Evaluation the Behavior of Beam-column Connections Having Hollow in Beam and Casted with different Concrete Types

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Abstract

Hollow structures have increasingly been performed in buildings, bridges, towers, and offshore structures to pass mechanical and electrical pipes, or other services. Deformations and strength caused by external forces in beam-column connections with a hollow beam are rarely examined in this investigation. In particular, the behavior of hollow beam frames with high-strength concrete and reactive powder concrete remains poorly studied. This paper aims to study the behavior of reinforced concrete frames with hollow beam and to compare it with a frames having a solid beam. The dimensions of beam are 1200mm long by 140mm wide and 200mm deep, and column dimensions are 700mm height by 140mm^2 of cross section. Impact loading is applied through a column in mid-span of a beam. The effect of hollow on the reinforced concrete frames is evaluated, in addition to study the effect of amount of steel fibers and concrete compressive strength on deformations and strength of frames. The hollow created in the beams resulted a reduction in the strength of the frame, and the hollow beam would carry almost higher load if the ratio of steel fibers and concrete compressive strength is increased.

Keywords: impact, hollow, connection, high-strength concrete, reactive powder concrete, steel fibers.

Introduction

The joints are weak due to insufficient of anchorages for the bar crossing the joint with in the column from the beam. The beam-column concentric connection is the one whose beam and column axes overlap. These styles of joints have been used mainly in recent building works. Much work has been done on these joints to mitigate the dangerous structural failure under an extreme combination of loads. The joints can be divided into three types according to a position in frame structure as the interior joint, external joint and corner joint at a time when resisting frame.

Research has found that the entire structure is affected within the joint region due to improper construction and detail, although other structural elements conform to design specifications. Within the members, the creation of plastic hinges results in structural damage under seismic stress. Therefore, the damage throughout the formation of plastic hinges is agreed in seismic design to be built in concentrated joints, particularly in beams an d not in columns[1]. It is therefore observed that the concept of a strong column and a weak beam during design should be favored. Column to beam flexural force ratio is the parameter that should be given more importance in the case of concentric joints. The joints must have adequate strength to withstand stress-induced and adequate rigidity to control the deformation. Most of the work has suggested the latest improved steel reinforcement description techniques. It is as follows:

1. Bend inclined column bars[2].
2. Headed bars in the connection zone[3].
3. Additional diagonal bars in the connection zone[4].
4. Crossing bars in the beam zone[5]

With the exception of the head bars, the above mentioned methods certainly provide the concrete's brittle failure in the seismic loading scope. Research [2] shows that there is an additional shear transfer mechanism created by the existence of inclined column bars.

The function of crossed inclined bars disappeared in increasing joint shear capacity when the ratio of beam height to column height (hb/hc) increased

Where hc= column width, hb= beam width. The technique of head bars used in experiments provides a possible solution to issues such as steel congestion, challenging production and building, as well as bad concrete positioning. This research suggests that the headed bars behaved well under the seismic loading action as compared with diagonal bracing bars and bent up bars[3]. In paper[4], however, that the existence of small diameter bars in the beam zone results in a decrease in the performance of the joint zone under loading from earthquakes. The seismic design theory is based on providing the structure with adequate ductility that can dissipate energy from the earthquakes. It is found in concentric beam-column structures that the joint behavior mainly depends on the reinforcement detailing. The extreme failure of the shear stress happens most of the time under the column's seismic load caused by an inadequate description of the joint section's reinforcing. The opening or hollowing of the members of the structure has already become increasingly popular in today's design of the building and has been increasingly used in the construction of structures, bridges, offshore structures, and towers to meet the requirements of driving of electrical and mechanical lines due to architectural appeal as well as other benefits such as reducing weight and material savings. Reducing the beam's surface area by inserting PVC pipe would, therefore, affect its efficiency and behavior in bending moment and shear strength, the experiment test will be carried out to determine frame capacity, deflection and failure pattern of frame. And then provide specific advice and on the adequate depth and volume of the hollow section. A comparison of solid and hollow reinforced concrete beams was made by (Alnuaimi et al, 2008) [6] (Solid and hollow beams of the same reinforcement) indicates that all hollow beams ruptured at low loading than solid beams. The hollow beams failed to achieve the design loads while the solid beams failed loads higher than design loads. (Jain Joy and Rajesh Rajeev, 2014) [7] sought to popular the weight and expense of reinforced concrete buildings by removing concrete in the neutral axis and surrounding. And then placing by PVC duct.

