Effect of Reinforced Concrete Beam with Hollow Neutral Axis

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Abstract— The objective of the investigation is to develop a Reinforced Concrete Beam with hollow neutral axis which may replace the position of reinforced concrete beam in near future. 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 material incorporated in the concrete beam is PVC pipe, which occupy the concrete volume in the neutral axis, where the compression and tension is zero thereby making the beam hollow. The properties of PVC is not been used since it is used only as a filler material in concrete. Specimens of solid RC beams and Hollow RC beams are cast and tested for four point flexure. Then the results are compared and the effects are studied. The self weight of this developed RC beams are expected to be reduced with the decrease in concrete volume hence proving the beams to be economical. Experimental validation is carried out analytically with ANSYS 12.1 software.

***Key words*:** Neutral Axis, Hollow Reinforced Concrete Beam, Light-Weight Material, Selfweight

I. INTRODUCTION

In this paper an attempt is being made to reduce weight and cost of the reinforced concrete structures by replacing the concrete in and near the neutral axis. 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 placing a PVC pipe instead, hence making the beam hollow at the neutral axis. This is an alternative to reduce the use of concrete. The concrete just above neutral axis is less stressed where as the concrete below the neutral axis serves as a shear transmitting media. The bond between PVC pipe and concrete layers at the pipe concrete interface should essentially be very good. It should be ensured that no slip will occur between the two layers. Experimental work is carried on the reinforced concrete beams with hollow neutral axis, with the view that the stresses in the beams are maximum at the top and bottom and zero at the neutral axis. So a cheap and light material can be used near the neutral zone. Sustainability can be achieved by replacing the partially used concrete. By saving concrete, we can save cement, which reduces the green house gases emissions. So it is considered as environment friendly. Behaviour of PVC pipe infilled reinforced concrete beams under 4 point flexure is find out experimentally and the results are compared with the conventional reinforced concrete beam and it is observed that saving of concrete is achieved. Experimental validation is carried out using ANSYS 12.

II. SIGNIFICANCE OF THE WORK

A. *Scope of the Project:*

From the studied literature reviews, it is understood that in RC beams, less stressed concrete in & near neutral axis can be replaced by some light weight material. Several types of infilled materials like Brick, Expanded polystyrene sheet, LSRC (Lightweight Sandwich Reinforced Concrete) sections, Teracotta hollow blocks, etc were already experimented which shows good result. But it was observed that expected reduction in self-weight & economy was not achieved and it was labour intensive too. To overcome this drawback an attempt has been made to investigate the effects of RC beam with hollow N.A. using PVC pipe.

B. *Objective of the Project:*

The objective is to reduce weight and cost of the reinforced concrete structures by replacing the concrete in and near the neutral axis. This is an alternative to reduce the use of concrete. Sustainability can be achieved by replacing the partially used concrete.

C. *Methodology:*

The methodology consist of

(1) Selecting the concrete grade (here M25)
(2) Design the mix for M25 concrete
(3) Using this mix solid RC beams and RC beam with hollow neutral axis were cast.
(4) Effects of these beams were studied by conducting 4-point flexural test.
(5) Experimental validation is carried out through ANSYS 12.1 software.

III. MATERIAL TESTS

TESTS	MATERIALS	EQUIPMENT USED	VALUES OBTAINED
Specific Gravity	Ramco Cement (PPC)	Le Chatelier Flask	2.9
Specific Gravity	Fine Aggregate	Pyconometer	2.63
Specific Gravity	Coarse Aggregate	Wire Basket	2.85
Water Absorption	Fine Aggregate	Vessel	1.42%
Water Absorption	Coarse Aggregate	Vessel	0.35%

Workability	M25 Concrete	Slump Cone Apparatus	75mm

IV. MIX DESIGN

Cement (Kg/m³)	394
Sand (Kg/m³)- FA	812.71
Aggregate (Kg/m³)-CA	1076.4
Water (Lit/m³)	177.3
Ratio	1: 2.06: 2.73
Water-cement ratio	0.45

Table 1: Mix Proportion of M25 ($1m^3$ of concrete)

V. EXPERIMENTAL INVESTIGATION

A. Experimental Specimen:

Nine specimens were cast and tested; three of these experimental specimens were just singly reinforced concrete beams and used as reference specimens, three specimens were singly reinforced concrete beams that were made hollow in their neutral axis using PVC pipe of 40mm ϕ and the remaining three specimens were singly reinforced concrete beams that were made hollow in their neutral axis using PVC pipe of 50mm ϕ.

