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Experimental and analytical study on flexural behaviour of reinforced concrete hollow beams

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ABSTRACT

This paper presents details of the studies carried out on flexural behavior of Hollow Core RC Beams with different core depths. As concrete is weak in 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 lightweight material. The experimental program consists of casting and testing of RC beams of size 100mm X200mmX2200mm with a hollow core in different diameter of PVC pipes like 12mm, 20mm, 30mm, 50mm from the top near Neutral axis. To study the flexural behavior, all beams are tested by two-point loading. The performance of Hollow Core Beams under flexure by using an analytical method (ANSYS) as well as Experimental method. It shows Ultimate cracking load is more for hollow sections when compared with Solid Beam.

Keywords— *Neutral axis, Hollow reinforced concrete beam, Light-weight material, Flexural behavior*

1. INTRODUCTION

Nowadays research effort are continuously looking for new, better and efficient construction material and method. In recent days the problem faced by the construction industry is an acute shortage of raw materials. In case of simply supported reinforced concrete beam, the region below the 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 affected by the environment condition and global warming. We have a 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, the contribution of tensile stress of the concrete is neglected in the design of R.C beams. 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.

The provision of longitudinal openings in beams to facilitate the passage of utility pipes and service ducts results not only in a more systematic layout of pipe sand ducts, but it also translates into substantial economic savings in the construction of a multi-storey building. To investigate the problem of openings in beams, the authors are initiated a research program in the early 1980s. Since then extensive research has been carried out giving a comprehensive coverage on both circular and large rectangular openings under flexural behavior of beam. In this paper, major findings relevant to the analysis and design of such beams under the most commonly encountered loading case of bending and shear are extracted and summarized. An attempt has been made to answer the frequently asked questions related to creating an opening in the beam and how to deal with openings. It has been shown that the design method for beams with large openings can be further simplified without sacrificing rationality and having an unreasonable additional cost.

Different types of services, including cooling and ventilation systems, Power and sewer systems, and technology and communication services, need to be effectively located and distributed within structures. The presence of openings in a beam is needed to accommodate several pipes and ducts related to various services. Steel beams with multiple web openings (cellular beams) are commonly used for this reason. In this study, the presence of openings in RC beams was considered to improve the design of RC structures. There are methods for increasing the effectiveness of concrete below and in neutral axis such as prestressing and converting the beam into other shapes such as Tee beams. But these methods cause a change in the geometry of the structure and increases the construction cost. An alternate method of replacing the zone below and in the neutral axis with inert weightless substances like polythene balls or PVC pipes will not greatly affect the strength and stress characteristics of the beam. Also, it will not affect the geometry and shape. In this paper, studies on partial replacement of concrete below the neutral axis by creating air voids using a different percentage of PVC pipes are discussed.

The presence of openings was assumed to provide a more efficient design by helping the stress concentrations around openings to be distributed to the entire beam length. Furthermore, the presence of openings in the central zone in addition to shear spans was assumed to shift the failure mode of the beam from brittle shear failure to ductile flexural failure. Attempts were made to prevent the brittle modes of shear failure (beam-type and frame-type), and the ductility of the beams by proper detailing: short stirrups in the chords, and posts and full-depth stirrups next to openings. RC beams with different opening geometries were tested within the scope of the program to establish the geometry which affects the strength and ductility of an RC beam to a lesser extent.

1.1 Objective of the study

The main objective of this study was to investigate the behavior of Solid and Hollow Reinforced Concrete beam.

(a) To find the load carrying capacity of Solid and hollow concrete beams.
(b) To find the load carrying capacity of Solid and hollow concrete beams.
(c) To conduct a study on introducing a new method by replacing some amount of the concrete below the neutral axis by creating air voids using PVC pipes without affecting the geometry of the section. It gives economical to the structure.

2. MATERIALS USED

This chapter presents the material properties are found by laboratory tests. All the materials were tested in the concrete laboratory as per relevant Indian Standard Codes.

2.1 Cement

In this work, Pozzolana Portland cement conforming to IS-1489-1991 has been utilized. The physical properties of this cement were obtained by conducting appropriate tests like standard consistency, initial setting time and final setting time as per IS-1489.

Table 1: Properties of cement

S no	Properties	Result
1	Specific gravity	3.13
2	Standard consistency	32 %
3	Initial setting time	32 minutes
4	Final setting time	320 minutes

2.2 Fine Aggregate

Locally available natural river sand with 2.36 maximum sizes has been used as fine aggregate, having specific gravity, fineness modulus and unit weight are given in table 2. It conforms to zone II as per IS-383 1970.

