International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 11 (2018) pp. 9450-9456
© Research India Publications. http://www.ripublication.com

Behavior of Reinforced Concrete Frames with Different Beam-column Joints Types

Aamer Najim Abbas*, Saif Khudhair Ali and Waleed Awad Waryoosh

AL-Mustansiriyah University, Iraq-Baghdad – 00964, Iraq.
*(*Corresponding Author)*

Abstract

The main aim of this investigation is to study the structural behavior of reinforced concrete frames. Four types of the beam-column joints were discussed in this investigation; One of the tested frames was poured monolithically that adopted as a reference specimen, two of specimens were poured monolithically with (0.5%) and (1%) of total volume steel fibers at the joints and the fourth specimen was poured with construction joint at the beam-column connection (non-monolithic way). The frames were geometrically similar, it contain two columns connected together by 120x120mm beam at top and by 120x200mm strip footing at the bottom of the columns. The ultimate carrying capacity, first crack load, ductility and stiffness were increased by about 5.2%, 16%, 27.5% and 18.98% respectively as a result of adding (0.5%) steel fibers at the concrete of joints. On the other hand, the ultimate carrying capacity, first crack load and stiffness were decreased by about 46%, 26.7%, 7% and 36.24% respectively as a result of pouring the frame specimen in non-monolithic way.

Keywords: reinforced concrete frame, steel fiber reinforced concrete, diagonal crack, stiffness, beam-column joint.

INTRODUCTION

According to the stiffness of the beam-column joint, the frames can be classified into three main types; rigid frames, flexible frames and semi-rigid frames. Rigid frames are specified by the resistance of the shear, moment and torsion more effectively than other types of frames. Flexible frames are specified by the free rotation of the joint to load. Semi-rigid frames are specified by that the actual stiffness of connections lies between the rigid and flexible connections [1], [2]. The overall stiffness of the frames depends mainly on the dimensions and material properties of beams and columns [3].

Previous studies deals with the effect of different variables on the behavior of beam-column joint, these research adopted different ways to strengthen the joints. Increasing the compressive strength at the joint, using additional amount of steel reinforcing bars and wrapping with carbon fiber strips and steel plate are the common methods to enhance the joints performance . G. M. S. Alva et. al [4] presented an experimental and theoretical study to discuss the effect of concrete compressive strength and the joint transverse reinforcement on degree of restriction of the joint. Based on the analysis of five reinforced concrete beam-column joint, it can be concluded that the concrete compressive strength clearly contribute to the changing the behavior of joint from rigid to semi-rigid through increasing the relative movement of beam-column joint by decreasing the concrete compressive strength of the frame.

K. M. Amanat and B. Enam [5] proposed a finite element model to investigate the effect of beam depth and steel reinforcement ratio on the degree of restraint of reinforced concrete beam-column joint. This study reported that, the rotational stiffness of beam-column joint increased when increasing the beam depth and reinforcement steel ratio.

Several researchers Aly M. Said and Moncef L. Nehdi [6] and Ali E. Yeganeh [7] showed extensive investigations on fresh and mechanical properties of concrete (compressive strength, splitting tensile strength, and flexural strength) through using new concrete types such as self compacting concrete and ultra-high strength concrete. Compared to normal concrete frame, the load capacity, initial stiffness and energy absorbing capacity of self compacting concrete and ultra high performance concrete frames were improved.

L. F. Maya and L. Albajar [8] conducted high performance fiber reinforced cement composite beam-column connections. The structural behaviors for the frame were evaluated based on the load-deflection response, flexural strength of the concrete beams and crack pattern at the joint. Subsequent analysis of the test data showed that there is a good response of steel fiber high performance concrete frames to loading in comparison with NC frames. Good structural performance of steel fiber high performance concrete frames comes through reduction in the mid span deflection of the beams in addition to restriction of cracks extension at the joints.

M. Soleymani Ashtiani, R. P. Dhakal & A. N. Scott [9] investigated the SCC beam-column joints under the effect of cyclic loading. The main focus of this study was to examine the effect of using SCC at the joints instead of normal concrete on the beam deflection, frame stiffness and ductility of the specimens before failure; they found that SCC joints exhibited lower deflection and large stiffness. In addition, the tested results show that the SCC joints had higher ductility and energy absorption for comparison with NC.