The construction of reinforced concrete beams with hollow neutral axis requires special preparation of the blocks to allow the placement of PVC pipe in the neutral axis. All the specimens had dimensions of 150x230x980mm with an effective span of 800mm. The reinforcement for the control beam specimens was 2 nos. of 10mmϕ at tension zone and 2 hanger bars of 10mmϕ with a cross-sectional area of $314mm^2$. Similarly, the concrete beam with hollow neutral axis, which were reinforced, had exactly the same amount of reinforcement i.e 2 nos. of 10mmϕ at tension zone and 2 hanger bars of 10mmϕ with a cross-sectional area of $314mm^2$. The shear reinforcement provided for both control beam specimens and for the hollow beams are of 6mmϕ stirrups at 125mm spacing. The designations of the control beam specimens are appended with (CB), while those of the hollow beams are appended with (HB). All the beams were subjected to 4-point flexural test in UTM.

The depth of neutral axis is calculated by considering M25 grade concrete and Fe415 steel with an effective cover of 20mm. Beams are assumed to fail when the concrete reaches failure compression strain. But in all cases of design, the steel need not have reached its yield point at the same time, unless it is so designed. If the section is designed as a balanced or under-reinforced one, the steel also reaches yield as concrete fails. But in over-reinforced beams, the steel stress at failure will be below its yield strength. As equilibrium of forces in bending requires that at all times tension be equal to compression, we have

Total tension $T = f_{st}A_{st}$

Total compression $c = 0.36 f_{ck} b(x_u)$

Where f_{st}= actual tension in steel corresponding to the strain in steel. Equating the two expressions, we obtain

$$f_{st}A_{st} = 0.36 f_{ck} b(x_u)$$

i.e. $$x_u = \frac{f_{st}A_{st}}{0.36 f_{ck} b} \quad (1.1)$$

For under-reinforced beams, steel first reaches yield stress of $0.87f_y$. Substituting its value and dividing both sides by the effective depth d (IS 456 Annexure G), we get

$$\frac{x_u}{d} = \frac{0.87 f_y A_{st}}{0.36 f_{ck} bd}$$

$$x_u = \frac{0.87x415x314}{0.36x25x150}$$

$$x_u = 83.97mm$$

The PVC pipe of 40mmϕ and 50mmϕ is placed 63mm from the top concrete surface which covers the neutral axis depth at 83mm (from the top surface). The length of the pipe inside the beam neutral axis is 620mm and an anchorage length of 180mm on each side is provided for the transfer of load.

Fig. 1: Reinforcement cage of control beam specimen

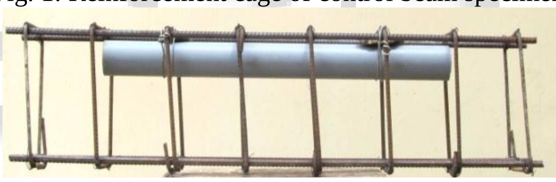

Fig. 2: Reinforcement cage of beam with hollow neutral axis

Fig. 3: Reinforcement cage inserted inside the formwork

Fig. 4: Casting of hollow beam

Fig. 5: Casted beam specimens

B. Test Procedure:

The specimens were tested using a 1000 kN Universal Testing Machine; a dial gauge having a travel of 25 mm was used to record the vertical deflection at the bottom of the mid-span of the beam. The behaviour of the beams was keenly observed from beginning to failure. The appearance of the first crack, the development and the propagation of cracks due to the increase of load were also recorded. The loading was continued after the initial cracking load and was stopped when the beam was just on the verge of collapse.

The universal testing machine consists of a set up for testing the three point bending set up facilities. For performing four point flexural test to achieve pure bending an additional fixture was made using an iron block of loading span 266mm and load is applied manually using hydraulic cylinder. The values of load applied and deflection are noted directly and further the plot of load vs deflection is performed which is taken as the output. The load in kN is applied with uniformly increasing the value of the load and the deflection under the different applied loads is noted down. The applied load increased up to the breaking point or till the failure of the material.

