Analytical Comparison of Deficient R/C Frames Strengthened with HPFRC Jacket and FRP Rods at NSM Method

M.K. Sharbatdar
Assistant Professor, Civil Engineering Department, Semnan University, Semnan, Iran

M.Gholami & A.Kosarian
Master of Science Student, Structural Engineering, Semnan University, Semnan, Iran

SAMMARY

Strengthening of existing RC beam and column of deficient frames is becoming a very common practice. Designers refer usually to traditional strengthening techniques that were based on externally bonded steel plates or a new solution that has recently gained great favour concerns the use of externally bonded fiber reinforced polymer (FRP). All these techniques can be successfully used but have some limits. Recently, new techniques have been developed for strengthening of deficient RC frames with application of a thin jacket in high performance fiber reinforced concrete (HPFRC) with a High compressive strength and a hardening behaviour in tension, and also inserting FRP rods in NSM method in the slots on beams and columns in weak R/C frames.
The aim of this paper is to investigate the effects of these two solutions for improving strengthening of columns in deficient RC frame by HPFRC jacket and NSM method at 7 frames. HPFRC jacket with 10, 12.5, 15 mm thickness and three types bars material carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP) and basalt fiber reinforced polymer (BFRP) were studied at the first and second technique.
Results showed that it is possible to strengthen available deficient RC structures using HPFRC jacket technique and also with NSM method. Ductility, energy dissipation and load-carrying capacity of strengthened RC frames for different parameters were calculated and compared at two proposed method.

Keywords: HPFRC jacket, NSM method, Nonlinear finite element, RC Frames, Strengthening

1. INTRODUCTION

In recent years, due to past design code regulations and weak constructions, the reinforced concrete structures needed to be retrofitted. Designers use different methods including steel jacket and FRP wrapping for retrofitting that each one has its own limitations, weakness of steel at high temperatures and possible FRP de-bonding. Recently, some researches have been conducted on retrofitting of concrete elements with HPFRC jacket. These studies showed that these materials are compatible with concrete and has an acceptable strength and ductility and durability properties for earthquake retrofitting [1]. This type of concrete, unlike conventional concrete, has strain hardening behaviour after reaching their maximum strength. This material has been overcome on many of the recent problems in retrofitting of concrete elements including steel and FRP jackets due to non consistency of their tensile strength and hardness with retrofitted concrete member [1]. This method can be used for weak and damaged beams and columns [2]. The key advantage of HPFRC for retrofitting is not similar to steel and FRP but tensile strength and hardness and thermal expansion coefficient is similar to retrofitted member[1]. In in-situ construction, in order to create adhesion between old and new concrete, sandblasting of old concrete surface is used and the mortar is shotcreted. The technology of the HPFRC application is relatively simple, curing at ambient temperature and humidity is sufficient to allow the development of the strength characteristics of the HPFRC; due to the self-levelling property, the material can be cast in a thin layer [2], and a normal sandblasting of the surface ensures a

good adhesion of the jacket without using any primer. The proposed technique is suitable for strengthening the existing RC structures characterized by low concrete strength or low reinforcement ratios [3].
Researchers have recently used the FRP rods made of CFRP, BFRP, GFRP for NSM (Near-Surface Mounted) retrofitting method [4]. In this method, FRP strips are inserted with adhesive in grooves that are created on concrete cover. Extensive studies have been recently conducted on flexural and shear strengthening of RC elements with NSM method that has many practical applications [5]. With the proposed strengthening technique premature de-bonding could be avoided [5]. In this paper two introduced methods were investigated on one frame as a reference. Three frames retrofitted with HPFRC jackets with 10, 12.5, 15 mm thickness and other three frames retrofitted with CFRP, GFRP and BFRP rods were selected for numerical study. And finally the specimen's load-displacement diagram and ductility were obtained and then the dissipated energy and load - carrying capacity of all specimens were compared together.

