Flexural Behaviour of Hollow Square Beam

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ABSTRACT

This paper presents details of the studies carried out on flexural behaviour of Hollow Core RC Beams with different core depths. As concrete is weak in taking tension, steel reinforcements are provided in this zone. The concrete is below the neutral axis act as a stress transfer medium between the compression and tension zone. However, in RC beams strength of concrete lying in and near the neutral axis is not fully utilized. So this un-utilized concrete is removed by replacing with any light-weight material. The experimental program consists of casting and testing of RC beams of size 1000mm x150mm x 150mm with hollow core in different zone. To study the flexural behaviour, all beams are tested by three points loading. The performance of experimental Hollow Core Beams under flexure shows better when compared with theoretical hollow core beam.

Key words: Neutral Axis, Hollow Reinforced Concrete Beam, Light-Weight Material, Flexural behaviour, tension, compression.

1. INTRODUCTION

Nowadays research efforts are continuously looking for new, better and efficient construction material and method. In recent days the problem faced by the construction industry is acute shortage of raw materials. In case of simply supported reinforced concrete beam, the region below neutral axis is in tension and above neutral axis is in compression Concrete materials are still a dominant material for construction due to its advantages such as workability, low cost and fire resistance as well as its low maintenance cost. It is formed from a hardened mixture of cement, fine aggregate, coarse aggregate, water and some admixture. Massive exploration of the natural resources for producing concrete is affect to the environment condition and global warning. We have responsibility to reduce the effect of the application of concrete materials to environmental impact. According to the natural behaviour of the concrete, it is strong in compression and weak in tension. Our assumption to design the R.C beams is the contribution of tensile stress of the concrete is neglected. The flexural capacity (MR) of the beam is influenced only by compression stresses of the concrete and the tensile stress of the steel reinforcement. Efficient use the concrete materials can be done by replacing the concrete in and near the neutral axis.

1.2 Objective of the Study

The main objective of this study was to investigate the behavior of hollow concrete square beam.

- To find the load carrying capacity of hollow concrete beams.
- To study the flexural behaviour of hollow concrete beam in different hollow size.
- To determine the no shear zone with respect to neutral axis.

2. LITERATURE REVIEW

1. **Nibin Varghese, Anup Joy (May2016)** the experimental programmed is Flexural Behaviour of Reinforced Concrete Beam with Hollow Core at Various Depth. The beam size is 200 x 300 x 2000mm. Core at depth 120mm, 160mm, 200mm and 240mm from top. The zone below the neutral axis is divided into four zones and each zone is

replaced with voids created by placing circular PVC pipes of diameter 50mm in zigzag pattern. Considering M30 grade concrete and Fe500 steel with an effective cover of 25mm. Presence of hollow PVC pipe instead of concrete in the low stressed zone has caused an increase of 21% in strength of reinforced concrete beams. As the depth of hollow core increases the ultimate load decreases. Also by the increase of core depth deflection is increases. The optimum depth of hollow core is 160 mm from top below the neutral axis.

2. Soji Soman, Anima.P (Jul 2016) the studied is experimental and analytical investigation on partial replacement of concrete in the tension zone. Air voids were created using polyethylene balls and PVC pipes. Dimension of all the specimens are 150mm x 200mm x 1250mm and M25 grade of concrete is used. The neutral axis using plastic balls of 3.7cm and PVC pipe of 3.8cm diameter. Specimens are with partial replacement of 4%, 8% & 16% below neutral axis. It tests result that partial replacement up to a range of 8% can be done and beyond that replacement leads to a decrease in the load carrying capacity.

3. S.Manikandan, S.Dharmar, S.Robertravi (Mar 2015) studied experimental study on flexural behaviour of reinforced concrete hollow core sandwich beams. The experimental program consists of casting and testing of RC beams of size 1500mmx150mmx200mm with and without hollow core in circular 75mm diameter and square 70mm used tension zone. Concrete mix design for M-25 grade concrete. By introducing hollow core in tensile zone up to 25% on the beams, the behavior of beam is not affected with respect to flexural strength, deflection and strain measurement. At about 60 to 70% of the ultimate load, shear crack appeared near the supports and processed towards the compression zone. The flexural strength and yield deformation of RC beam with square hollow is less compared with RC solid and RC circular hollow beams.

4. Aswathy S Kumar, Anup Joy (Aug 2015) the experimental investigated is the partial replacement of concrete below neutral axis of beam. The specimens are of dimension 200mm x 300mm x 1000mm with an effective span of 800mm. A replaced beam with 4% and 8% of air voids created using polythene balls of 3.5cm diameter respectively. The M30 grade of concrete is used. The zone below the neutral axis is divided into three zones and the two zones adjacent to the neutral axis is replaced The load values and corresponding deflection of solid control beam and beam with replacement at the neutral axis up to a safe load of 220kN. The deflection solid beam is 30.73mm and beam with 4% and 8% air voids created polythene balls 35.16mm and 37.85mm.