Fig. 6: UTM test setup for 4-point flexure

VI. EXPERIMENTAL RESULTS

A. Load Carrying Capacity:

Ultimate strength of beams under four point flexural test was confirmed through recording the maximum load indicated by load dial, but the cracking load was specified with developing the first crack on the concrete. It was found that there is not much difference in the load carrying capacity of solid control beam section and that of beam section with hollow neutral axis. However the hollow section decrease in load capacity and increase in corresponding deflection for the same properties when compared with solid control beams. The comparison of the results between the solid control beam and beam with hollow neutral axis is shown in fig7&8..The solid control beam are designated as CB1, CB2, CB3. Beam section with hollow neutral axis with 40mmϕ pipe is designated as HW1, HW2, HW3 and that with 50mmϕ pipe is HW4, HW5, HW6.

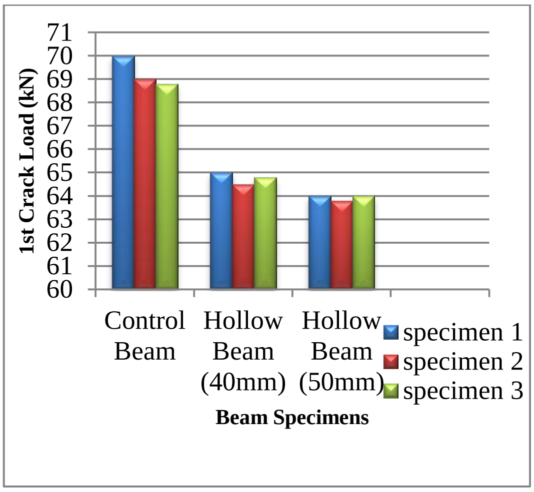

Fig. 7: First Crack Load of beam Specimens

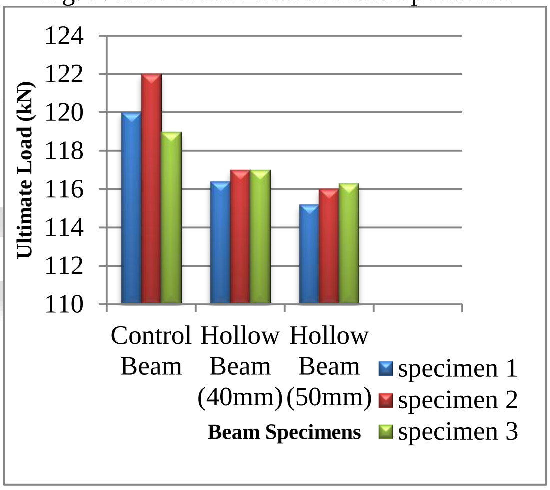

Fig. 8: Ultimate Crack Load of beam

B. Load Vs Deflection Graph:

Due to increase in the load, deflection of the beams starts, up to certain level the load vs. deflection graph will be linear that is load will be directly proportional to deflection. Due to further increase in the load the load value will not be proportional to deflection, since the deflection values goes on increasing as the strength of the material goes on increasing material loses elasticity and undergoes plastic deformation. Hence by this graph we can predict the strength of the material by knowing the deflection at the respective load values. The load values and corresponding deflection of solid control beam and beam with hollow neutral axis is given in table 2.

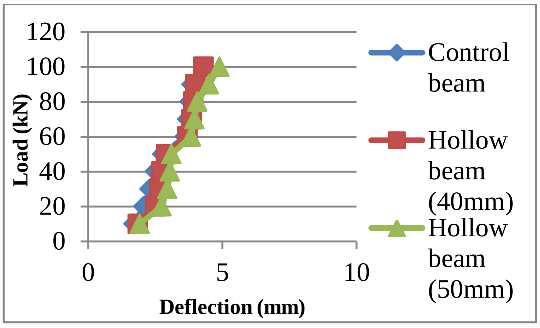

Fig. 9: Load Vs Deflection Graph of beam specimens

LOAD (kN)	DEFLECTION (mm)		
	CB	HB (40mmϕ)	HB (50mmϕ)
10	1.70	1.85	1.92
20	2.07	2.50	2.73
30	2.29	2.65	2.95
40	2.50	2.73	3.05
50	2.77	2.90	3.10
60	3.60	3.70	3.83
70	3.70	3.85	3.96
80	3.79	3.92	4.07
90	3.85	4.00	4.50
100	4.28	4.30	4.90

Table 2: Load and Deflection Values of Beam specimens

C. Crack Pattern:

It is clear that in all beams the hollow beams cracked at lower loads than the solid ones. The difference in loads are small which is about 5kN only. This indicates that the concrete core in the solid beams participates in increasing the cracking load to some extend only i.e. the concrete in neutral axis, do not play a significant role in increasing cracking load. This is because the concrete in neutral axis do not experience any stress. The crack patterns of the solid and hollow beam sections are as shown in fig 10.