Table 2: Properties of Fine Aggregate

S no.	Properties	Result
1	Specific gravity	2.62
2	Bulk density	1.56 g/cc
3	Fineness modulus	2.78

2.3 Coarse Aggregate

The shape and particle size distribution of the aggregate is very important as it affects the packing and voids content. The sieve analysis of coarse aggregate conforms to the specifications of IS 383:1970 for graded aggregate. The physical properties of coarse aggregate are given in table 3.

Table 3: Properties of Coarse Aggregate

S no.	Properties	Result
1	Specific gravity	2.84
2	Bulk density	1.61 g/cc @loose state 1.69 g/cc @compacted state
3	Fineness modulus	7.55

3. CASTING OF CONCRETE CUBES AND CYLINDERS

The test moulds are kept ready before preparing the mix. Tighten the bolts of the moulds carefully because if bolts of the moulds are not kept tight the concrete slurry coming out of the mould when vibration takes place. Then moulds are cleaned and oiled on all contact surfaces of the moulds and place the moulds on a vibrating table. The concrete is filled into moulds in layers and then vibrated. The top surface of the concrete is struck off level with a trowel. The number and date of casting are put on the top surface of the cubes, cylinders and moulds.

3.1 Stipulation for proportioning

Grade designation =M25
Type of cement = PPC
Maximum nominal size of aggregate =20mm
Minimum cement content =300 kg/m^3
Maximum water cement ratio =0.5
Workability =100 (slump)
Exposure condition =Moderate
Maximum cement content =437 kg/m^3

3.2 Mix proportion

Cement = 437kg/m^3
Water = 197 kg/m^3
Fine aggregate = 661.07 kg
Coarse aggregate = 1169.17 kg

3.3 Mix ratio

Cement:FA: CA = 437:661.07: 1169.17
= **1:1.4:2.6**

4. Mechanical PROPERTIES OF CONCRETE

4.1 Test for Compressive strength of concrete cubes

Table 4: Test result for Cubes

No. of days	No. of cylinders	Average tensile strength (n/mm^2)
7TH DAY	3	2.31
14TH DAY	3	2.68
21ST DAY	3	2.89
28TH DAY	3	3.05

Table 5: Test result for Cylinders

No. of days	No. of cubes	Average compressive strength (n/mm^2)
7TH DAY	3	19.96
14TH DAY	3	23.21
21ST DAY	3	27.92
28TH DAY	3	31.89

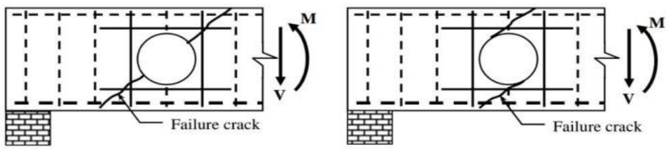
5. BEAMS WITH OPENINGS

5.1 Introduction

In the construction of modern buildings, a network of pipes and ducts is necessary to accommodate essential services like water supply, sewage, air- conditioning, electricity, telephone, and computer network. Usually, these pipes and ducts are placed underneath the beam soffit and, for aesthetic reasons, are covered by a suspended ceiling, thus creating a dead space. Passing these ducts through transverse openings in the floor beams leads to a reduction in the dead space and results in a more compact design. For small buildings, the savings thus achieved may not be significant, but for multi-storey buildings, any saving in story height multiplied by the number of stories can represent a substantial saving in total height, length of air-conditioning and electrical ducts, plumbing risers, walls and partition surfaces, and overall load on the foundation. It is obvious that the inclusion of openings in beams alters the simple beam behaviour to a more complex one. Due to abrupt changes in the sectional configuration, opening corners are subject to high stress concentration that may lead to cracking unacceptable from aesthetic and durability viewpoints. The reduced stiffness of the beam may also give rise to excessive deflection under service load and result in a considerable redistribution of internal forces and moments in a continuous beam. Unless special reinforcement is provided in sufficient quantity with proper detailing, the strength and serviceability of such a beam may be seriously affected. However, circular and rectangular openings are the most common ones in practice. When the size of the opening is concerned, many researchers use the terms small and large without any definition or clear-cut demarcation line. From a survey of available literature, when the opening is small enough to maintain the beam-type behaviour or, in other words, if the usual beam theory applies, then the opening may be termed as a small opening. In contrast, large openings are those that prevent beam-type behaviour to develop. Thus, beams with small and large openings need separate treatments in design. In this paper, beams containing small and large openings are treated separately. Based on the research work reported in the literature, an attempt has been made to give a comprehensive treatment of openings under bending and shear, addressing the major issues concerning structural design. It has been shown that the design of beams with large openings can be further simplified by maintaining its rationality and upholding construction economy.

