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BEHAVIOR OF BEAM-COLUMN JOINTS WHIT DIFFERENT BEAM-COLUMN CONCRETE STRENGTHS

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الملخص العربى:

يهدف هذا البحث دراسة مدي تأثير اختلاف مقاومة الخرسانة بين العمود و الكمرة عند منطقة وصلة العمود بالكمرة.

تم دراسه عدد ثلاث عينات من الخرسانه المسلحة مكونه من عمود كمرة وتم التأثير بحمل ثابت علي الكمرة و بعد ذلك تم التأثير بحمل أستاتيكي من أعلى عند رأس العمود حتي الأنهيار وكان المتغير بين هذة العينات مقاومة الخرسانة بين الكمرة و العمود حيث أن العينه الاولى مقاومة خرسانة الكمرة 38نيوتن/مم^2 و مقاومة العمود 38 نيوتن/مم^2 والعينه الثانيه مقاومة خرسانة الكمرة 38نيوتن/مم^2 و مقاومة العمود 50 نيوتن/مم^2 والعينه الثالثة الاولى مقاومة خرسانة الكمرة 38 نيوتن/مم^2 و مقاومة العمود 94نيوتن/مم^2 كل عينه لها نفس شكل التسليح ونسبة التسليح ولها نفس الأبعاد تم تعيين حمل الأنهيار للثلاث عينات والترخيم والحركه الأفقيه والأنفعال بالحديد الرئيسي وتم عمل تحليل بطريقة العناصر المحددة للتحقق من النتائج التى تم الحصول عليها معمليا. و بصفة عامة، كان هناك توافق كبير بين كل من النتائج المعملية و العددية.وتم عمل أستنتاجات ومقترحات من هذا البحث.

ABSTRACT

In high-rise buildings and heavy loaded structures where RC columns are subjected to heavy loads, High Strength Concrete (HSC) used in column construction is essential for the purpose of reducing column size and increasing column capacity. However, from the economic standpoint, combination of high and normal strength concrete (NSC) in building construction is becoming common practice, where HSC is used for columns and NSC is used for the beams and slabs floor system. This creates a situation where concrete strength of the column portion at the beam and slab floor level is lower than concrete strength used for rest of the column. Previous studies indicated that such variation in concrete strength affects the load carrying capacity of the RC columns. A numerical investigation utilizes the non-linear finite element modelling (FEM) was performed in ANSYS® to validate the experimental results. Overall, the numerical results agreed very well with the corresponding experimental results at all stages of loading.

KEYWORDS

High concrete strength, Normal concrete strength, Beam-column Joints, Concentric load, Non-linear structural analysis.

1 INTRODUCTION

A beam-column joint is a very critical zone in reinforced concrete framed structure where the elements intersect in all three directions. Joints ensure continuity of a structure and transfer forces that are present at the ends of the members. In reinforced concrete structures, failure in a beam often occurs at the beam-column joint making the joint one of the most critical sections of the structure. Sudden change in geometry and complexity of stress distribution at joint are the reasons for their critical behavior. In recent years, the design of joints in reinforced concrete structures was generally limited to satisfying anchorage requirements. In succeeding years, the behavior of joints was found to be dependent on a number of factors related with their geometry; amount and detailing of reinforcement, concrete strength and loading pattern.

In this research, the behavior of beam–column joint in the different concrete strength between column & beam while the concrete strength of column more than the concrete strength of beam under the failure load of column. In this case load capacity of the column may be reduced and was found to be a function of the ratio of the column concrete strength (HSC) to the beam concrete strength (NSC). In this study, a variety of experimental & theoretical models of concrete strength for column and beam were used in order to investigate the structural behavior of integrated RC building frames under concentric failure static loads.

Study was implemented depending mainly on static analysis and design regulations of the Egyptian code for the design & construction of reinforced concrete buildings. In recent years the evolution of computer technology has advanced to the stage where the finite element method (through codes such as ‘ANSYS’) can realistically be used to model full-scale buildings and subject them to a variety of loads, including seismic. Modelling through a detailed finite element discretisation of the structure can provide a more realistic representation of the actual behaviour of RC buildings. Therefore in this research the theoretical models of beam - column joints of RC framed structures were implemented using ANSYS computer package ver.14.