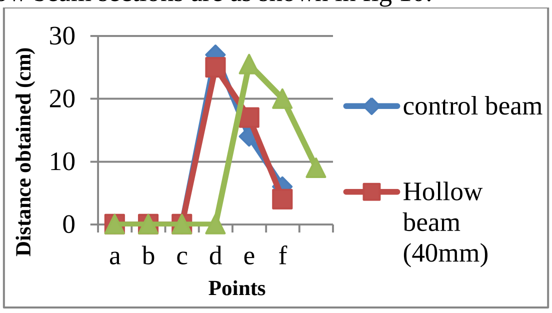

Fig. 10: Crack Pattern of beam specimens

D. Failure Mode:

The failure mode noticed from the beams tested represents Shear Tension Failure. Shear in concrete can cause inclined cracking across a member. It is also possible that shear stresses may cause a sliding type of failure along a well-defined plane This type of failure is similar to diagonal tension failure but applies to short beams. The shear crack propagates through the beam but doesn't cause failure of the beam on its own. Secondary cracks travel along the longitudinal reinforcement from the last flexural crack and can cause a loss of bond between the reinforcement and the concrete or anchorage failure. When the beam reaches a critical point it will fail as a result of splitting of the compression concrete.

Fig. 11: Shear Tension Failure of tested beam specimens

VII. ANALYTICAL INVESTIGATION

ANSYS 12.1 (2010) was employed to simulate the flexural and shear behaviour of the beam by finite element method. ANSYS is a general-purpose finite element analysis (FEA) software package. Finite element analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all, creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand.

A. Calibration Model:

An RCC beam with two point loading case was taken for analysis as shown in the Fig. 12, with: size of the reinforced concrete beam – 150mm × 230 mm; size of loading and support steel plates- 25mm x 150mm, 5 mm thick; steel reinforcement details: 2 rebars of 10 mm diameter at bottom and top each, stirrups of 6 mm diameter at 125 mm c/c.

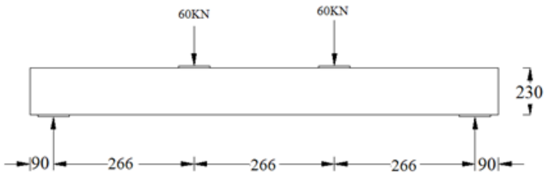

Fig. 12: Beam Model

B. Modelling Procedure:

1) Reinforcement Modelling:

There are three techniques to model steel reinforcement in finite element models for reinforced concrete: the discrete model, the embedded model, and the smeared model. The smeared model assumes that reinforcement is uniformly spread throughout the concrete elements in a defined region of the FE mesh. This approach is used for large-scale models where the reinforcement does not significantly contribute to the overall response of the structure. Here, in this problem, the smeared model was used to model reinforcement.

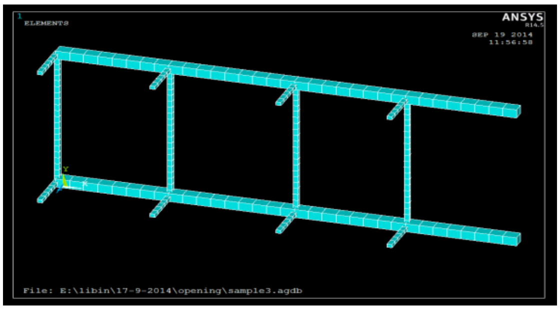

Fig. 13: Reinforcement modelled in Hollow beam (1/4 portion)

2) *Element Types:*

MATERIAL	ANSYS ELEMENT
Concrete	SOLID 65
Steel Reinforcement	LINK 8
PVC Pipe	SHELL 181
Steel Plates (At Support & Loading)	SOLID 45

3) *Real Constants:*

ANSYS ELEMENT	REAL CONSTANT
SOLID 45	Nil
SOLID 65	Set 1
LINK 8	Set 2, Set 3

[1] S e t 1: solid 65 all values given zero.
[2] S e t 2. Area 10 mm bar 78.5 m^2.
[3] S e t 3. Area 6mm stirrup 28.26 m^2.