2. SPECIMENS CHARACTERISTICS

Dimensions and reinforcement details of the selected frames are given in Figure 1. The selected frame was a 1/3 scale, one-bay, one-storey undamaged RC frame. The beam and column cross section of in all specimens were 110 x 190 mm and 170 x 120 mm, respectively. Four 10 mm diameter bars and four 14 mm diameter bars were used as longitudinal reinforcement in the beams and columns with 6 mm diameter stirrups in the beams and 8 mm diameter stirrups in the columns all spacing at 80 mm. The yield strength of the 6 mm and 10 mm diameter rebars were 552.5 MPa and 347.8 MPa, respectively. The yield strength of the 14 mm was 470 MPa. The cubic strength of concrete was f_c = 20.9 MPa and the tensile strength was f_t = 2.5 MPa. The vertical loading of the specimen was divided into two parts, i.e. the vertical load applied to beam and the vertical load applied to column. The vertical loads applied to beam and each column was 9.6 kN and 11.85 kN. The vertical load was constant during analysis. The horizontal load was applied to rigid plate that merged to the beam end section.

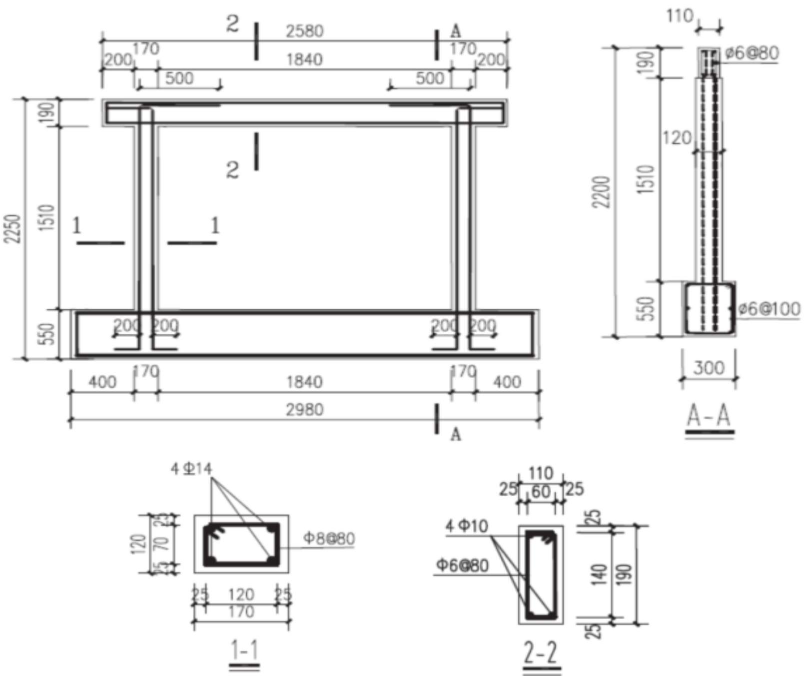

Figure 1. Dimensions and reinforcement details of the control specimen[6]

The HPFRC material using as strengthening jacket had the mechanical characteristics summarized in Table 1 and the tensile behaviour shown in Figure 2. The CFRP, GFRP and BFRP strips, which were provided in rolls, had a diameter of 3.68 mm. The stress-strain relationships were linear up to failure, which indicates an elastic behaviour for rods. The elasticity modulus and tensile strength of CFRP rods were 159000 MPa and 1741 MPa, respectively, and those values for GFRP rods were 73000 MPa and 1500 MPa, respectively and for BFRP rods were 91000 MPa and 2100 MPa, respectively.

Table 1. Characteristics of HPFRC [3]

Average compressive strength	130	MPa
Average tensile strength	6	MPa
Average elastic modulus	42	GPa
Type of fibers	Steel	
Fibers length	15	mm
Fibers equivalent diameter	0.18	mm
Fibers volume	1.5	%

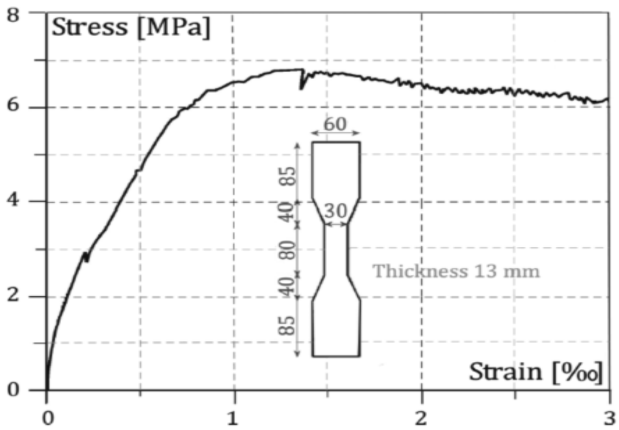

Figure 2 . Direct tensile test results for HPFRC [3]

In order to investigate and compare two introduced methods, one frame was selected as a control specimen and three frames retrofitted with HPFRC jacket with 10, 12.5, 15 mm thickness and other three frames retrofitted with CFRP, GFRP and BFRP rods. In specimens HP_1, HP_2, HP_3, the two columns and joint of frames were covered with HPFRC 10, 12.5 and 15 mm thickness jacket shown in Figure 3. In CFRP, GFRP and BFRP specimens, the CFRP, GFRP and BFRP rods were placed respectively in grooves that created from the bottom to the top of the two columns of frames in horizontal load direction as shown in Figure 4.

