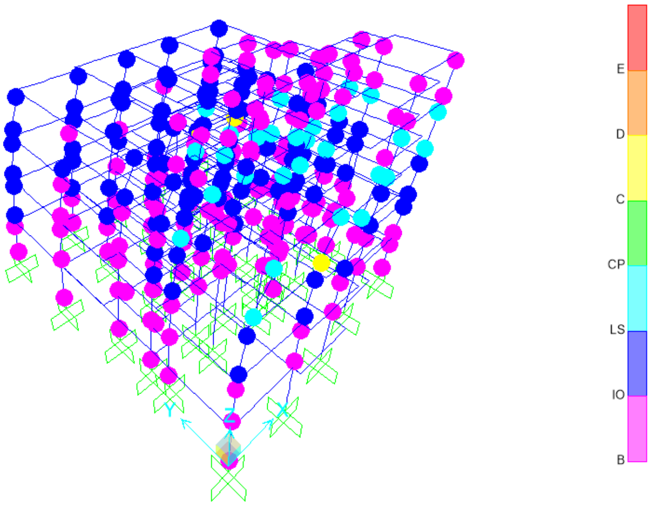


Figure4a X-direction

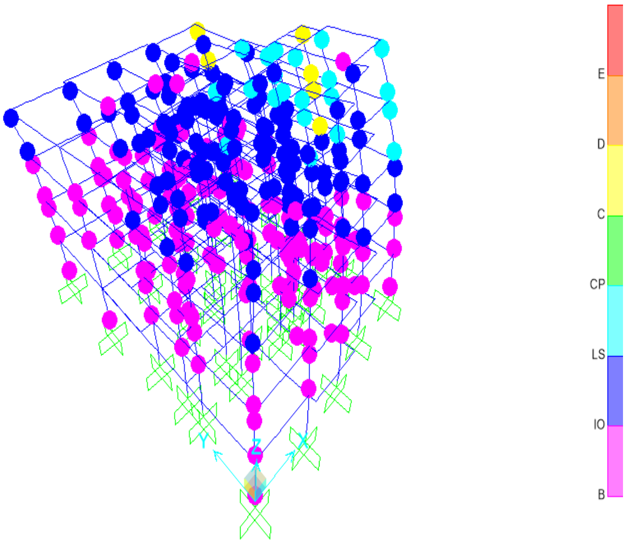


Figure 4b Y-direction

Figure 4. Deformation and distribution of plastic hinges for RC frame reinforced by steel bars

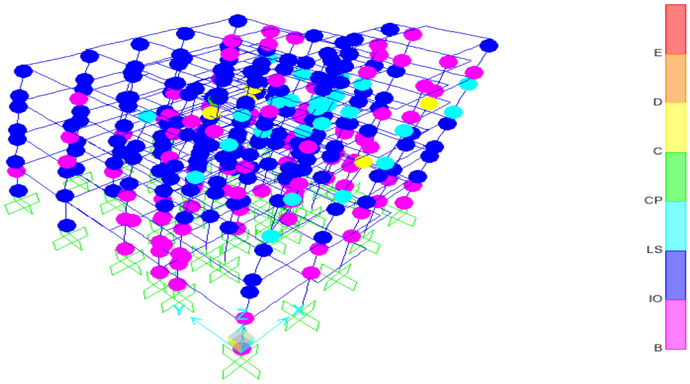


Figure 5b Y-direction

Figure 5. Deformation and distribution of plastic hinges for RC frame reinforced by FRP bars

Figure 6 shows results of the 3D frame system with maximum seismic base shear forces in X-direction for different idealizations namely steel bars and FRP bars. The base shear is plotted along vertical axis and roof displacement along horizontal axis. It can be seen that, for the case in using FRP bars, roof displacement increases linearly with increase in base shear up to around 4440 KN and the structure will not take any further load. The percentage for increasing of base shear and roof displacement are 18% and 13% respectively.