Recently, the strengthening technique of beam-column connection using carbon fiber laminates was proposed by Mario R.F. Coellio et.al [10]. This investigation including cyclic testing of three full steel reinforced concrete joint. Two strengthening configuration was used in this study, warping the CFRP in one direction and multidirectional warping of CFRP laminate. The strengthening technique was very efficient in increasing of strength capacity up to 35%, the initial stiffness was record and energy absorption was increased .other researchers have waked to strengthen the beam-column joint by warping technique with carbon fiber sheets for example U. Akguzel and S. Pampanin [11] and N. Vijayalakshmi et.al [12].

A steel sheet was used for strengthening the reinforced concrete frames by Yulita Rahmi et.al [13]. The finite element model was developed using ABACOS. Two reinforced concrete frames were analyzed, one included reference frame (without strengthening) and other including steel plate at the joint. The comparison of the result indicated that steel plate could increase lateral strength, ductility, energy dissipation and increase the shear strength of the joint.

IMPORTANCE OF STUDY

Steel fiber reinforced concrete is expected to have predominant ductility and provide excellent energy dissipation capacity. Once the design is being done, it is required to achieve that the designed building present the adequate behavior. Present study is an attempt to improve the overall performance of reinforced concrete frames through pouring the steel fiber reinforced concrete at the beam-column joints, while the structural members poured with normal concrete.

EXPERIMENTAL PROGRAM

The tested frames include casting two identical columns with (120 x120)mm cross section and (1000 mm) height, connect together at the top by (120 x 120) mm cross section of reinforced concrete beam, and connect at the bottom by (120 x 200) mm cross section of strip footing, the clear span of beam and strip footing is (960 mm). The columns were reinforced with; (4Ø10mm) of longitudinal and (Ø6@120mm) transverse reinforcement. While, the tie beam and strip footing were reinforced with (3Ø10 mm), (2Ø10 mm) and (Ø6@120) for tensile reinforcement, compression reinforcement and transverse reinforcement respectively, see Figure (1) and Table (1).

For comparison, four reinforced concrete frames were cast. The first frame was adopted as the reference frame; it was poured monolithically with normal concrete only. The second and third frames were poured monolithically with steel fibers reinforced concrete at the joints, (0.5%) and (1%) steel fiber ratios were added to the concrete of the joints. The fourth frame was poured non-monolithically with normal concrete.

All frames were tested under static point load applied at the mid span of the beam; the rate of loading was 1.5 kN/min. The deflections were recorded by dial gauge at the mid span of the beam exactly below the point load, see Figure (2).