3. NONLINEAR FINITE ELEMENT PROGRAM

The frames were analyzed using LS-DYNA code. LS-DYNA is a FEM program for nonlinear dynamic analysis of the inelastic structures. The reinforcing bars were modelled as a Plastic-Kinematic material by a 2 node nonlinear truss element. Winfrith concrete and winfrith concrete reinforcement (Mat 84-85) were selected for modelling of concrete and HPFRC materials [7]. HPFRC was used a base concrete with compressive strength of 50 MPa with 1.5% steel fiber volume. Dog bone and Cubic specimens accordance with the listed specifications in Table 1 and shown in Figure 2 were modelled in FEM software. The compressive and tension stress-strain diagrams obtained from analyse are shown in figure 5. FRP was used as elastic material (mat 1) [7] that Table 2 shows the mechanical properties of Material Models.

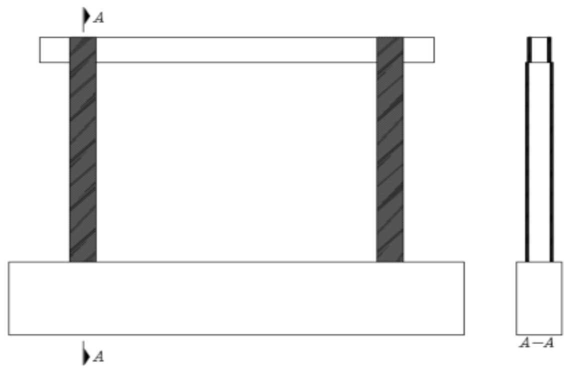

Figure 3. The column and joint covered with HPFRC

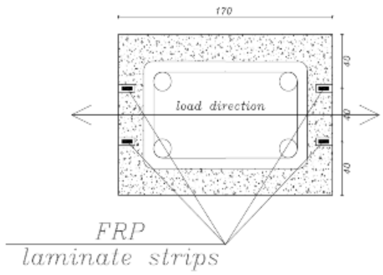

Figure 4. The placement of FRP bars in the column

Table 2 . Mechanical properties of Material Models

Material	*Property*	*Notation*		*Value*
Concrete	Elastic Modulus		E_c	21.49 (GPa)
	Poisson's Ratio		v_c	0.19
	Average Compressive Strength		f_{cu}	20.90 (MPa)
	Fracture Energy*		G_f	40 (N/m)
	depend on value of rate*		FE^*	0.032(mm)
Reinforcement Steel	Elastic Modulus		E_s	$2\times10^5(MPa)$
	Poisson's Ratio		v_s	0.29
	Yield Strength	Φ_6	f_y	552.5 (MPa)
		Φ_{10}		347.8 (MPa)
		Φ_{14}		470.0 (MPa)
CFRP rod	Elasticity modulus		E_{CF}	159 (GPa)
	Tensile Strength		X_{TCF}	1741 (MPa)
GFRP rod	Elasticity modulus		E_{GF}	73 (GPa)
	Tensile Strength		X_{TGF}	1500 (MPa)
BFRP rod	Elasticity modulus		E_{BF}	91 (GPa)
	Tensile Strength		X_{TBF}	2100 (MPa)

* $u_t = 2G_f/t$, crack width at which crack-normal tensile stress goes to zero [7]