They observed that the loading capacity of the solid reference beam and that of the beam with a hollow neutral axis did not vary significantly. (N.P. Dhinesh and V.S. Satheesh, 2017)[8]. A comprehensive research on flexural behavior on hollow reinforced square beam was introduced, both beams being tested by three points load testing. It has been observed that the beam's overall load carrying strength is high in the hollow core tensile regio n as opposed to other hollow core areas.

Research significant

While a lot of research has been conducted on beam- column connections , no work has been done on connections having hollow in beam . the main purpose of this paper is to examine the behavior of frames contain hollow in longitudinal direction of beam. Tests are used to determine the capacity, deflection measurement. Failure pattern of reinforced concrete frames having hollow in beams. It will be seen that they may be different in the case of solid beam.

Test program

Figure (1) shows the beam and column geometry and reinforcement in additional to supports position. Through beam was 1200mm long by 140mm wide 200mm deep, and column dimensions were 700mm height by 140mm^2 of cross section. The examined specimens were divided in to three groups according to existing of longitudinal hollow and concrete type ; group a was casted with normal strength concrete , one of frames was casted with solid beam, and other specimen was casted with 50mm longitudinal hollow beam. Group B was casted with reactive powder concrete , one of frames was casted with solid beam , and other two specimens were casted with hollow beams but with two ratios of steel fibers ,1% and 2% of total volume . third group have three high strength concrete frames ; one of frames was casted with solid beam , and other two specimens were casted with hollow beams but with two different compressive strength ; 70MPa and 50MPa.

Transverse shear ties of beams were bars with 8mm diameter at 120mm distance .the longitudinal steel bars is arranged 2@12mm at compression zone and 3@12mm at tension zone of the beam. The column is reinforced with 6@120mm for stirrups and 4@12mm for longitudinal reinforcement . The frame specifications are mentioned in Figure (1).