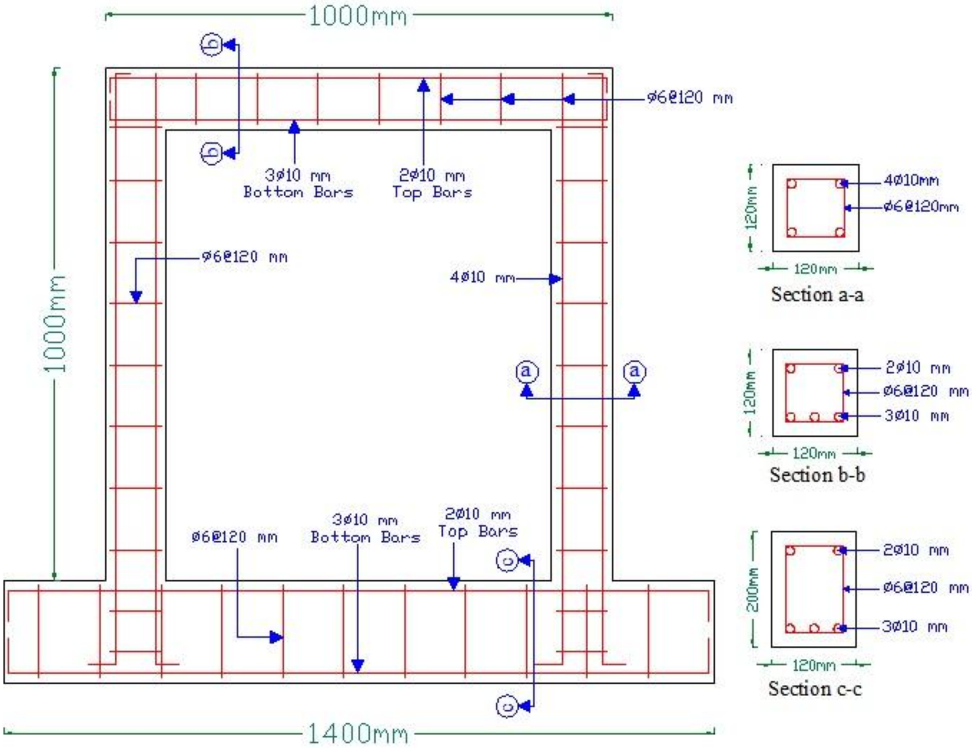

Figure 1. Details of Tested Frames

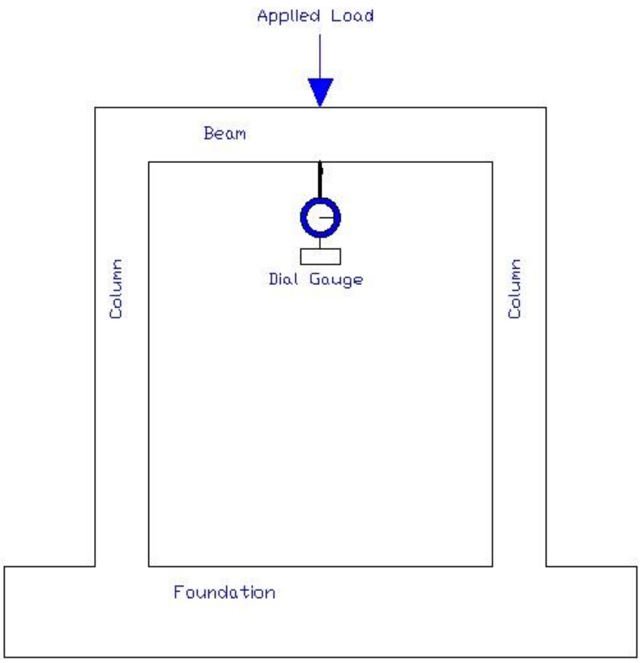

Figure 2. Testing Setup

Table 1. Geometric Details of Tested Frames

Specimens Conf.	Column Dimensions			Beam Dimensions			Footing dimensions		
	Section Width (mm)	Section Height (mm)	Length (mm)	Section Width (mm)	Section Height (mm)	Length (mm)	Section Width (mm)	Section Height (mm)	Length (mm)
F1	120	120	1000	120	120	960	120	200	1400
F2	120	120	1000	120	120	960	120	200	1400
F3	120	120	1000	120	120	960	120	200	1400
F4	120	120	1000	120	120	960	120	200	1400

Table 2. Mechanical Properties of Concrete

Mix No.	Concrete type	Compressive strength (MPa)*	Modulus of elasticity (MPa)*	Splitting Tensile (MPa)*
1	Normal concrete	27	24229	3.18
2	Normal concrete with 0.5% steel fiber	31.3	38298	6.83
3	Normal concrete with 1% steel fiber	32.6	38370	9.84

*Average of three specimens results.

Materials Properties

Concrete: - All frames were cast using normal weight ready mixed concrete with designed compressive strength (f_c') of (28 MPa). (2400 kg/m^3) unit weight concrete mixture with (12 mm) maximum size of gravel, (4.75) maximum size of sand and ordinary Portland cement (Type I) were used. Hooked end steel fiber with (100) of aspect ratio was used in a steel fiber reinforced concrete mixes.

Steel reinforcement: - Two diameters of (Ø10) mm and (Ø6 mm) were used as a longitudinal reinforcement and transverse reinforcement respectively; with average yield stress (437 MPa), ultimate tensile strength (548 MPa) and modulus of elasticity was (198 GPa).

Steel fibers : (50 mm) and (100) the length and aspect ratio of steel fibers used in this investigation.

Mechanical Properties of Concrete

The test results of concrete compressive strength, modulus of elasticity and splitting tensile strength are illustrated in Table (2), which performed according to BS1881[14], ASTM C469 [15] and ASTM C496 [16] respectively.

Concrete Composition of Materials Mixture

The compositions of conventional and steel fiber concrete were produced with same amount of cement, sand, gravel and w/c ratio, except the concrete at beam-column connections of the frames (F-2) and (F-3) was produced with different amount of steel fibers (0.5% and 1%) of total volume respectively. The used compositions are described in Table (3).