2 EXPERIMENTAL PROGRAM

The experimental work of the present study consists of testing three specimen’s reinforced concrete.

2.1 Test Specimens

This research consists of three specimens the variable of specimens is the concrete strength of column while the concrete strength of beam is constant were tested in the laboratory and labelled with S1, S2, and S3. Each specimen will be studied and analyzed under the effect of different concrete strength. All specimens have the same dimensions and steel reinforcement but differ in the concrete compressive strength of the columns. The three specimens have a one beam 800 mm long, 150 mm width and 250 mm depth framed at mid-height of a column of 150 x 250 mm cross section and height of 1300 mm with column heads of height of 400 mm in the lower and upper part of column. All specimens were provided with the same identical amount of main reinforcement, as shown in **table (1). Fig. (1)** shows the geometry and reinforcement details of the tested specimen.

Table (1)*: Description of the Tested specimens*

Specimen NO.	Dimensions (mm)		Main Reinforcement		Stirrups		Concrete strength F_{cu} (N/mm²)	
	beam	column	beam	column	beam	column	beam	column
S1	800 x 150 x 250	1300 x 250 x 150	2Ø16	4Ø12	6Ø8/m'	8Ø8/m'	38	38
S2			2Ø16	4Ø12	6Ø8/m'	8Ø8/m'	38	50
S3			2Ø16	4Ø12	6Ø8/m'	8Ø8/m'	38	94

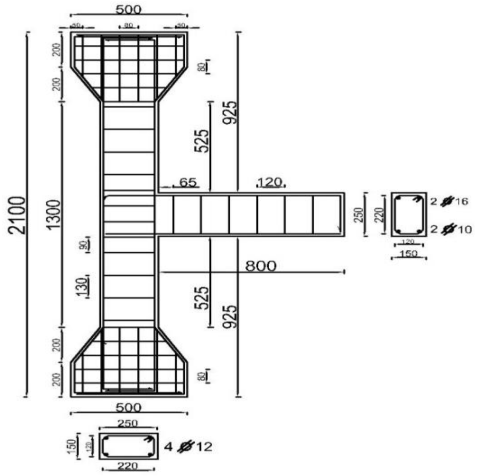


Fig. (1): Steel Reinforcement Details of the all tested specimens

2.2 Equipment and Instruments:

The three specimens were tested in the RC laboratory of Ain Shams University. The specimens were tested using a hydraulic jack of 300 ton capacity that they were tested directly by applying a concentrated load at the top of the column head for S1, S2 and S3 as shown in **Fig. (2)**. Before testing the specimens, a calibration was done for hydraulic jack by using a calibration ring in order to control the load on the column and the beam during the tests. A hydraulic jack imposed the axial load. Beam was loaded with a constant load of 21kN load increments downwards at distance of 100 mm from the free end of the beam. Columns were loaded by applying an axial load until failure occurred.

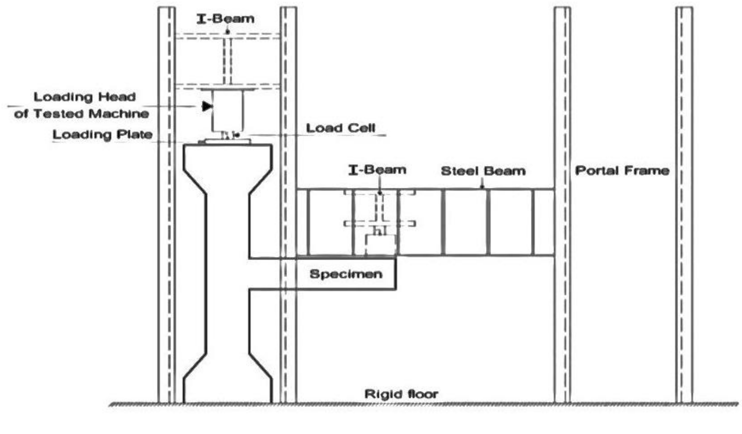


Fig. (2): *Testing Set-Up For all specimens*

2.2.1 Measuring devices:

Two linear variable displacement transducers (LVDT) with 120 mm range were used to measure the beam deflection at the mid span of beam and under beam load. The strains of concrete were measured using electrical strain gauges with 120.3±0.5 ohm resistance fixed on the extreme compression fiber and mechanical strain gauges, called tensometers with 60 mm gauge length, and 0.001 mm accuracy. The strains in steel bars were measured using electrical strain gauges with 120.4±0.4 ohm resistance. For the bar with diameter 16 mm used strain gauge 10 mm gauge length and for the bar diameter 10 mm and 12 mm used strain gauge 6 mm gauge length. These gauges were fixed on the steel bars before casting using special glue and covered with a water proofing material to protect them. The data acquisitions were used in the measurements of strains and deflection and corresponding acting load on tested specimen. **Fig. (3)** Show general arrangement for deflectometer and electrical strain gauges for all specimens.