5.2 Beams with Small Openings

Openings that are circular, square, or nearly square in shape may be considered as small openings provided that the depth (or diameter) of the opening is in a realistic proportion to the beam size, say, about less than 40% of the overall beam depth. In such a case, beam action may be assumed to prevail. Therefore, analysis and design of a beam with small openings may follow a similar course of action as that of a solid beam. The provision of openings, however, produces discontinuities or disturbances in the normal flow of stresses, thus leading to stress concentration and early cracking around the opening region. Similar to any discontinuity, special reinforcement, enclosing the opening close to its periphery, should, therefore, be provided in sufficient quantity to control crack widths and prevent possible premature failure of the beam.



(a) Beam-type failure (b) Frame-type failure

5.3 Pure Bending

In the case of pure bending, placement of an opening completely within the tension zone does not change the load-carrying mechanism of the beam because concrete there would have cracked anyway in flexure at ultimate. Mansur and Tan, (1999) have illustrated this through worked out examples, supported by test evidence. Thus, the ultimate moment capacity a beam is not affected by the presence of an opening as long as the minimum depth of the compression chord, h_c, is greater than or equal to the depth of ultimate compressive stress block, that is, when in which A_s= area of tensile reinforcement; f_y = yield strength of tensile reinforcement; c f′ = cylinder compressive strength of concrete; b = width of the compression zone. However, due to the reduced moment of inertia at a section through the opening, cracks will initiate at an earlier stage of loading. In spite of this, the effects on maximum crack widths and deflection under service load have been found to be only marginal, and may safely be disregarded in the design

.

5.4 Combined Bending and Shear

In a beam, shear is always associated with bending moment, except for the section at inflexion point. The first type is typical of the failure commonly observed in solid beams except that the failure plane passes through the centre of the opening (Fig. 1a). In the second type, the formation of two independent diagonal cracks, one in each member bridging the two solid beam segments failure. Labelled respectively as a beam-type failure and frame-type failure. Similar to the traditional shear design approach, it may be assumed in both the cases that the nominal shear resistance, $V_n$is provided partly by the concrete, V_c, and partly by the shear reinforcement crossing the failure plane, V_s. Design for bending may be carried out independently in the usual manner and combined with shear design solutions.

5.5 Beam-Type Failure

In designing for beam-type failure, a 45-degree inclined failure plane, similar to a solid beam may be assumed, the plane being traversed through the centre of the opening.

5.6 Frame-Type Failure

Frame-type failure occurs due to the formation of two independent diagonal cracks, one on each of the chord members above and below the opening. It appears that each member behaves independently similar to the members in framed structures.

6. MODELING IN ANSYS

In ANSYS modelling and analysis can be done in two ways either with MECHANICAL APDL or with ANSYS WORKBENCH. In a comparison of both these tools APDL is not user-friendly, which includes a lot of detailing and is time-consuming. Error identification is a bit difficult in APDL but in the case of WORKBENCH, it is a lot easier. Modelling in work bench is the quite advanced and all the tools are predefined having an easy user interface. In a comparison of these two tools WORKBENCH is preferable because the geometry required for this research is quite complicated to model and involves minute detailing. One should incorporate the fillet edged stirrups in the concrete block which is very difficult in APDL. Further analyses are done in the division of mechanical. All the material properties are available (predefined) in the engineering data table but even though manually the properties are assigned because some of the predefined properties are not acceptable in this design analysis. The material properties for concrete are taken as per standards and for Fe-415 steel, the properties are taken from the code IS-1786:2008.

6.1 Meshing in ANSYS

Meshing plays a vital role in FEM. Meshing is nothing but dividing a specific object or element into a number of smaller parts for analysis. Basically in ANSYS meshing can be done in two ways i.e., either automatically nothing but predefined which is default or user-defined. In automatic meshing software operates the meshing in which the size of the element, relevance factor, curvature and proximity etc., are the default. In the case of user-defined meshing, user can define all the parameters according to the required output and the method of meshing can also be assigned based on the requirement.

7. BOND BETWEEN CONCRETE AND STEEL

Bonding plays a key role in load distribution and action of certain portion in load transferring to substructure. Improper bonding causes uneven load distribution which leads to failure of the beam. In this case, a number of trails has been done with different bond types. The bonding for all the members that are between concrete to concrete, steel to steel and concrete to steel is given as bonded. Bonding contact is the type of connection which is available in ANSYS. The bond configuration is that it won't allow sliding of the composites materials and no separation. Simply it acts like glue. Whereas other bond configurations like frictional, non-frictional and rough bond require Elgen solver in addition to ANSYS.

8. ANSYS RESULT AND DISCUSSION

Table 6. Ultimate Crack Load (ANSYS)

Beam designation	Size of pipes(mm)	Ultimate crack load (kN)
Control Beam	Nil	61
HW1	12	58
HW2	20	49
HW3	30	41
HW4	50	34

8.1 Ultimate Deflection for Solid Beam and Hollow Beam

- The beam is originally straight, and any taper is slight
- The beam experiences only linear elastic deformation
- The beam is slender (length to height ratio is greater than 10)
- Only small deflections are considered (max deflection less than 1/10 the span).