Table 3. Mix Proportions of Concrete

Material	Mix proportions		
	Normal Concrete (Mix -1-)	Steel Fiber Concrete	
		mix-2-	mix-3-
Cement	420	420	420
Sand	545	545	545
Gravel	1200	1200	1200
w/c	0.45	0.45	0.45
Steel fibers	Non	0.5%	1%

RESULTS AND DISCUSSIONS

Load-deflection Relationship and Failure Pattern

As shown in Figure (3), three major stages can be seen; elastic stage, that starts at load application and continue linearly until first crack appearance. The second stage characterized by appearance several cracks at the joint and extends to the outer edge of the connection, this stage is approximately linear and finished when yielding of reinforcing steel took place, it is the elasto-plastic stage of behavior. The third stage starts after crack appearance until failure of the specimen. In this stage, the specimen loses gradually a large part of stiffness as a result of propagation of cracks and increasing its width and height.

The first crack appears at the interior face of beam-column joint, then extend to the outer face with an angle about (45°). The width and height of the cracks increased gradually until appearance of flexural cracks at the mid span of the beam. At the advanced loading stages, wide diagonal shear cracks propagate at the supports and extend rapidly with an angle about (45°) toward the upper face of the tie beam until failure of frame by diagonal shear mode. As shown in Figure (4) to Figure (7), the cracks were propagated through the beam-column joints in reference specimen (F-1) clearly more than that of specimens (F-2) and (F-3) which poured with steel fibers reinforced concrete at the beam-column joints. The steel fibers delayed the cracks propagation by bridging effect. So, the specimen with steel fibers ratio (1%) of total volume blocked the cracks effectively larger than the specimen with (0.5%) steel fibers. In addition to diagonal cracks at the tie beam in the specimen that have construction joint, a bond failure was observed at the construction joint between the beam and column.

At the same loading levels, the beam of reference frame (F-1) recorded deflections larger than these of frames (F-2) and (F-3) that poured with steel fibers reinforced concrete at the joints, presence of steel fibers significantly effect on the performance of beam-column joints, also effect positively on the performance of individual members. The ductility and strength of the joint were increased which decreased the deflections

of the tie beam. On the other hand, the rotational stiffness of the joint was decreased in frame (F-4) (non-monolithic frame), the flexibility of the joint was increased to the limit that making the beam deformed largely more than that of monolithic frame (F-1), see Table (4).

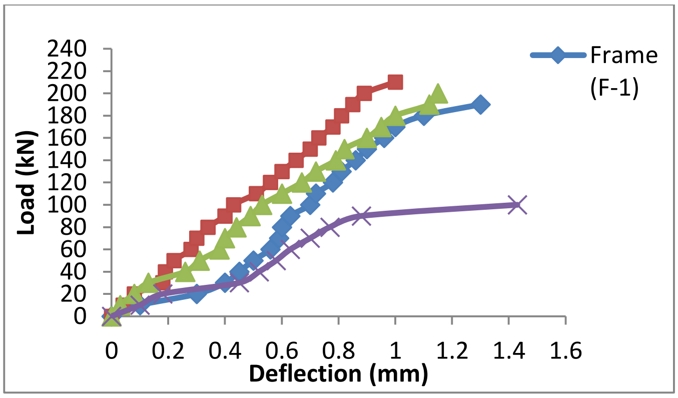

Figure 3. Load-deflection Curves of Tested Frames

Table 4. Deflection Characteristics

Specimen Configuration	Cracking Deflection (mm)	% of Reduction	Ultimate Deflection (mm)	% of Reduction
F1	0.43	R*	1.3	R*
F2	0.28	34.88	1.15	11.53
F3	0.24	44.18	1	23.07
F4	0.49	14	1.43	10**

R* : Reference Specimen.

** : Decreasing.

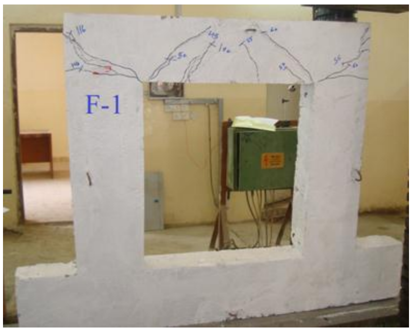

Figure 4. Failure Pattern of Frame (F-1)

Figure 5. Failure Pattern of Frame (F-2)

Figure 6. Failure Pattern of Frame (F-3)

Figure 7. Failure Pattern of Frame (F-4)

Frame Ultimate Capacity

The carrying capacity of tested frames has significantly affected by using steel fibers reinforced concrete at beam-column joints. As indicated in Table (5), the frame capacity had enhanced about (5.2%) and (10.78%) of specimens (F-2) (0.5% steel fibers) and (F-3) (1% steel fibers) respectively in comparison with reference frame (F-1), this improvement in frame capacity can be attributed to the increase in the joint stiffness resulting from efficiency of steel fibers in delay the propagation of cracks though the joint, the restraint of the beam at the joints result a redistribution of stresses along the beam span.