Figure 7 shows the same results of the 3D frame system with maximum seismic base shear forces in Y-direction. It can be seen that, for the case in using FRP bars, roof displacement increases linearly with increase in base shear up to around 9520 KN and the structure will not take any further load. The percentage for increasing of base shear and roof displacement are 26% and 42% respectively which is higher than that in X-direction due to orientation and behavior of vertical elements (columns).

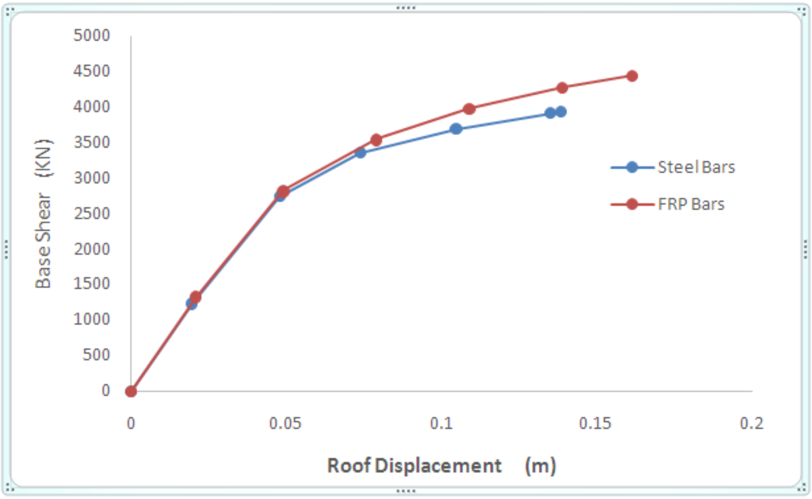


Figure6Pushovercurvesfor3Dframesystemwithseismic force in X- direction

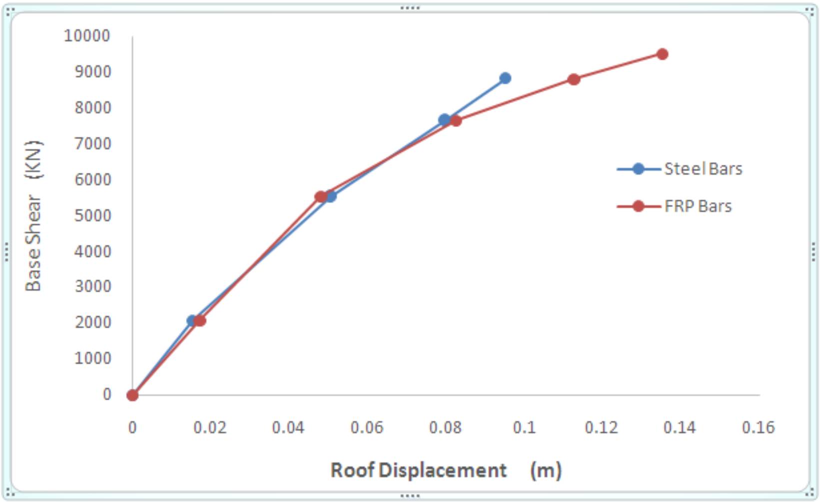
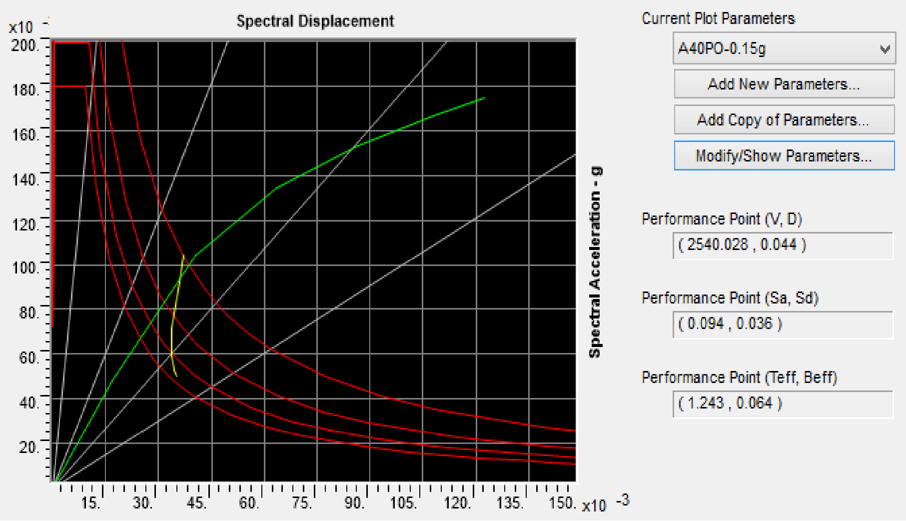