Table 7. Maximum Deflection (ANSYS)

Load (kN)	Deflection (mm)	Beams
61	18.92	CB
58	13.76	HW1
49	12.83	HW2
41	11.68	HW3
34	10.23	HW4

9. EXPERIMENTAL ANALYSIS

9.1 Concrete saving and self-weight reduction

- In construction industries, huge wastage in concrete occurs.
- Material cost is the main component in the total cost of the product varying from 25 to 70%.
- It should be made sure that the right quantities of materials are consumed with less wastage.
- This issue can be minimized by avoiding concrete in the neutral axis without bearing significant strength.
- By calculating the volume, the percentage reduction in concrete volume is 9.8%
- If we can reduce the volume of concrete then the self-weight of the beam also get reduced, the reduction of weight (weight of concrete) is 10.79 kg of the total weight of the beam.
- Since we have assumed a small beam, the self-weight reduction is also small. When we assume this for a larger section, the weight reduction will be larger.

9.2 Mode of failure

- Both control beam and hollow beams failed in flexure zone.
- After the first crack load, the reinforcement started yielding and number of cracks have formed in the flexure zone and extended towards the point loads with increment in loads.
- In control beams, less number of cracks occurs. No shear cracks have formed because the beam is designed safely in shear.
- Shear cracks were found in a hollow beam (30mm and 50mm) due to less number of reinforcements.
- In beams, the initial crack had widened due to increase loads and extended towards the point loads. No minor cracks are formed.
- A number of cracks in hollow beams is more than that of control beam.

Table 8: Maximum Deflection (EXP)

Beam Designation	Initial Crack Load(kN)	Ultimate Crack Load (kN)
Control Beam	34	69
HW(12mm)	30	64
H(20mm)	24	58
HW(30mm)	23	51
HW(50mm)	14	38

Table 9. Maximum Deflection (EXP)

Load (kN)	Mid Deflection (mm)	Beams designation
69	26.91	CB
64	17.63	HW(12mm)
58	16.31	HW(20mm)
51	12.32	HW(30mm)
38	16.95	HW(50mm)

Table 10. Maximum Deflection (EXP)

Load (kN)	1/3rd Deflection (mm)	Beams designation
69	7.77	CB
64	3.1	HW(12mm)
58	2.9	HW(20mm)
51	1.9	HW(30mm)
38	2.81	HW(50mm)

10. CONCLUSION

Based on the Analytical study conducted on solid and hollow RC beams and test result obtained, the following conclusions were drowned:

(a) Flexural behaviour of reinforced concrete beams with a hollow core is similar to that of conventional reinforced concrete beams.
(b) Presence of hollow PVC pipe instead of concrete in the low stressed zone has caused an increase of 21percentage in the strength of reinforced concrete beams.
(c) The optimum depth of the hollow core is 75 mm from the top, that is just below the neutral axis.
(d) It has been observed that the replacement of concrete by a hollow pipe in reinforced concrete beams does not require any extra labour or time.
(e) Economy and reduction of weight in beams depend on the percentage replacement of concrete. The concrete saving will be more effective as the length and depth of the beam increases.
(f) Hollow reinforced concrete beams can be used for sustainable and environment-friendly construction work as it saves concrete which reduces the emission of carbon dioxide during the production of cement.

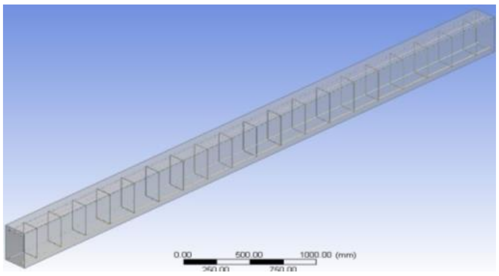


Fig 1: ANSYS Beam Model

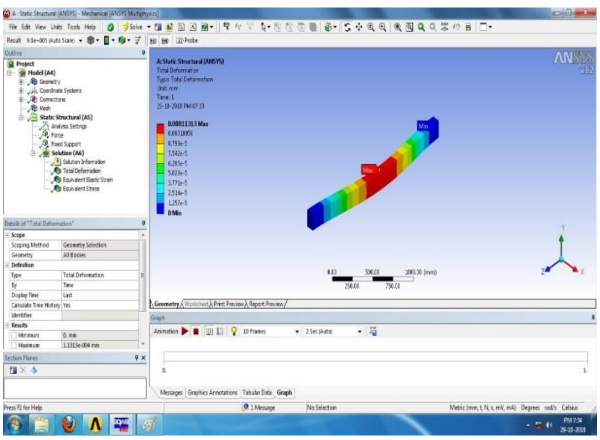


Fig. 2: Deflection profile for 12mm PVC Pipe

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