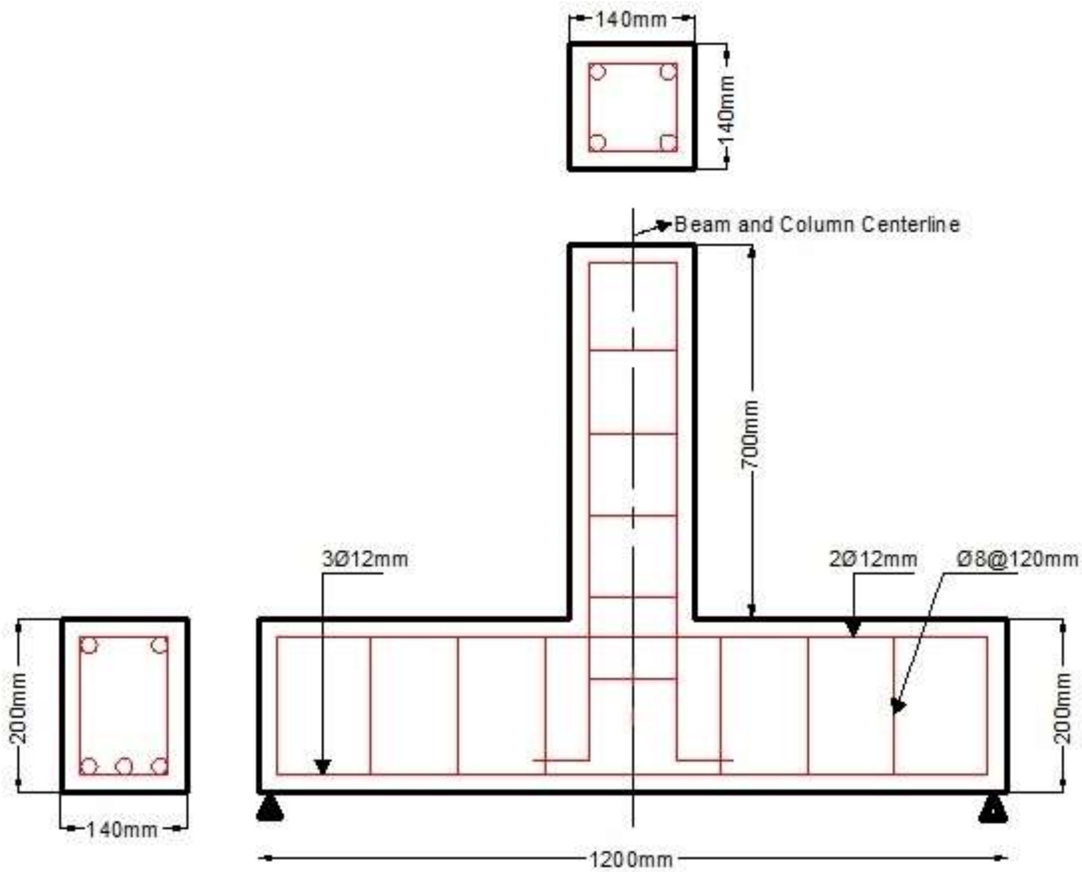

Figure (1) Frame Specifications

Material properties

The frames were manufactured of ordinary Portland cement, with a maximum gravel size about 10 mm and average of compressive strength of 30 MPa, 70MPa and 50MPa for normal strength, reactive powders and high strength concretes. Three cubes of 150mm3 ,three cylinders of 300 mm height and three 100*100*500 mm prisms were manufactured from each mix of concrete . in the same day of frames tests, the cubes, cylinders and prisms were tested to evaluate values of mechanicals properties of concrete.

Details of materials properties are summarized in Tables (1) to (9) obtained from laboratory tests and manufacturer data sheets.

Table (1) Mix Proportions

Type of concrete	Cement (Kg/m^3)	Water (Kg/m^3)	Gravel (Kg/m^3)	Sand (Kg/m^3)	Superplastisizer ($litre/m^3$)	Silica fume (Kg/m^3)	Steel fiber (%)
NSC	660	277	416	416			
HSC (50MPa)	505	141	1108	683	4.7		
HSC (70MPa)	501	115	1008	832	11		
RPC	768	160		1140	40	192	1

Table (2) Grading of the Fine Sand

No.	Size of Sieve (mm)	Percentage of Passing
1	4.75	93
2	2.36	87
3	1.18	84
4	0.6	70
5	0.3	32
6	0.15	8

Table (3) Grading of the Extra Fine Sand

Sieve Size (mm)	Passing (%)
10	100
4.75	100
2.36	100
1.18	100
0.60	100
0.30	47
0.15	6

Table (4) Grading of Coarse Aggregate

No.	Size of Sieve (mm)	Course aggregate
1	14	100
2	10	96.6
3	5	8
4	2.36	3
5	1.18	0

Table (5) Properties of Steel Fiber

Property	Specification
Density.	7860 kg/m3
Ultimate strength	1500 MPa
Modulus of elasticity	$2*10^5$MPa
Possions ratio	0.28
Length	50 mm
Diameter	0.5mm
Aspect ratio	100

Table (6) Chemical Analysis of Silica Fume

Compound Composition	Chemical Composition	Content (%)
Lime	CaO	0.5
Iron oxide	Fe_2O_3	1.4
Alumina	Al_2O_3	0.5
Silica	SiO_2	92.1
Magnesia	MgO	0.3
Sulphate	SO_3	0.1
Potassium oxide	K_2O	0.7
Sodium oxide	Na_2O	0.3
Loss on ignition	L.O.I	2.8

Table (7): Properties of Steel Bars

Nominal Diameter (mm)	Modulus of Elasticity (GPa)	Yield strength (MPa)	Ultimate strength (MPa)	Elongation%
8	200	542	664	10.3
10	200	576	650	10.1