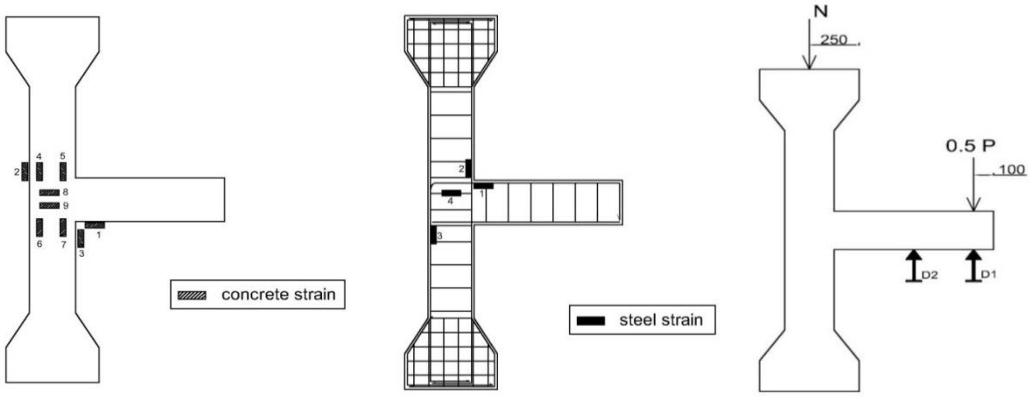


Fig. (3): *General Arrangement for Deflectometer And Electrical Strain Gauges For Specimens (S1, S2, S3)*

2.3 Test Procedure:

The three specimens were tested using an incremental static loading procedure. Firstly the applied load on the column was around 10% of the failure load for the purpose of specimen installing, Secondary the applied load on the beam was constant vertical load equal to $0.5P_{failure}$ ($P_{failure}$ is ultimate load of beam section = 4.2 tons) and after that the loading of column started again upon the failure. All the readings of beam deflection, compression and tension strain were recorded at all load stages using computer controlled data acquisition system. All the cracks lines were marked using marker pen. All the process took time at about 30 minutes for every specimen.

3 EXPERMENTAL RESULTS

3.1 Crack Patterns, Cracking Loads and Failure Loads

For the tested three specimens, the cracks started from the connection zone between beam and column. At further load increments, caused the crack to extend diagonally towards the opposite corners of the connection zone, and generated one or two other cracks. Other cracks appeared at the beams of these specimens and the lower part and upper part of the columns. **Table (2),** shows the cracking load at which the first crack appeared and the failure load at which the deflection increases although the load is constant for the tested specimens. **Figure (4)** show the general crack patterns for the tested specimens.

Table (2)*: Experimental Results of Cracking Load, Failure Load*

Specimen NO.	Concrete strengths F_{CU}(N/mm^2)		Beam axil load (KN)	The load of First crack (KN)	Ultimate load (KN)	Ultimate beam deflection (mm)
	Beam	Column				
S1	38	38	21	320	1241	49.38
S2	38	50	21	310	1195	38.52
S3	38	94	21	330	1287	61.98

Figure (4)*: General Crack patterns of Specimens (S1, S2 and S3)*

From **table (2) and figure (4),** the following remarks could be concluded:

For the tested specimens, Investigation of the results reveals that the failure load of model S1 (124.1 ton) is more than failure load of S2 (119.5) although the concrete compressive strength of column of S2 (500 kg/cm^2) is more than S1 (380 kg/cm^2). Then the failure load of model S3 (128.7 ton) increases with small value than S1 (124.1 ton) although there is a big difference between them in the concrete compressive strength equal to 560 kg/cm^2.