Figure7Pushovercurvesfor3Dframesystemwithseismic force in Y- direction

The response modification factor (R) for the 5storey RC building is evaluated from capacity and demand spectra (ATC-40). The capacity diagram and the demand diagram are shown in Fig. 8 and Fig. 9 in x and y directions for RC frame with FRP bars andsteel barsrespectively. The results show that:
For RC frame with FRP bars,
-The performance base shear V performance is 2540kN and 3410kN in X and Y directions respectively.
-The lowest calculated response reduction factor R equals 2.8.

For RC frame with steel bars,
-The performance base shear V performance is 2525kN and 3290kN in X and Y directions respectively.
-The lowest calculated response reduction factor R equals 4.5.



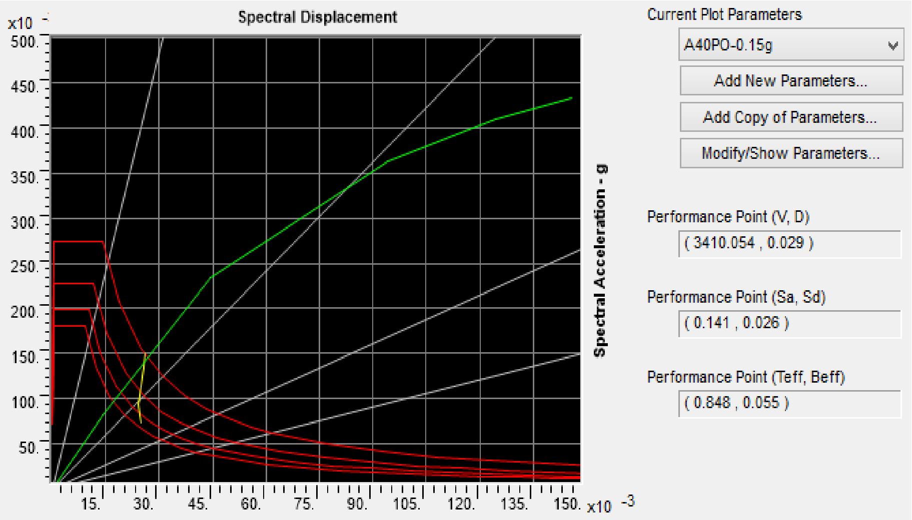
Current Plot Parameters
A40PO-0.15g

Performance Point (V, D)
(2540.028 , 0.044)

Performance Point (Sa, Sd)
(0.094 , 0.036)

Performance Point (Teff, Beff)
(1.243 , 0.064)