Table (8) Chemical Composition of Cement

Chemical composition	Content (percent)
CaO	61.87
SiO_2	21.7
Al_2O_3	5.13
Fe_2O_3	4.04
MgO	2.63
SO_3	2.83
L.O.I	0.94
Insoluble residu	1.31
L.S.F	0.94
C_3S	35.12
C_2S	36.6
C_3A	7.84
C_4AF	12.10

Table (9) Physical Properties of Cement

Physical properties	Test result
Fineness modulus	266.6
Soundness	0.52
Initial Setting time (min) Final Setting time (hr)	141 5
Compressive strength at 3 days (MPa) 7 days (MPa) 28 days (MPa)	 18 27 41

Results and Discussion

Failure pattern

All the beam- columns specimens had a similar failure pattern as shown in Figure (2). Sever vertical cracks were detected at the connection of column with beam. And extended downward to the bottom of the beam .the depth of vertical crack depend mainly on the type of concrete and existing longitudinal opening. Table (10) shows the effect of study parameters for all tested frames. This table indicates that the value of deflections at first crack and at failure are significantly affected by types of concrete and exist of opening . However, the effect of opening on deflections of tested frame is obvious compared with solid frames.

The first crack of normal strength concrete solid frame was observed at blow 12, while the normal strength concrete frame with opening attained first crack at blow 7. This crack extended in length and increased in width with each blow until failure of specimen by vertical splitting crack . on the contrary, initiation of first crack was observed in the beam of reactive powder concrete solid specimen (R) at blow 18 . on the other hand, same specimen specification having opening recorded first crack at blow 14 . when reducing the steel fiber in the mix of reactive powder concrete , it was noticed that the specimen achieved first crack at blow 11. It was found that because of the fiber bridging function, the higher the fiber volume, the higher the first cracking load, which indicates the higher tendency of fiber-reinforced beams to withstand flexural stresses.

After first crack appearance , no obvious cracks were observed until failure of specimen . the first crack of high strength concrete solid frame was developed initially at blow 16 . on the contrary, opening in beam caused the first crack .

Appeared earlier in specimen HO1(having 70MPa concrete compressive strength with longitudinal opening) , this specimen recorded first crack at blow 12. When reducing the concrete compressive strength to 50 MPa, it was noticed that the first crack appeared at blow 9.

For beams with PVC pipe the crack widths of beams were wider. This clearly shows that the concrete core in the solid beams helps to improve the crack load. The improvement in cracking capacity can be conveniently related to the fiber bridging capacity of friction cracks

Figure (2) Frames Typical Failure Pattern

Table (10) Failure and Deflections Characteristics of Tested Frames

Specimens Configuration	Ultimate No. of Blows	No. of Blows at First Crack	Deflection at Failure (mm)	Deflection at First Crack (mm)
N	17	12	14.1	7.1
NO	12	7	17.8	8.8
R	32	18	11.1	6.3
RO1	25	14	14.8	7.6
RO2	21	11	16.3	8.6
H	28	16	13.1	6.9
HO1	24	12	15.3	8.2
HO2	20	9	16.9	9.4

Load carrying capacity

As indicated in Table (10), it may be seen that number of blows at failure decreased with existing longitudinal opening with constant hammer height and specimen geometry for example ,a solid specimen of normal strength concrete , a failure was occurred after 17 impact hammer, but failure of hollow normal strength concrete was took placed after 12 impact hammer. The solid section of normal strength concrete achieved failure with 14.1mm deflection, while hollow normal strength concrete recorded 17.8mm ultimate deflection at failure. Since the specimen carrying capacity is directly related to existing hollow, one can conclude that for reactive powder concrete frames, there exist, a certain decrease in frames capacity .

The solid frame (R) failed fewer than 32 blows according to existing hollow in frame; the frame capacity was decreased to 25 blows. Also, reducing this amount of steel fiber to 1% contributed to decrease the ultimate capacity to 21 blows.