Regarding of column failure loads of specimens S1, S2 and S3, the experimental results indicates to decreasing of failure loads with the increasing of concrete compressive strength of columns due to the discontinuity of concrete compressive strength of columns at beam - column joint that leads to creation of weakness point at joints.

3.2 Load-beam deflection relationship of specimens

The experimental results of load-beam deflection curves at end of beam (D1) and load- beam deflection curves at mid span of beam (D2) were plotted for the three tested specimens as shown in **figures (5) and (6).**

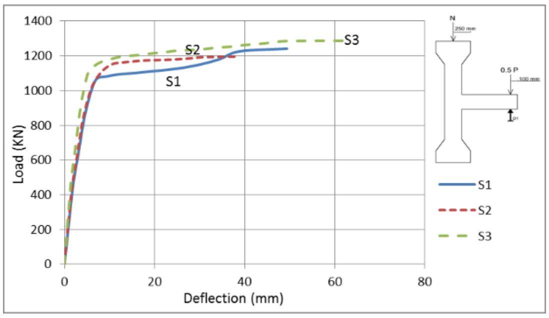


Figure (5)*: Experimental Results of R – Deflection Curves at end of beam*

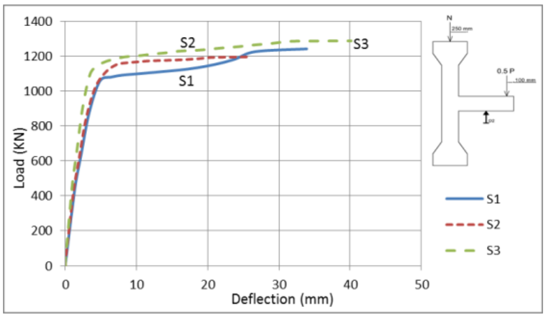


Figure (6)*: Experimental Results of R – Deflection Curves at mid span of beam*

From **figures (5) and (6)**, the following remarks could be concluded:

For the tested specimens, the maximum beam deflections (D1 & D2) at failure load of specimens S1, S2 and S3. Figures and table demonstrates that deflection of beam decreases from S1 (38 N/mm^2) to S2 (50 N/mm^2) with percentage 28.3% then increased for S3 (94 N/mm^2) with percentage 25.5% than S1 (38 N/mm^2).

From these figures, it can be noted the effects of concrete strength increasing of column on beam deflections that when the concrete strength increases from S1 (38 N/mm^2 - NSC) to S2 (50 N/mm^2 - HSC) the failure load decreased and consequently beam deflection decreased but when the concrete strength increases from S1 (38 N/mm^2 - NSC) to S3 (94 N/mm^2 – high performance concrete) the failure load increased very little and consequently beam deflection increased. As the confinement of joint region, size and stiffness are the same for all models; the main affecting factor on beam deflection is the increasing of concrete strength of column specimens.

Finally, the load deflection curves of the tested frames are nearly linear at the early stages of loading, up to the yielding load. However, once the yielding occurs excessive cracks take place, and accordingly the deflections increase rapidly.

3.3 Strains

3.3.1 Load-reinforcement strain relationship for specimens

The experimental results of load load-strain curves for the longitudinal reinforcement & stirrups of the column and beam of models (S1, S2 and S3) were plotted for the three tested specimens as shown in **figure (7).**