Also, the maximum carrying capacity of the frame is clearly affected by the frame type (monolithic or non monolithic frame), the reduction in frame capacity attained about (46%) in non-monolithic frame (F-4) in comparison with monolithic frame (F-1).

Table 5. Load Characteristics

Specimen Configuration	Ultimate Capacity (kN)	% of Difference	First Crack Load (kN)	% of Difference
F-1	190	R*	37.5	R*
F-2	200	5.2	43.5	16
F-3	210.5	10.78	52.5	40
F-4	102.5	46**	27.5	26.7**

R* : Reference Specimen.

** : Decreasing.

First Crack Load

The effect of using steel fibers reinforced concrete at the beam-column connection is illustrated in Table (5). The first crack load was significantly increased by increasing the amount of steel fibers. By contrast, the contribution of using steel fibers as 0.5% and 1% of total mix volume is pronounced in improving the first crack load by about 16% and 40% of frames (F-2) and (F-3) respectively in comparison with reference frame (F-1). This observation was largely attributed to the increase of concrete tensile strength award to good extent the stability of the frame through improving the lateral restraint of the joint.

In case of non-monolithic frame, the crack load was much less than that of monolithic frame, the flexibility of the joints made the beam to deflect freely without any lateral obstructions other than reinforcing steel bars at the joints.

Effect the Joint Type on the Beam Stiffness

The main parameters in the stiffness analysis include the failure load and the deflection of the member at failure; the tensile strength and modulus of elasticity of concrete at the joints were supposed the most important parameters that improve the ultimate load capacity and reduce the deflection by the effect of lateral restraint of the tie beam. As shown in Table (6), using steel fibers reinforced concrete at the beam-column joints contribute in increase the stiffness of the frames by about 18.98% and 43.68% of specimens (F-2) (f_{ct} = 6.83 MPa and E_c= 38298 MPa) and (F-3) (f_{ct} = 9.84 MPa and E_c=

38370 MPa) respectively larger than the reference frame (F-1) (f_{ct} = 3.18 MPa and E_c= 24229 MPa).

The non monolithic frame (F-4) exhibits 50.95% a decrease in its stiffness in comparison with the monolithic frame (F-1) as a result of dropping the ultimate load capacity and large displacement at failure.

Table 6. Stiffness of Tested Specimens

Specimen Configuration	Frame Type	Ultimate Capacity (kN)	Maximum Deflection at Failure (mm)	Stiffness (kN/mm)	Variation (%)
F1	Monolithic Frame with normal concrete	190	1.3	146.15	R*
F2	Monolithic Frame with (0.5%) steel fiber concrete at joints	200	1.15	173.9	18.98
F3	Monolithic Frame with (1 %) steel fiber concrete at joints	210	1.0	210	43.68
F4	Non-monolithic Frame with normal concrete	102.5	1.43	71.67	50.95**

R* : Reference Specimen.

** : Decreasing.

Ductility

Ductility describes the extent to which a material or structure can undergo large deformations without failing. A ductile structures ability to dissipate energy during an earthquake is, therefore, advantages as it will keep deforming without reaching collapse. The ductility index can be determined by dividing the ultimate deflection to the deflection at yielding.

Table (7) describes the effect of joint type on the ductility of tested frames. If the beam-column connection is strengthened by 0.5% and 1% steel fibers, the ductility was improved by about 27.5% and 38.89% over the reference specimen that casted monolithically. While, if the frame casted in non-monolithic way, the ductility index was decreased about 7% in comparison with reference frame F-1.

Table 7. Ductility of Tested Specimens

Specimen Configuration	Frame Type	Maximum Deflection at Failure (mm)	Deflection at Yield (mm)	Ductility Index	Variation (%)
F1	Monolithic Frame with normal concrete	1.3	0.65	2.0	R*
F2	Monolithic Frame with (0.5%) steel fiber concrete at joints	1.15	0.45	2.55	27.5
F3	Monolithic Frame with (1 %) steel fiber concrete at joints	1.0	0.36	2.77	38.89
F4	Non-monolithic Frame with normal concrete	1.43	0.77	1.86	7**

R*: Reference Specimen.