The reactive powder concrete hollow specimen failed with 14.8mm deflection, while solid specimen failed with 11.1mm maximum deflection at failure .Accordingly, when reducing the steel fibers ratio to 1%, there is an increase in ultimate deflection of specimen to 16.3mm. Table () also shows that the specimen capacity is affected by exists hollow in high strength concrete frames, the frame capacity of solid high strength concrete frame is about 1.17 times the hollow frame with constant hammer height and specimens specifications reducing the concrete compressive strength from 70 MPa to 50 MPa decreased the capacity of frame about 20% . also, the specimen with compressive strength 70MPa and hollow recorded maximum deflection about 15.3mm , and specimen with 50MPa and hollow recorded 16.1mm maximum deflection , it is high than the reference solid specimen by about 16.8% and 29% respectively.

Number of blows versus deflection relationship

Figures (3) (4) and (5) show the relationship between the deflections and number of blows for three groups. After the first drop, the mid span deflections were linearly increased with increasing the number of blows , the linear zone of deflection curves finished with appearance of first crack . in the failure zone (second zone of curve), the deflection continue to increase with faster rate , in this stage the specimens deterioration appeared higher than the previous stage . For the frames with hollow beam, the peak load and its subsequent deflection are considerably higher than the frames with solid beam,this reflects a significant reduction in the flexural behavior between th e solidframes and the hollow frames, and reductions as higher steel fiber con tent is used,which implies the elastic stiffness of the beams increases when t he fiber content increases.

In most circumstances, the hollow beams became more flexible than the solid beam (i.e. more deflection at the same loading value), the stiffness of hollow section is lower than that of solid specimen. Additionally, all hollow section recorded deflection at first crack and at failure higher than reference solid specimen.

For comparison, the RPC and HSC specimens appear stiffer than normal strength concrete specimens . The recorded deflections is lower than that of normal strength concrete specimens.

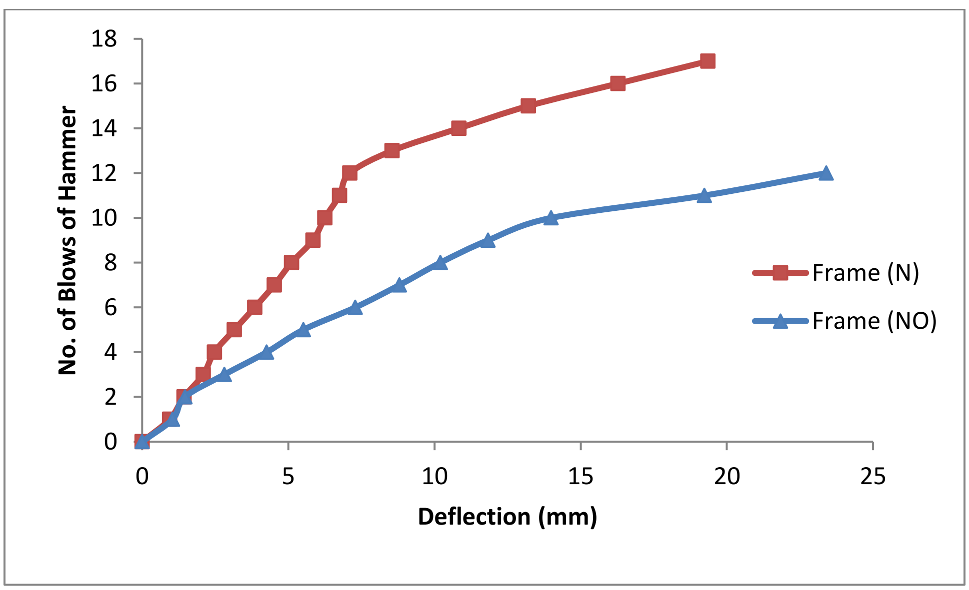

Figure (3) Number of Blows-deflection Relationships of Normal Strength Concrete Frames