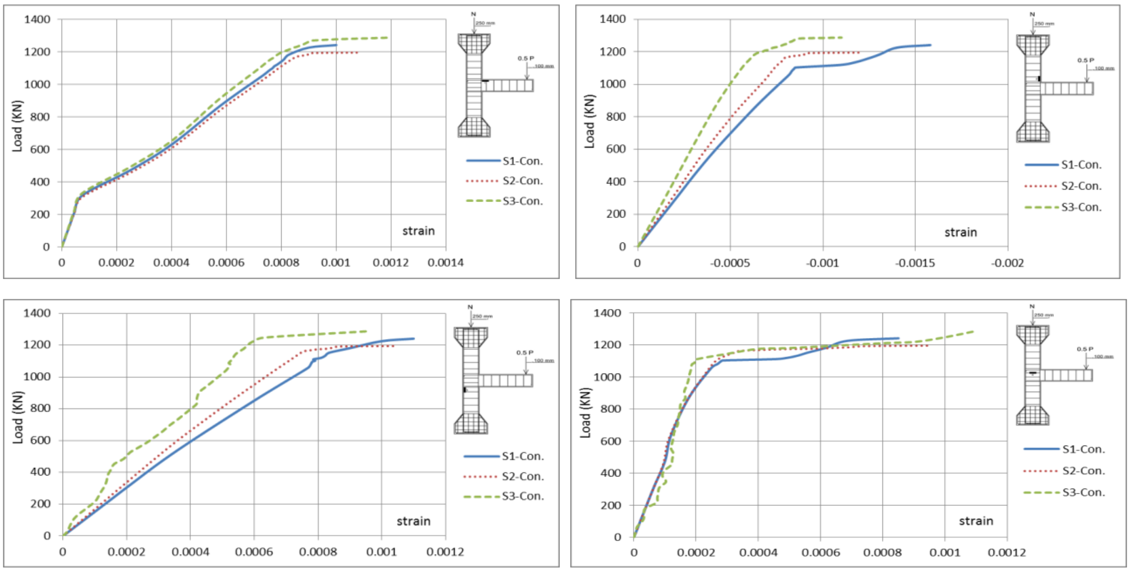


***Figure (7)**: Experimental Results of R – Strain of Reinforcement Curves*

From **figure (7)** the following remarks could be concluded:

For the tested specimens, Compression & tension strains of vertical reinforcement of column at location 2 & 3 respectively at upper & lower parts of joint having the same behavior that at location 2, strain for S1 (38 N/mm^2) is -0.00158 increases with percentage 43.6% than S2 (500 N/mm2) and 50.5% than S3 (94 N/mm^2). This means when concrete strength of upper & lower parts of column increases to HSC & and high performance concrete, the compression & tension strains of vertical steel reinforcement of column above and below joint part (NSC - 38 N/mm^2) in column decrease with bigger value and there are effects of beam moment on joint that can transfer the strains from compression to tension.

- Tensile strains of main longitudinal reinforcement of beam in face of column at joint location 1 are resulted from negative moment of beam at this location. Strain for S1 (38 N/mm^2) is 0.001 less than S2 with percentage 7% (500 N/mm^2) and 10% than S3 (94 N/mm^2). This means when concrete strength of column increases to HSC and high performance concrete, the strains of beam reinforcement in tension zone increase.
- Due to moment resulted from beam on column at joint, strains of stirrup of column at beam-column joint (locations 4) were tension and increased generally with increasing of column concrete strength. Strains at location 4 for S1, S2 and S3 are 0.00085, 0.00093 and 0.00106 respectively. This means that the negative moment resulted from beam on joint caused tension on beam-column joint zone.

3.3.2 Load-Lateral concrete strain relationship for specimens

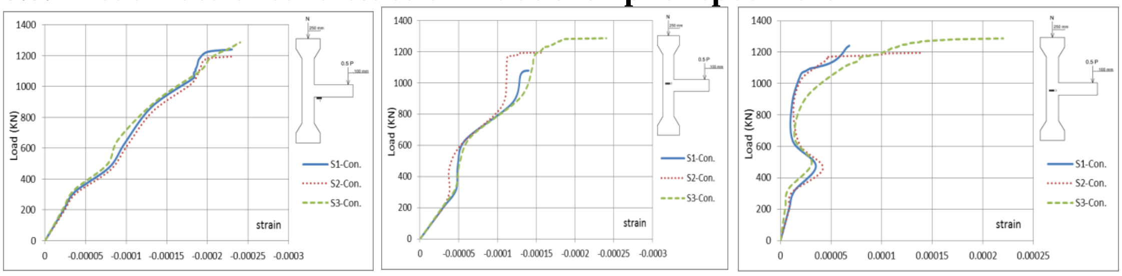


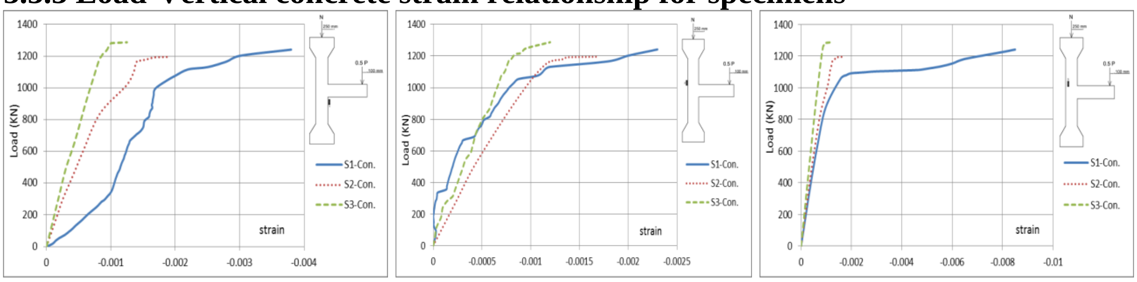
***Figure (8)**: Experimental Results of R – Strain of Lateral concrete Curves*