4) *Material Properties:*

MATERIAL	YOUNG'S MODULUS (N/mm^2)	POISSON'S RATIO
M25 Concrete	E_c = 25000	V = 0.15
Steel (Fe 415)	$E_s = 2x10^5$	V = 0.30
PVC Pipe	E_p = 3300	V = 0.40

C. *Meshing:*

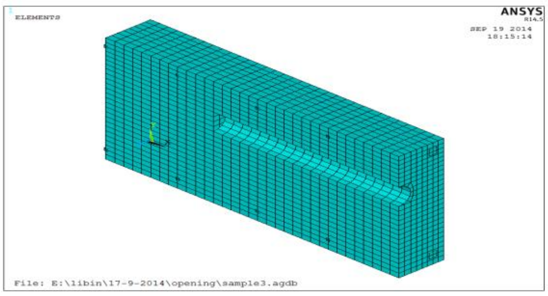

Fig. 14: Meshing diagram of Hollow Beam (Isometric view of 1/4 portion)

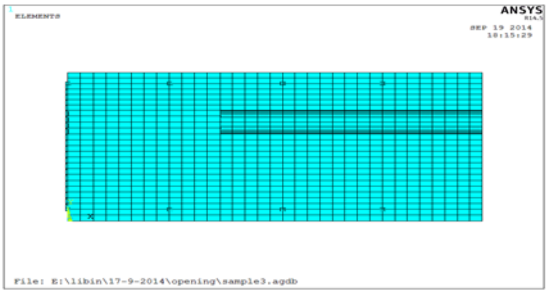

Fig. 15: Meshing diagram of Hollow Beam (Front view of 1/4 portion)

D. *Loads And Boundary Conditions:*

Displacement boundary conditions are needed to constrain the model to get a unique solution. The support was modelled in such a way that a roller was created. A single line of nodes on the plate were given constraint in the *UY*- and *UZ* directions, applied as constant values of 0. By doing this, the beam will be allowed to rotate at the support. The force, *P*, applied at the steel plate is applied across the entire centre line of the plate.

E. *Analysis:*

The finite element model for this analysis is a simple beam under transverse loading. For the purposes of this model, the static analysis type is utilized.