Fig. 8 (a) X-Direction



Current Plot Parameters
A40PO-0.15g

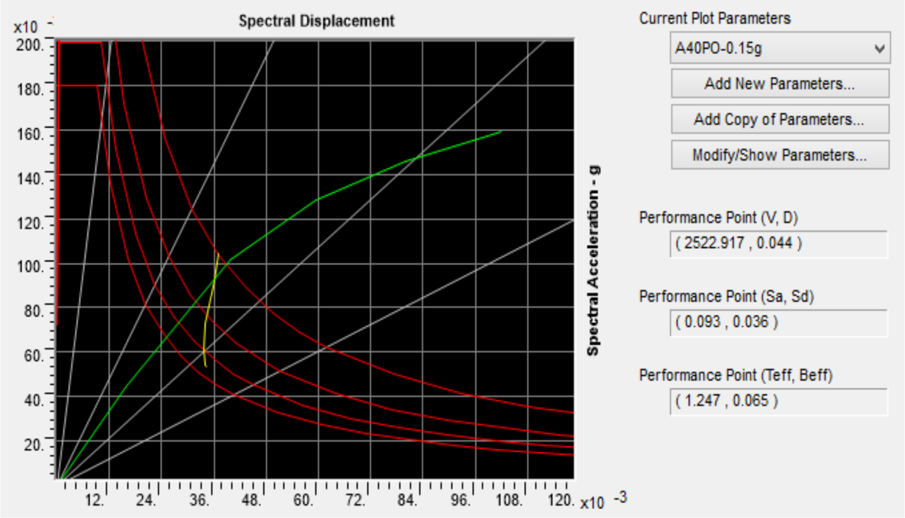
Performance Point (V, D)
(3410.054 , 0.029)

Performance Point (Sa, Sd)
(0.141 , 0.026)

Performance Point (Teff, Beff)
(0.848 , 0.055)

Fig. 8 (b) Y-Direction

Fig. 8 ATC40 Capacity spectrum, design spectrum function for RC building reinforced by FRP bars



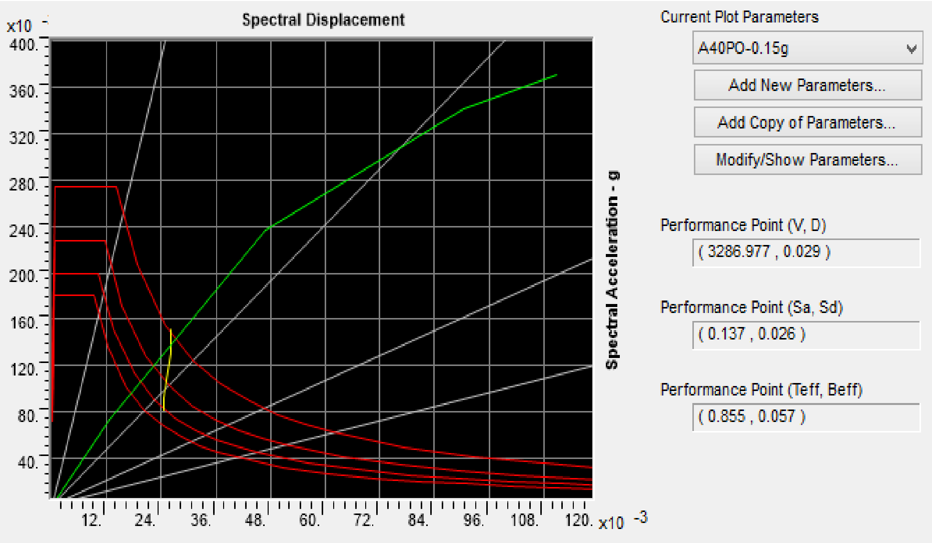
Current Plot Parameters
A40PO-0.15g

Performance Point (V, D)
(2522.917 , 0.044)

Performance Point (Sa, Sd)
(0.093 , 0.036)

Performance Point (Teff, Beff)
(1.247 , 0.065)

Fig. 9 (a) X-Direction



Current Plot Parameters: A40PO-0.15g

Performance Point (V, D): (3286.977 , 0.029)

Performance Point (Sa, Sd): (0.137 , 0.026)

Performance Point (Teff, Beff): (0.855 , 0.057)

Fig. 9 ATC40 Capacity spectrum, design spectrum function for RC building reinforced by steel bars

III. Concluding Remarks

The present study makes an effort to evaluate the seismic performance of RC moment resisting frame reinforced with FRP bars.Thefollowingarethe majorinferences fromthe present paper:-

- FRP reinforced columns and beams can be design to satisfy strength and deformabilityrequirements of earthquake resistant structures.
- Using FRP bars improving the overall performance of frame under sequential seismic hazard.
- FRP reinforced concrete columns can be confined to develop inelastic deformations.
- Seismic design strategies for FRP reinforced concrete elements may be to design them remain elastic, with sufficient lateral deformability. The design approach may be improved by providing sufficient confinement for compression members by means of closely spacedtransverse FRP reinforcement.
- It is recommended that additional manufacturers of FRP bars be evaluated by testing thematerial properties. It is desirable to determine the bars' properties from the productioninventory.
- The FRP bars should be evaluated to determine the bond strength with concrete, themodulus of elasticity, the yield strength, the ultimate strength.