3. METHODOLOGY

The methodology of the work consist of
1) Selection of grade of concrete; M20.
2) Mix design of M20 grade concrete.
3) Casting beam specimens of partially replaced beam specimens.
4) Conducting three point load test using 50T loading frame.
5) Study the effect and documentation

4. MATERIALS AND EXPERIMENTAL PROGRAM

The test program consists of casting and testing eight beams in the size 150 x 150 x 1000mm out of which two are beams with hollow core depth 34mm from near the compression zone, two are beams with hollow core at depth 75mm from centroid axis; two are beams with hollow core at depth 116mm from tension zone, two are beams with hollow core at depth 75mm and 116mm from centroid and tension zone. The beams designed as under reinforced section according to IS 456-2000.It is reinforced with 2-8Dia at bottom, 2- 8Dia at top and shear reinforcement using 6mm Dia stirrups @ 150mm c/c casting process is performed according to the basic standards and concrete treatment process is performed for 28 day. All the beam specimens were subjected to a single point bending test. Three main aspects were examined; flexural strength, center span deformation and strain behaviour of beam.

The depth of neutral axis is calculated by considering M20 grade concrete and Fe415 steel with an effective cover of 25mm. The section is designed as a balanced or under reinforced one, the steel also reaches yield as concrete fails. According to IS 456-2000

Area of steel Provided $=2*(\pi*8^2 /4)$

$=100.57$ mm2

Depth of Neutral axis

$Xu = 0.87*fy*Ast/0.36*fck*b$….(1)

$Xu = = \frac{0.87 \times 415 \times 100.571}{0.36 \times 20 \times 150}$

Xu = 34 mm

Limiting Value of the Depth of Neutral axis

Xumax = 0.48 *121 = 58 mm

(Xu < Xumax)

Hence section is under reinforced.

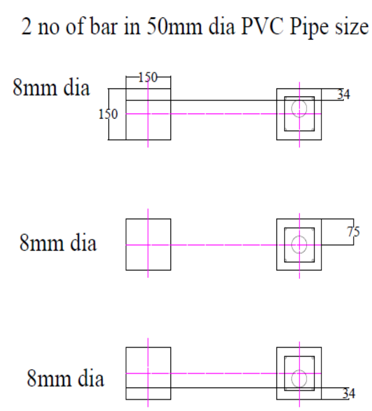

Fig: 1 Schematic crosses sectional view of beam specimens

The zone below the neutral axis is divided into three zones and each zone is replaced with voids created by placing circular PVC pipes of diameter 50mm.

4.1 Control Specimens

Concrete used for the beam specimens was normal concrete (M20) using Portland pozzolanic cement, fine aggregates, coarse aggregates and potable water. Portland pozzolana cement conforming to IS 1489 (part 1):1991 was used obtained. Locally available river sand was used as fine aggregate. They were tested as per IS 2386.crushed aggregate with maximum grain size 20mm and down was used as coarse aggregate and characterization tests were carried out as per IS 2386. Fresh potable water, which is free from acid and organic substance, was used for mixing concrete. The detail the properties of concrete are presented in Table 1.

Table 1: Characteristics of Concrete

Concrete Strength Parametric	Value(N/mm^2)
Compressive Strength	23.43
Spilt Tensile Strength	3.11

4.2 Reinforcing Steel

The longitudinal steel reinforcement was provided using Fe415 steel rods and shear stirrups were provided using Fe 415 grade steel rods. The proof stresses of the reinforcement are 0.2 %. Steel reinforcement tensile strength was determine according to IS code. Two tensile tests were made for each bar diameter longitudinal tensile reinforcement (8mm), longitudinal compression reinforcement (8mm) and stirrups bars (6mm).

4.3 Mix proposition and Mix Details

Concrete mix design was designed as per IS 10262:2009 [7] for M-20 grade concrete.

Table 2: M-20 Mix proposition

Cement (kg/m^3)	378
Water (lit/m^3)	197
Fine Aggregate(kg/m^3)	705.96
Coarse Aggregate(kg/m^3)	1164.5
Water Cement Ratio	0.52
Mix Ratio: 1:0.52:1.86:3.08	

4.4 Casting

The actual quantity of materials were weighed and kept ready before mixing. The moulds were kept ready on table vibrator with reinforcement placed in position with cover blocks. The aggregate are mixed by concrete mixer and filled in the mould by three layers and compacted well by table vibrator each time for 10 seconds. After 24 hours, the beam and companion specimens were removed from the moulds and placed in sack for curing.