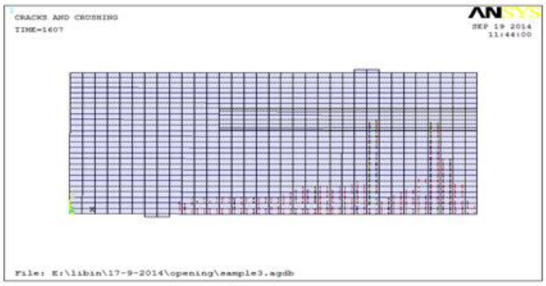

Fig. 16: First Crack of Hollow Beam at 60kN

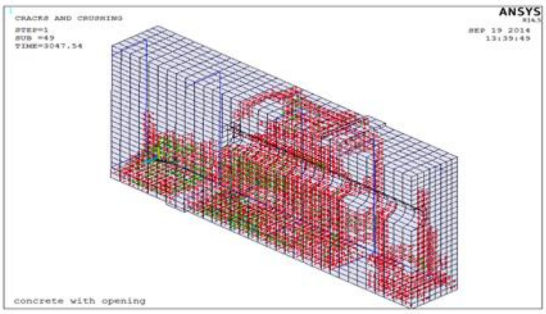

Fig. 17: Crack at Ultimate Load in Hollow Beam at 116kN

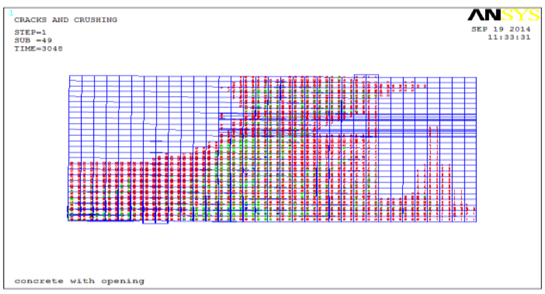

Fig 18: Crack pattern at Ultimate Load in Hollow Beam

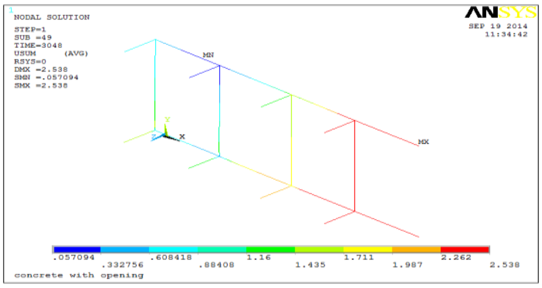

Fig. 19: Deflection at Rebars in Hollow Beam

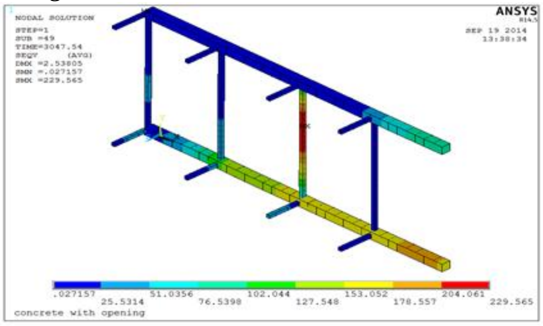

Fig 20: Von-Misses Stress of Rebars at Ultimate Load in Hollow Beam

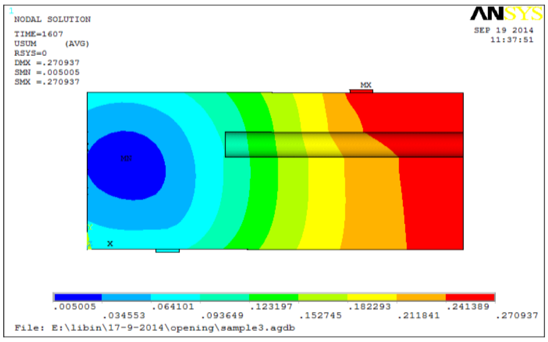

Fig. 21: Deflection Diagram (at First Crack in Hollow Beam)

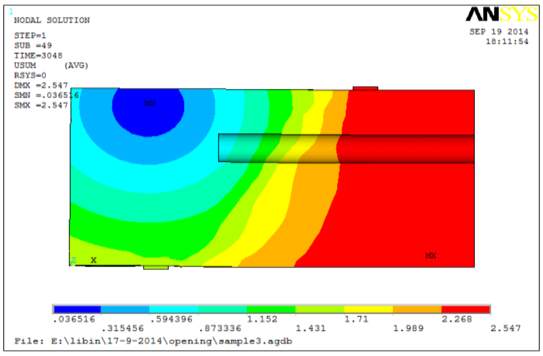

Fig. 22: Deflection Diagram (at Ultimate Load in Hollow Beam)