From **figure (8)** the following remarks could be concluded:

For the tested specimens, by comparing the maximum strain values of S1, S2 and S3, it is revealed that:

- Lateral strains of concrete at location 1 below beam (**figure (8a)** - compression zone) for S1 (38 N/mm^2) is -0.000221, S2 (500 N/mm^2) is -0.00022 and S3 (94 N/mm^2) is -0.00023. This means the strains of beam in compression are almost the same when concrete strength of column increases to HSC and high performance concrete.
- Lateral strains of concrete at location 2 & 3 at beam-column joint **(figures 8b & 8c)** having the same behavior that at location 2, strain for S1 (38 N/mm^2) is -0.000122 less than S2 with percentage 2.3% (500 N/mm^2) and 80.3% than S3 (94 N/mm^2). This means when concrete strength of upper & lower parts of column increases to HSC and high performance concrete, the strains of joint part (38 N/mm^2) in column increase.

3.3.3 Load-Vertical concrete strain relationship for specimens



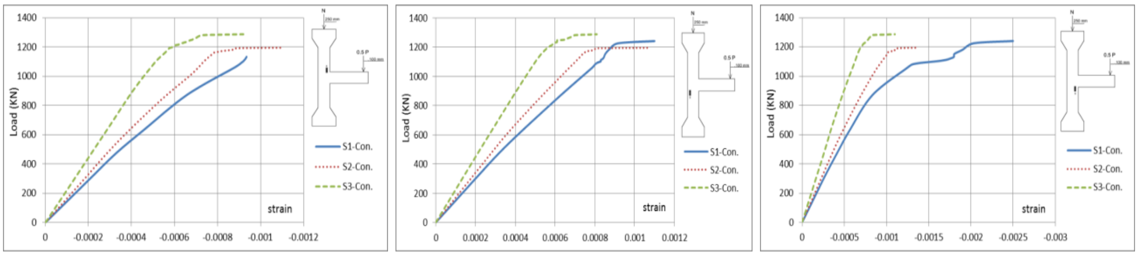


Figure (9): *Experimental Results of R –Strain of Vertical concrete Curves*

From **figure (9)** the following remarks could be concluded:

For the tested specimens,

- Vertical strains of concrete at location 1, 2, 3 & 6 at upper & lower parts of joint having the same behavior that strain of S1 (38 N/mm^2) is larger more than S2 with percentage 100% (500 N/mm^2) and 204% than S3 (94 N/mm^2). This means when concrete strength of upper & lower parts of column increases to HSC and high performance concrete, the strains of column above and below joint part (NSC - 38 N/mm^2) in column decrease with bigger value.
- Due to moment resulted from beam on column at joint, strains at locations 4 and 5 (compression zone & tension zone receptivity) increases generally with increasing of column concrete strength.

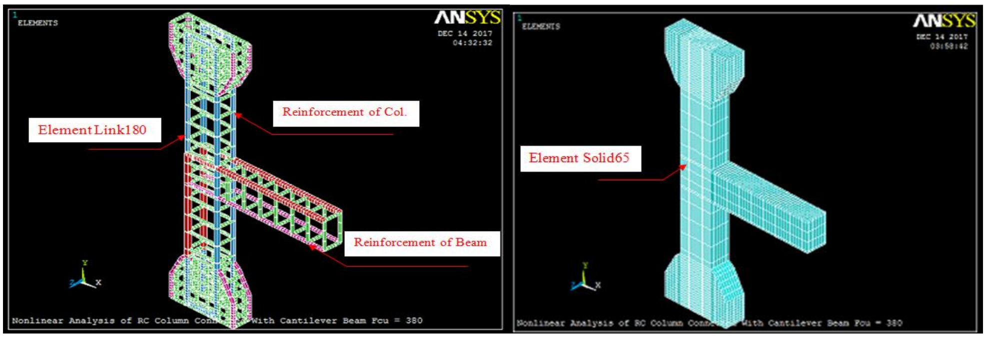
General analysis of these results above shows the effects of high strength of concrete for upper & lower parts of column and normal strength concrete of joint (middle part of column 38 N/mm^2) which creates weaker zone in the column (discontinuity of strength of the same structural member).