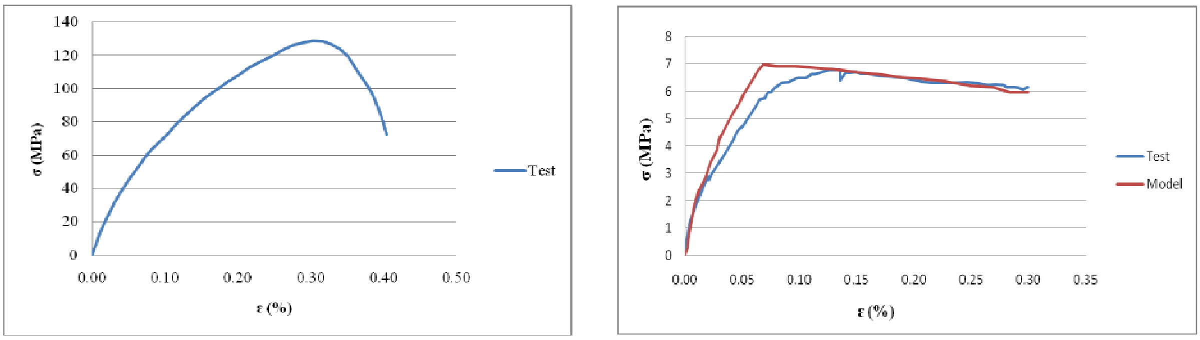

Figure 5. The compressive and tension stress-strain diagrams obtained from analyse

4. RESULTS & DISCUSSION

4.1. Effect of Jacket Thickness in Strengthened Frames

Lateral load-displacement curves for C_1, HP_1, HP_2, HP_3 specimens are shown in Figure 6. The specimen C1 was as control frame without strengthening. It should be underlined that the maximum load of the frames with the HPFRC jacket was higher than that exhibited by the RC frame without the HPFRC jacket. The application of a 10 mm thickness HPFRC jacket around the column and on joint of the frame (HP_1) provided an increasing of the ultimate load up to 1.3 times; those increasing for HP_2 and HP_3 specimens with 12.5 and 15 mm thickness HPFRC jackets were about 1.18 and 1.42 times. The numerical results point out the effectiveness of the proposed technique in improving the bearing capacity.

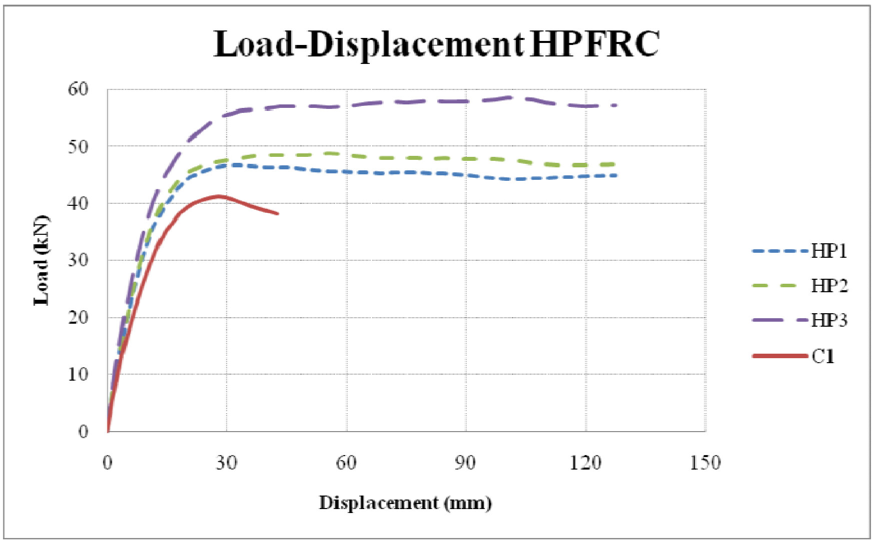

Figure 6 . Lateral load-displacement curves for C_1, HP_1, HP_2, HP_3 specimens

4.2. Effect of FRP Rods in Strengthened Frames

Lateral load-displacement curves for C_1, CFRP, GFRP, BFRP specimens are shown in Figure 7. The maximum load of the frames with the FRP bars was higher than that exhibited by the RC frame without the FRP bars. The application of FRP bars increased the load-carrying capacity in strengthened frames with NSM method. The application of FRP bars CFRP rods in column slits on joint of the frame provides an increase of the ultimate load up to 1.07 times; referring to specimen with GFRP rods, this increase is about 1.04 times and for specimen with BFRP rods is similar to reference specimen.