Fig: 2 Casting of beam specimen

4.5 Test Procedure

The test specimens were (150mmx150mm size and 1m long) tested as was fitted in center of the beam specimens. A set of "demec" points was placed on the side of the specimen to allow measuring the strain versus load during the test. Demec points were centered on the centerline of the specimens.. The specimen is mounted on beam testing frame of 50 ton capacity. The beams are simply supported over a span 1000mm, and subjected to single loads placed symmetrically on the span. A Linear Variable Data Transformers (LVDT) was placed under the specimen at the center to measure the deflection versus load. Load was applied by a Hydraulic Power pack system attached with jacks. The strains are recorded demec point by using demec gauge. An Automatic Data Acquisition system with PC Interface is used to collect the data from load cell and LVDT during test. At the time of testing, the specimen was painted with white cement to facilitate the visual crack detection during testing process. Cracks were traced throughout the sides of the specimen and then marked with color markers. The first cracking load of each specimen was recorded. The load was increases until complete failure of the specimen was reached.

5. EXPERIMENTAL RESULTS AND DISCUSSION

5.1. Load Carrying Capacity

Ultimate strength of beams under three point tests was confirmed through recording the maximum load indicated by LVDT, but the cracking load was specified with developing the first crack on the concrete. It was found that the load carrying capacity is all partially replaced beams are more than that of solid control beam section. The result of the beam with replacement is below the neutral axis. The beams with hollow core depth 34mm from near the compression zone, beam is hollow core at depth 75mm from centroid axis, beam is hollow core at depth 116mm from tension zone and beam is hollow core at depth 75mm and 116mm from centroid and tension zone.

5.2 Loads vs. Deflection Graph

As the load increases the deflection of the beam begins. Load will be directly proportional to deflection. The load values and corresponding deflection beam with replacement at the neutral axis up to a safe load of 26 kN is given in Table 3 per the test result it is observed that all partially replaced beams.

Table 3: Load vs Deflection

Load (kN)	Deflection (mm)			
	Hollow Core Various Depth of Beam			
	35mm	75mm	116mm	75& 116mm
2	0.8	0.3	0.6	0.2
4	1	0.6	0.8	1.2
6	1.3	1.1	1	1.6
8	1.5	1.5	1.4	2.3
10	1.7	1.9	1.6	2.5
12	1.9	2	2	2.8

14	2	2.6	2.4	3
16	2.5	3.3	2.6	3.4
18	2.8	4	2.8	4
20	3.2	5.2	3.4	4.6
22	3.4	5.8	3.9	4.9
24	-	-	4.6	5.5
26	-	-	5.7	-

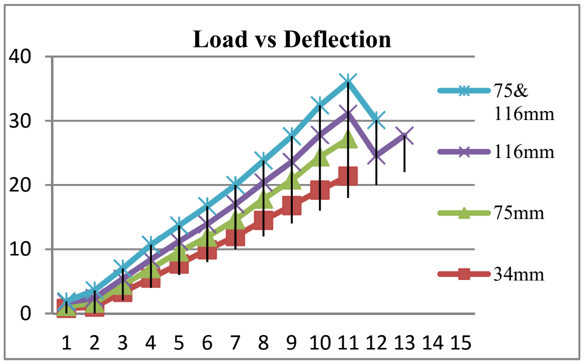

Fig:3 Load vs Deflection Graph

5.3 Ultimate Load vs. Depth of Hollow core

As the depth of hollow core increases the ultimate load decreases. Also, the increase of core depth deflection increases. It can be observed from Figure 5. So the optimum depth for providing hollow core is just below the neutral axis (here it is 116mm).

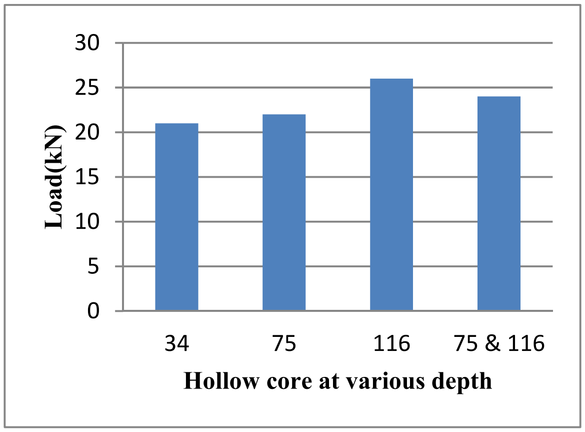

Fig: 4 Ultimate Load vs Depth of Hollow Core

5.4 Crack Pattern

Initial stages of loading, all beams were un-cracked beam. When the applied load reached to the rupture strength of the concrete on specimens, the concrete started to crack. The failure pattern in the all the tested beams was observed as a flexure-shear failure. The beams showed initial cracking in the constant bending moment region and then the cracks patterns in the vertical direction as the load was increased. At about 60 to 70% of the ultimate load, shear crack appeared near the supports and processed towards the compression zone. At the stage of ultimate failure, the shear cracks extended till the loading point and the crushing of concrete at that point of loading. All the beams showed the same pattern of failure.