4 FINITE ELEMENT MODEL

4.1 Methodology

The main aim of performing a finite element analysis of the models was to extend the investigations carried out experimentally to have better understanding of the behavior of all tested specimens

The application of the appropriate boundary conditions for column bases, which were assigned equal to zero for all degrees of freedom (creating fixed ends and simultaneously the modelling of the fixation in experimental work). The main Three-dimensional finite element model of the RC beam - column joint models (S1, S2, and S3) that were generated using ANSYS is shown in **Fig.(10)**.The differences between models are the concrete compressive strength (F_{cu})



(a) **(b)**

Fig. (10): *F.E models*

(a) The main 3D finite element model of the S1, S2 and S3 models (beam – column joint) - Difference between models are F_{cu} of column & beam

(b) Steel reinforcement of the 3D finite element model of all models (S1, S2 and S3).

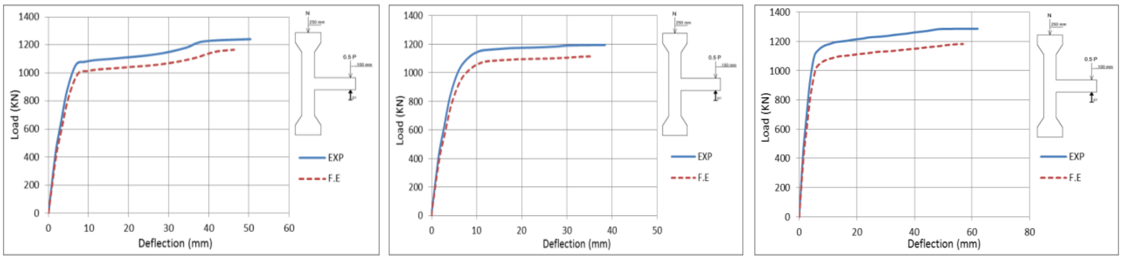
4.2 Results and Verification of FE Models

To verify the FE model, a comparison of the results from tests and those from the FE analyses was made; as shown in **Table (3).** It can be seen that the FE model captured the structural behavior in a satisfactory way. The maximum failure load resistances obtained in the FE analyses are equal to those obtained in the tests to within 9% difference.

Table (3): *Comparison for failure loads in Exp. and FE analysis*

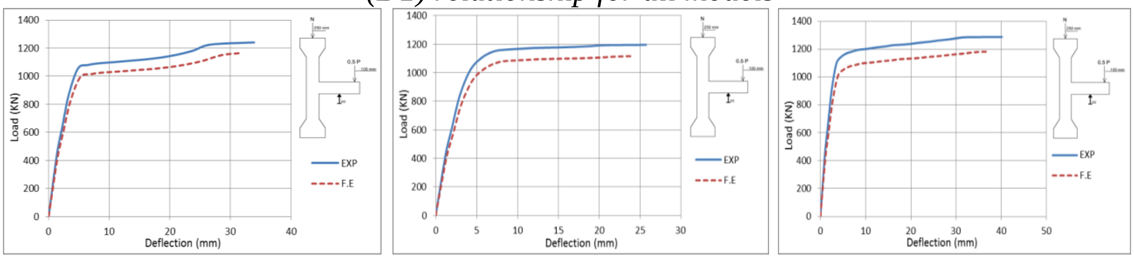
Model NO.	Concrete strengths F_{CU}(N/mm^2)		Beam axil load (KN)	The load of First crack (KN)			Ultimate load (KN)		
	Beam	Column		EXP.	F.E.A	$P_{EXP}/P_{F.E.A}$	EXP.	F.E.A	$P_{EXP}/P_{F.E.A}$
S1	38	38	21	32	298	0.11	1241	1165.5	1.06
S2	38	50	21	31	285	0.11	1195	1115.55	1.07
S3	38	94	21	33	303	0.11	1287	1182.15	1.09

Figures (11) and (12) show samples of comparisons between load- lateral deflection curves of the finite element analysis and test results obtained for specimens S1, S2 and S3 at the critical section. The model agreed well with the test results in terms of failure loads as well as the deformation and the strain values.