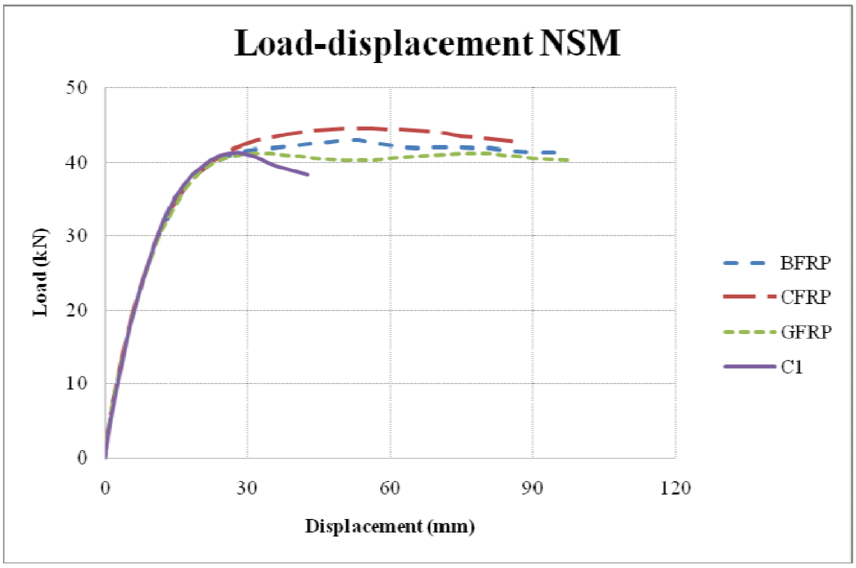

Figure 7 . Lateral load-displacement curves for C_1, CFRP, GFRP, BFRP specimens

4.3. Comparison Between Two Strengthening Methods

Lateral load–displacement curves for all specimens are shown in Figure 8. The maximum load carrying capacity was for HP_3 specimen with 15 mm thick jacket. It should be noted that jacketing method with thin layer of HPFRC not only increased the bearing capacity of structures but also increased the stiffness value of the specimen, that it confirmed that this method was suitable when the structure was made of low-strength concrete, ductility shown good growth but the stiffness had no increase in NSM method.

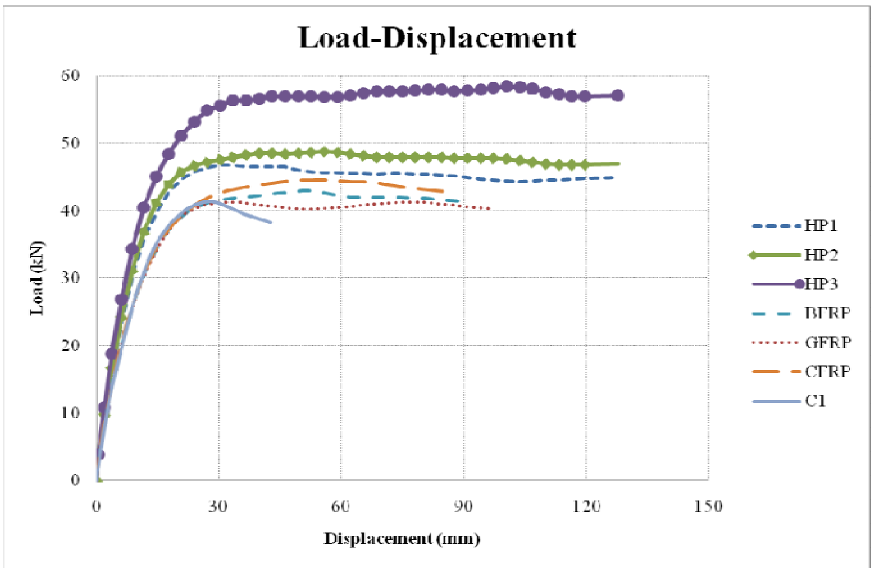

Figure 8 . Lateral load-displacement curves for all specimens

4.4. Dissipated energy and ductility

Figures 9 and 10 and Table 3 show the dissipated energy and ductility values for C_1, HP_1, HP_2,HP_3, CFRP, GFRP, BFRP specimens, respectively. The dissipated energy and ductility value of the strengthened specimens proving the validity of the proposed rehabilitation methods for seismic applications.