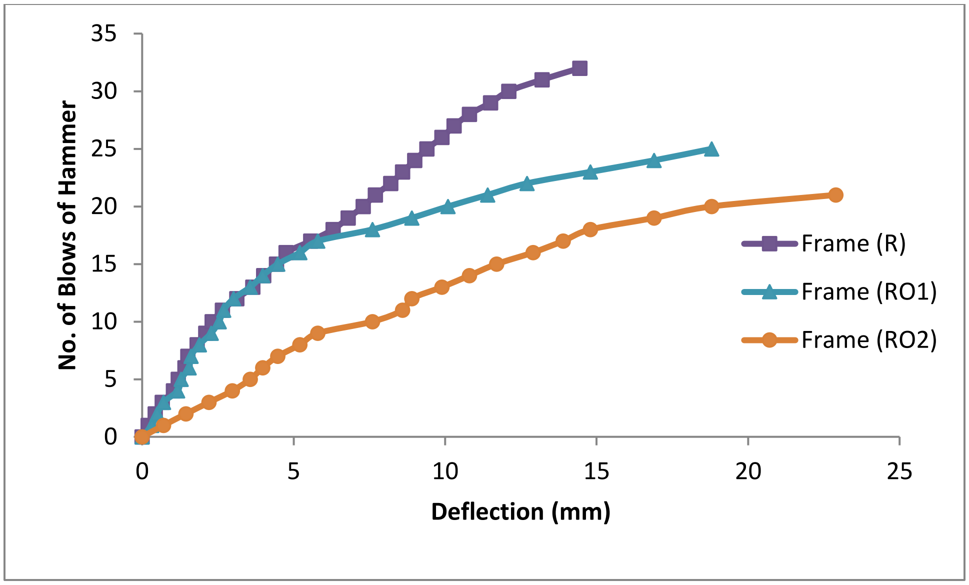

Figure (4) Number of Blows-deflection Relationships of Reactive Powder Concrete Frames

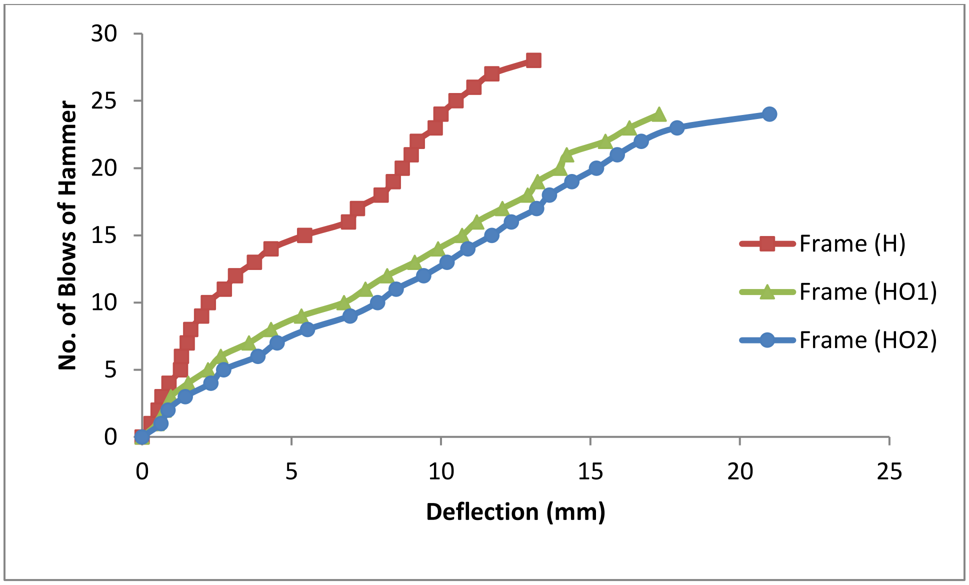

Figure (5) Number of Blows-deflection Relationships of High Strength Concrete Frames

Conclusions

1. The load carrying capacity of tested frames decreased in case of hollow beams.
2. Decreased load capacity of normal strength concrete frames due to the effect of a hollow beam is higher than that of reactive powder concrete and high-strength concrete frames.
3. The crack width in frames having hollow in its beam is wider than that of solid beam frames.
4. The first crack load decreased in frames having hollow in beam.
5. The deflection of frame increased due to the effect of hollow beam.
6. When increasing the steel fibers ratio and concrete compressive strength, a significant increase was observed in load carrying capacity and first crack load associated with a decrease in deflection of specimen

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