It should be noted that for reaching results that are more general, more detailed analyses with variable structuralsystemverying in height, dimensions, vertical structural distributions and different types of FRP bars should be examined.

References

[1]. AdeelZafar and BassemAndrawes (2014), " Experimental and Analytical Study of Innovative Shape Memory Alloy-Based FRP Composite Reinforcement for Seismic Applications", Tenth U.S. National Conference on Earthquake Engineering, Frontiers of Earthquake Engineering, July 21-25, 2014, (10NCEE Anchorage, Alaska).

[2]. Bedard, Claude, (1992). “Composite Reinforcing Bars: Assessing their use in Construction”,Concrete International: Design and Construction, Vol. 14 No. 1, pp. 55-59.

[3]. CSA S806-02.(2002) “Design and construction of building components with fibre-reinforced polymers,Canadian Standards Association, Rexdale Ontario, May 2002.

[4]. Curtis B. Boyd (1997), "A Load-Deflection Study of Fiber Reinforced Plastics as Reinforcement in Concrete BridgeDecks", Thesis (M.S.), Virginia Polytechnic Institute and State University, 1997.

[5]. Egyptian Code for Design and Construction of Concrete Structures (ECP 203- 2007).

[6]. Egyptian Code of Practice for the Use Of Fiber Reinforced Polymer (FRP) In The Construction Fields (ECP 208-2005)

[7]. Egyptian Loading Code, ECP-201 (2012), p 108-158.

[8]. Khalifa, Maghi A., Kuska, Sharon S. B., and Krieger, James, (1993). “Bridges Constructed UsingFiber Reinforced Plastics”, Concrete International: Design and Construction, 15(6), 43-47.

[9]. Nakahara H., Saniko K., Esaki F. Experimental study for developing self-centering RC structural frameswith column yielding mechanism. J. Struct. Constr. Eng. AIJ, June 2008; Vol. 73 No. 628, 957-964.

[10]. Nehdi M., M. S. Alam, M. A. Youssef. Development of corrosion-free concrete beam column joint withadequate seismic energy dissipation. Engineering Structures 2009; 32 2518_2528.

[11]. Saatcioglu, M. and Razvi, S. R. (2002) “Displacement based design of reinforced concrete columns forconfinement, ACI Structural Journal, Vol. 90, No.1. January 2002, pp.3-11.

[12]. Saiidi M., M. Zadeh, C. Ayoub, A. Itani. A pilot study of behavior of concrete beams reinforced with shapememory alloys. Journal of smart materials in civil engineering. ASCE, 2007; Vol 19, N0.6, pp 454-461.

[13]. SAP2000 V15 (2013), Integrated Software for Structural Analysis & Design. Computers & Structures, Inc., Berkeley, California, USA, V. 16.0.

[14]. Sharbatdar M. Kazemand Murat Saatcioglu (2004), "Behaviourof FRP Reinforced Concrete Under Simulated Seismic Loading",

13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004,Paper No. 2717.

[15]. Speicher M.S., DesRoches R., Leon R.T. Experimental results of a NiTi shape memory alloy SMA)-basedre-centering beam-column connection. Engineering structures, doi:10.1016/jeng-struct. 2011, 04.018.

[16]. WengKam Y., Pampanin S. The seismic performance of RC buildings in the 22 February 2011Christchurch earthquake. Structural Concrete 12 2011; No. 4. DOI:10.1002/suco.201100044.