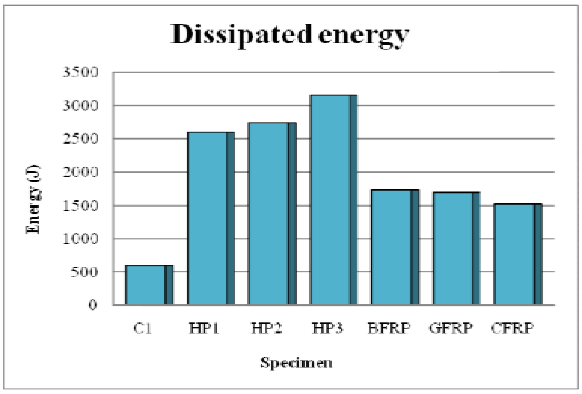

Figure 9. dissipated energy values for all specimens

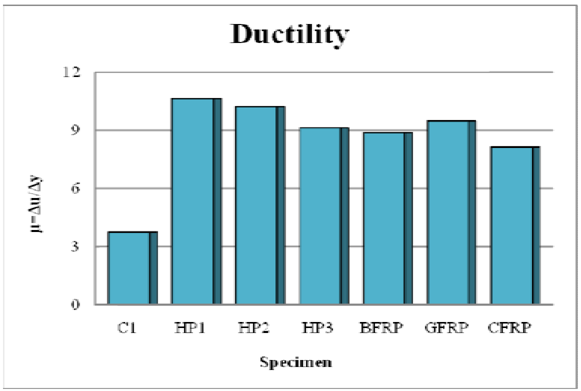

Figure 10. ductility values for all specimens

Table 3. Dissipated energy and ductility values for C_1, HP_1, HP_2,HP_3, CFRP, GFRP, BFRP specimens

Name of specimen	*Dissipated energy value (J)*	*Increase value of dissipated energy (%)*	*Ductility value*	*Increase value of ductility (%)*
C_1	599	-	3.74	-
HP_1	2600	334	10.64	184
HP_2	2740	357	10.22	173
HP_3	3160	427	9.12	144
BFRP	1733	189	8.87	137
GFRP	1695	183	9.49	154
CFRP	1520	154	8.13	117

5. CONCLUSION

According to behavioral and obtained results of numerical investigation of seven reinforced concrete frames including one reference unstrengthened and three strengthened with HPFRC jacket and more three strengthened with FRP rods in NSM method and comparison of their results, the following results were obtained:

1. The strengthened specimens with HPFRC jacket were demonstrated the efficiency of this technique for seismic retrofitting. It was possible to increase the bearing capacity of the RC Frames with the

application of a high performance fiber reinforced concrete jacket, reaching also an adequate level of ductility and dissipated energy.

2. Strengthening technique based on bonding FRP laminate strips into slits opened on the concrete cover was applied to RC columns of deficient frames can increase the values of load carrying capacity, ductility and dissipated energy and so with the proposed strengthening technique, premature de-bonding at FRP laminate could be avoided.

3. strengthening with HPFRC jacket impress geometry of members but NSM method don`t. installation of FRP rod into slits of cover concrete in NSM method is easier than preparation of surface and installation of new concrete to old one with adhesive.

REFERENCES

1. Alaee F.J., Karihaloo B.L. (2003). Retrofitting of reinforced concrete beams with CARDIFRC. *Journal of Composite Construction.* **7:3**,174 -186.
2. Martinola, G., Meda, A., Plizzari, G.A., Rinaldi., Z. (2010). Strengthening and repair of RC beams with fiber reinforced concrete. *Journal of Cement & Concrete Composites.* **32**,731-739.
3. Beschi, C., Meda ,A. and Riva., P. (2011). Column and Joint Retrofitting with High Performance Fiber Reinforced Concrete Jacketing. *Journal of Earthquake Engineering* **15:7**,989-1014.
4. Barros, J.A.O., Varma, R.K., Sena-Cruz, J.M., Azevedo., A.F.M. (2008). Near surface mounted CFRP strips for the flexural strengthening of RC columns: Experimental and numerical research. *Journal of Engineering Structures*. **30**,3412-3425.
5. Barros, J.A.O., Ferreira, D.R.S.M., Fortes, A.S., Dias, S.J.E. (2006). Assessing the effectiveness of embedding CFRP laminates in the near surface for structural strengthening. *Journal of Construction and Building Materials*. **20**,478-491.
6. Zhu, J.T., Wang, X.L., Xu, Z.D., Weng, C.H. (2011). Experimental study on seismic behavior of RC frames strengthened with CFRP sheets. *Journal of Composite Structures.* **93**,1595-1603.
7. LS-DYNA Users Manual version 971, *livermore software technology corporation(LSTC)*, May 2007.
8. Comite Euro-International du Beton, CEB-FIP model code 1990, Redwood Books, Trowbridge, Wiltshire, UK, 1993.