Fig:5 Crack Pattern

5.5 Strain Behavior

Strain value of the beams in shown in fig. The strain distribution over the cross section is plotted for the initial and final strain. The beams are tension zone in get the highest strain value. The strain measure in demec gauge in two points the center of the beam along the length side.

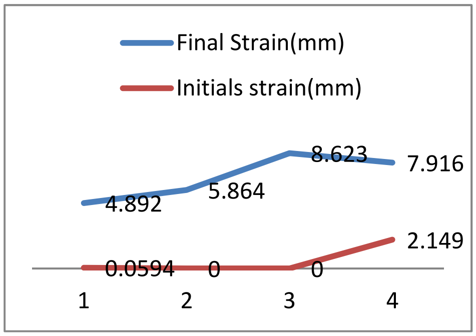

Fig:6 Strain Behaviour

6. THEORETICAL LOAD CALCULATION

Breadth=150mm, Depth=150mm, length =1000mm

Ast = 100.574 mm2 fck =20 N/mm2

fy =415 N/mm2 Deff = 121 mm

6.1 Depth of neutral axis

If , Xu = depth of neutral axis
=34 mm
Limiting value of (Xu/d) for Fe-415 grade steel is 0.48
Xumax = 0.48 *121 = 58 mm
(Xu < Xumax)
Hence section is under reinforced.

6.2 Moment of resistance

$$Mu = 0.87\times415\times100.571\times125\times[1-(415\times100.571)/(20\times150\times125)]$$

$$= 4.134 \text{ kN.m}$$

6.3 Load carrying capacity

Single point loads at l/2 distance from both ends
4.134 = Wu×1/2
8.27 = Wu
Wu = 8.27 kN at each point
The total load carrying capacity = 16.54 kN

6.4 Deflection of Beam

$$\Delta = Pl/AE \ldots(3)$$

Where, P- load applied (kN)
l – Length of the beam (mm)
E - Young's modulus (N/mm^2)
A – Area of concrete (mm^3)
$\Delta = (16.54 \times 10^{\wedge}6 \times 1000^3/150^2 \times 2 \times 10^{\wedge}5)$
= 3.67 mm

6.5 Concrete Saving

Total Volume beam V1= 1x0.15x0.15
= 0.0225 m3
Volume of pipe V2= π x 0.052 x 1
= 0.00196 m3
% of reduction in concrete = (V1 /V2)*100
= 11.48%
Since we have assumed a small beam, the percentage reduction is also small. When we assume this for a larger section, the percentage reduction will be larger.

6.6 Self-weight Reduction

Dead load shall include weight of all structural and architectural components which are permanent in nature. It includes self- weight of the structure. The unit weight of concrete is 25kN/m2. If we can reduce the volume of concrete then the self-weight of the beam also get reduced.

Weight of 1 m3 concrete = 2500 kg
Weight of beam, W1 = 56.25 kg
Weight of pipe, W2 = 5.73 kg
Weight of hollow beam = W1- W2 = 50.52 kg

7. CONCLUSIONS

Behaviour of reinforced concrete beams with region below the neutral axis with voids created using PVC pipes. Presence of voids instead of concrete in the low stressed zone has not caused significant reduction in strength of reinforced concrete beams. It has been observed that the replacement of concrete by voids in reinforced concrete beams does not require any extra labour or time. Economy and reduction of weight in beam depends on the percentage replacement of concrete. Replaced reinforced concrete beams can be used for sustainable and environment friendly construction as it saves concrete which reduces the emission of carbon dioxide during the production of cement. This work can be further investigated by using different diameter PVC pipe. Several other parameters can also be tested like impact resistance, abrasion, fatigue resistance, etc. The work can be extended in other mixes and also by introducing other weightless inert materials.

- It is found that the ultimate load carrying capacity of the beam is high in tensile zone of hollow core when compared to other zones of hollow core.
- First crack was observed at 80-90% of the ultimate load.
- Actual experimental results are match with the theoretical calculations as per IS code.
- The hollow core can be used as Duct.
- The strain values are optimum depth of hollow core is 116 mm from tension zone.

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