**: Decreasing.

CONCLUSION

The following conclusions can be drawn based on the results of experimental works:

1. The use of steel fiber reinforced concrete at the beam-column connection was effective in decreasing the beam deflections.
2. In case of construction joint at the beam-column connection, the frame have not qualified as a strong frame from the carrying capacity, first crack load, stiffness and failure pattern point of view.
3. As a result of using steel fibers reinforced concrete at the beam-column connection, the carrying capacity, first crack load, stiffness and ductility were increased significantly.

REFERENCES

[1] ACI 352R-02," Recommendations for Design of Beam-column Joints in Monolithic Reinforced Concrete Structures", American Concrete Institute , ACI-ASCE Committee 352, Detroit, 2002.

[2] Wight, J. K. and Macgregor, J. G., "Reinforced Concrete Mechanics and Design", 6th Edition, Pearson Education Inc., November, 2012.

[3] Haluk, S., "Effect of Connection Rigidity on Seismic Response of Precast Concrete Frames", PCI Journal, January-February 1995, pp. 94-103.

[4] Alva, G. M. S., Ferreria, M. A. and El debs, A. L. H. C., " Partially Restrained Beam-column Connections in Reinforced Concrete Structures", IBRACON Structures and Materials Journal, Vol. 2, No. 4, December, 2009, pp 356 – 379.

[5] Amanat, K. H. and Enam, B., " Study of The Semi-rigid Properties of Reinforced Concrete Beam-column Joint", Journal of civil engineering the institution of engineering, Vol.27, No.1, pp. 59-69.

[6] Said, A. M. and Moncef, L. N., " Behavior of Beam-column Joints Cast Using Self-consolidating Concrete under Reversed Cyclic Loading", 13th World Conference on Earthquake Engineering, Vancouver, Canada, August 1-6, 2004, pp. 10.

[7] Yeganeh, A. E., " Structural Behavior of Reinforced High Performance Concrete Frames Subjected to Monotonic Lateral Loading", M.Sc. Thesis, BEng, Ryerson University, Toronto, Ontario, 2013, pp. 95.

[8] Maya, L.F. and Albajar, L.," Beam-Column Connections for Precast Concrete Frames Using High Performance Fiber Reinforced Cement Composites", Material and structures, RILEM, 2012, p.p. 347-354.

[9] Ashtiani, M. S., Dhakal, R. P. and Scott, A. N.," Seismic Performance of High-Strength Self-Compacting Concrete in Reinforced Concrete Beam-Column Joints", Journal of Structural Emgineering, 140 (5), 2014, 04014002.

[10] Coelho, M. R. F., Fernandes, P. M. G., Sena-Cruz, J. and Barros, J. A. O.," Efficiency of Different Technique in Seismic Strengthening of RC Beam-column Joints", 15th World Conference on Earthquake Engineering, University of Minho, Civil Engineering Department, September, 2012.

[11] Akguzel, U. and Pampanin, Stefano," Assessment and Design Procedures for the Seismic Retrofit of Reinforced Concrete Joints Using FRP Composite Materials", Journal of Composite for Construction, Vol. 16, Issue 1, February, 2012.

[12] Vijayalakshmi, N., Kalaivani, M., Murugesan, A. and Thirugnanam, G. S.," Experimental Investigation of RC -Beam", International Journal of Civil and Structural Engineering", Vol.1, No.1, 2010.

[13] Rahmi, Y., Saputra, A. and Siswosukarto, S.," Numerical Modeling of Interior RC Beam-column Joints for Non-engineered Buildings Strengthened Using Steel Plates", MATEC Web of Conference, 2017, EDP Sciences, France.

[14] British Standard Institute, "Method for Determination of Compressive Strength of Concrete Cubes", BS 1881: part116: 1983.

[15] ASTM C469,"Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression", Annual Book of American Society for Testing Concrete and Materials, Philadelphia, Pennsylvania, 2014.

[16] ASTM C496-86, "Splitting Tensile Strength of Cylindrical Concrete Specimens" , Annual Book of American Society for Testing Concrete and Materials, Philadelphia, Pennsylvania, 2014.