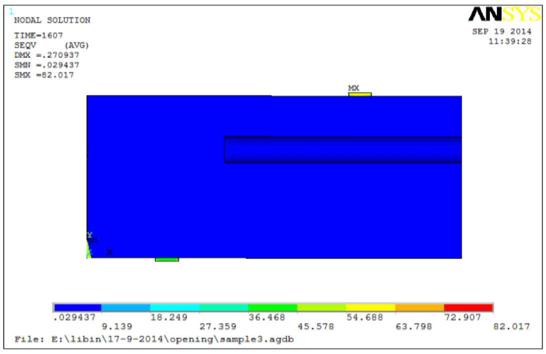

Fig 23: Von-Misses Stress at First Crack Hollow Beam

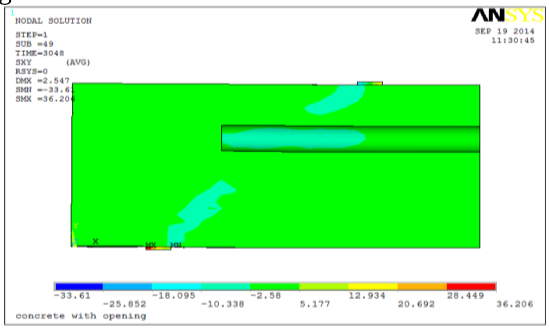

Fig. 24: XY Shear Stress at Ultimate Load in in Hollow Beam

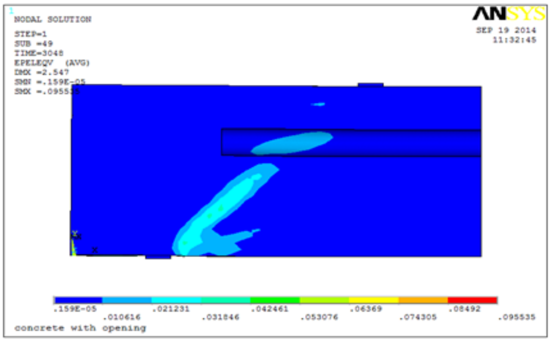

Fig. 25: Von-Misses elastic Strain at Ultimate load in hollow beam

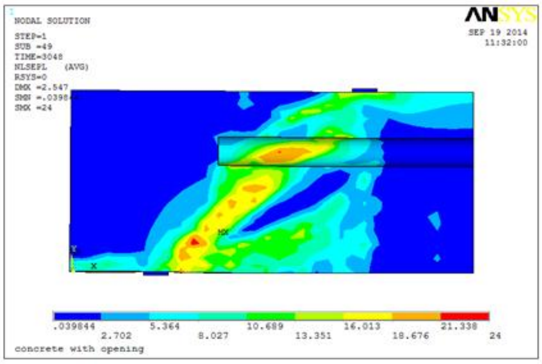

Fig. 26: Plastic Equivalent Stress at ultimate load in hollow beam

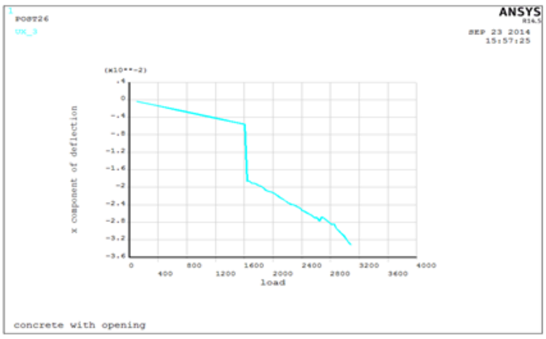

Fig. 27: Load Vs x component of Deflection

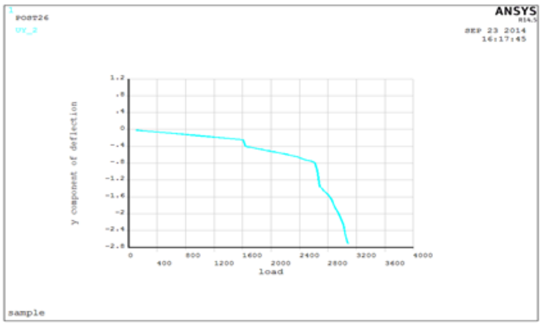

Fig. 28: Load Vs y component of Deflection

Analytical investigation result shows that more deflection occurs in the mid-span of the hollow beam. From the crack pattern it was observed that first crack occurs at 60kN and ultimate crack occurs at 116kN and propogation of shear cracks as in experiment was developed. First crack was noticed in red colour, second crack in green and third crack in blue. Deflection at rebars was also located near the mid-span. Von-misses stress of rebars at ultimate load was observed nearer to the pipe end.

VIII. Evaluation & Discussion

A. Stress-Strain Relationship:

Fig 29 shows the stress-strain curve for control beam and reinforced concrete hollow beam tested under four point flexure.

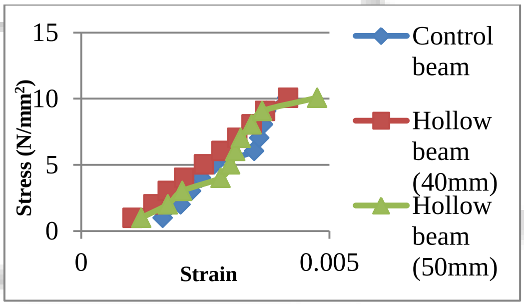

Fig. 29: Stress-Strain Curve of beam specimens

B. Concrete Saving:

Concrete is one of the most versatile building material. In construction industries huge wastage in concrete occurs. Material cost is a main component in the total cost of the product varying from 25 to 70%. Therefore, in order to control the cost, it is necessary to pay maximum attention for controlling material cost especially through abnormal losses. 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. Saving of concrete can be efficiently achieved with increase in length and depth of the beam. Therefore it can be effectively utilised during the construction of plinth beams, raft foundation, piers and similar other works. If we consider the beam in this study, the dimensions are of length= 98cm, breadth= 15cm and depth=23cm with a PVC pipe having 2cm radius and length 62cm. By calculating the volume, we can know the percentage reduction in concrete volume.