Model (S1) *Model (S2)* *Model (S3)*

Fig. (11): *Comparison between the Experimental and Analytical Load- beam deflection (D1) relationship for all models*



Model (S1) *Model (S2)* *Model (S3)*

Fig. (12): *Comparison between the Experimental and Analytical Load- beam deflection (D2) relationship for all models*

5 CONCLUSIONS

Based on the obtained experimental and numerical results, the following main conclusions can be drawn:

1. For columns tested under axil loads, the failure load of second specimen [50N/mm^2] was less than first specimen [38N/mm2], and third specimen [94N/mm^2] more than first & second specimens. The HSC of column gives lower failure load then NSC but high performance concrete [94N/mm^2] gives more failure load.
2. With respect to the columns tested under axil load, the ratio of column concrete strength to beam concrete strength between S2 & S1 is 1.3 and S3 & S1 is 2.5. The ratio of column failure load between S2 & S1 is 0.96 and S3 to S1 is 1.04. The difference in concrete strength between column & connection zone has a

negligible effect on the failure load of (S1&S2) but has improved for (S1&S3).

3. The longitudinal steel reinforcement of column & stirrups at beam-column joint were yielded which demonstrates clearly that failure occurs at connection of beam with columns for all specimens.
4. Due to the high performance concrete of column [94N/mm^2] the deflection of beam is more than NSC [38N/mm^2] of column & beam.
5. Axial forces in building columns are one of the important factors which affect the ductility (section rotation capacity) of beam - columns joint. In general a reduction in the compressive axial load will increase the ductility of the section, but may compromise the ultimate strength. Therefore when concrete strength increases the section ductility decreases which leads to failure occurs at joint. This happened in columns S3 (concrete strength 94 N/mm^2 under concentric load).
6. The simulation of specimens (beam-column joint) using F.E analysis in the ANSYS 14.0 program are quite well since mode of failure, failure loads and deflection of beams predicted were very close to those measured during experimental testing.
7. Results of the F.E. analysis showed good agreement with the experimental results with difference in rang of 9%.

6 REFERENCES

[1] Egyptian code for the Design and Construction of Concrete Structures (ECCS 2007) HBNRC.

[2] ACI-ASCE Committee 352 (1985). Recommendations for Design of Beam-Column Joints in Monolitic Reinforced Concrete Structures. ACI Structural Journal. Proccedings Vol. 82 No. 3 : 266 – 283.

[3] Hanson, Norman W., and Harold W. Conner. "Seismic resistance of reinforced concrete beam-column joints." Journal of the Structural Division 93.5 (1967): 533-560.

[4] Park, R. and Paulay, T. (1975). Reinforced Concrete Structures. New York : John Wiley and Son.

[5] Meinheit, D. F., and Jirsa, J. O. (1981). Shear Strength of Reinforced Concrete Beam-Column Connections. Journal of The Structural Division. Vol. 107 No. ST11 : 2227 – 2244.

[6] Ospina, C. E., S. D. B. Alexander, and James G. MacGregor. "Transmission of Loads from High-Strength Concrete Columns through Normal-Strength Concrete Floors." Special Publication167 (1997): 127-148.

[9] Scott, R. H. (1996). Intrinsic Mechanisms in Reinforced Concrete Beam-Column Connection Behaviour. ACI Structural Journal. Vol. 93 No. 3 : 336 – 346.

[7] Pessiki, Stephen Paul, et al. "Seismic behavior of lightly-reinforced concrete column and beam-column joint details." (1990).

[8] Paulay, T. (1989). Equilibrium Criteria for Reinforced Concrete Beam-Column Joints. ACI Structural Journal. Vol. 86 No. 6 : 635 – 643.

[9] Paulay, T., R. Park, and M. H. Phillips. "Horizontal construction joints in cast-in-place reinforced concrete." Special Publication42 (1974): 599-616

[10] ANSYS Program Release 5.7, Analysis User Manual Revision 14.0, Swanson Analysis System Inc., 2014.