Volume of the beam, V_1= lbh= 98x15x23= 33810cu.cm

Volume of the pipe, $V_2= \pi r^2 l$= 3.14x$(2)^2$x 62 = 778.72cu.cm

% reduction in concrete= $[(V_2)/(V_1)]$x100 = [778.72/33810]x100= 2.3%

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. Hence it is more advantageous for larger constructions where wastage is more.

C. Labour Reduction:

Labours are one of the major resources in construction industries. Construction labour is most disorganised in india. Direct labour cost is also a part of the prime cost. It is clearly evident from the study that the total volume saving in concrete is directly proportional to the percentage reduction in labour. Concreting works in construction industry is labour intensive. When the volume of concreting works reduces, the need for labour also get decreased simultaneously, which in turn minimise the production cost.

D. Cost Reduction:

In current days of competition, it is necessary that a business concern should have utmost efficiency and minimum possible wastages and losses to reduce the cost of production. If the cost of inputs increases, then naturally, the cost of the production will go up. The inputs in construction fields include material, machines, labour and other overhead expenses. From the above conducted study we have come to a conclusion that by using reinforced beam with hollow neutral axis, we can save significant amount of concrete without bearing the strength upto a limit. This saving in material cost is more effectively utilised when considering large depth and length of beam or in similar other works, where abnormal lose of concrete occurs. This can be compared to a chain reaction because as the volume of concrete decreases, the material cost reduces which decreases the labour cost, which in turn minimise the construction cost.

E. Decrease In Self-Weight:

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/m^2. If we can reduce the volume of concrete then the self-weight of the beam also get reduced.

Weight of 1cu.feet concrete=68.15kg

Considering beam of dimensions: length= 98cm=39.2inch

Breadth= 15cm= 6inch; depth= 23cm= 9.2inch

Volume of beam, V_1= lbh= 39.2x6x9.2= 2163.84cu.in.

1cu.feet = 1728cu.in

So, V_1 = 2163.84/1728 = 1.25cu.ft.

Weight of beam, W_1= 1.25x68.15= 85kg

Considering PVC pipe of dimensions: radius= 2cm= 0.8inch; length= 62cm= 24.8inch

Volume of pipe, $V_2= \pi r^2 l$= 3.14x$(0.8)^2$ x 24.8 = 49.838cu.in.

So, V_2= 49.838/1728= 0.0288cu.ft.

Weight of concrete saved, W_2= 0.0288x 68.15 = 1.965kg~ 2kg

Weight of hollow beam=W_1-W_2= 85-2= 83kg

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.

F. Applications:

From the evaluation of the results, it was observed that the areas of application of the experimental reinforced beam with hollow neutral axis include various fields of construction where abnormal losses in concrete occurs. The wastage of concrete can be minimised by adopting this technique of hollow neutral axis of low stress zone without suffering much strength. The fields of application are:

- Plinth beams
- Raft foundations
- Piers
- Similar other works

IX. CONCLUSIONS

Behaviour of reinforced concrete beams with hollow neutral axis is similar to that of conventional reinforced concrete beams. Presence of hollow PVC pipe 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 hollow pipe in reinforced concrete beams does not require any extra labour or time. Economy and reduction of weight in beams depends on the percentage replacement of concrete. The concrete saving will be more effective as the length and depth of the beam increases. The selection of circular hollow section proves to be advantageous because curved sections bear more load than any other sections since it avoids sharp corners. 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. The results obtained from the experimental and analytical investigation are found to be comparable.

A. Scope of Future Study:

Further investigations can be carried out by placing the pipe at tension zone without considering the position of neutral axis. Comparative study can be conducted by utilizing different diameters in PVC pipe and their flexural and shear behaviour can be evaluated. Several other parameters can also be tested like impact resistance, abrasion, fatigue resistance, crack propogation, etc. The work can be extended in other mixes also.

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