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Experimental and Analytical Investigation on Partial Replacement of Concrete in the Tension Zone

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Abstract— A beam is a one dimensional (normally horizontal) flexural member which provides support to the slab and vertical walls. In a normal beam (simply supported) two zones generally arise, i.e. compression zone at top and tension zone at bottom. As concrete is weak in tension, steel is introduced in the tension zone to take the tension, so logically no concrete is required in tension side. But concrete is to be provided on tension side to act as a strain transferring media to steel and may be called as 'sacrificial concrete'. Partial replacement of the concrete below the neutral axis is an idea that can create reduction in weight and savings in materials. In this paper, an experimental and analytical investigation on partial replacement of concrete in the tension zone that is below the neutral axis by creating air voids is discussed. Air voids were created using polyethylene balls and PVC pipes. Beams were cast using different percentage of polyethylene balls and PVC pipes. The results obtained for control specimens, beams with polyethylene balls and for beams with PVC pipes were compared. And analytical study of the same is done using ANSYS.

Keywords— Neutral axis, Polyethylene balls, PVC pipes, Sacrificial concrete, Tension and Compression.

INTRODUCTION

Concrete is the primary structural component that exists in buildings and bridges. In recent days the problem face by the construction industry is acute shortage to 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. As concrete is weak in taking tension, steel reinforcement is provided in this zone. Concrete below the neutral axis act as a stress transfer medium between the two zones. Therefore the concrete below the neutral axis is known as sacrificial concrete. (The compressive force acts in the top zone at a distance of 0.42 X_u, X_u is the neutral axis distance from the top of the section.)

Numerous studies are carried out for the investigation of alternate materials that can be used in concrete. Some locally available materials like fly ash, coper slag, rice hush etc. are experimentally evaluated. An alternate method is replacing the zone below the neutral axis with inert weightless substances like polyethylene balls, hollow PVC pipes etc. will not greatly affect the strength, stress geometry and shape characteristics of the beam.

In this paper, studies on partial replacement of concrete below the neutral axis in beams by creating air voids using different percentage of polyethylene balls and PVC pipes are discussed. Experimental results are compared with analytical results obtained using Ansys.

SIGNIFICANCE OF THE WORK

A. Scope of the Work

From the referred previous works, it is understood that in RC beams, less stressed concrete in & below the neutral axis can be replaced by some light-weight materials. Different materials like brick, expanded polystyrene sheet, terracotta, hollow blocks etc. were already studied which shows good results in reducing self-weight. But the ultimate load carrying capacity and first breaking load is very small when compared to control beam. To overcome these drawbacks air voids are created alternatively below the neutral axis by using plastic balls of 3.7cm and PVC pipe of 3.8cm diameter.

B. Objective of the Work

The objective is to reduce the amount of material, weight and cost of the reinforced concrete structures by replacing the concrete below the neutral axis.

C. Methodology

The methodology of the work consists of:
(1) Selection of concrete grade; M25
(2) Mix design for M25 grade concrete
(3) Casting beam specimens of normal RC beams and beams with 4%, 8% & 16% replacement using polyethylene balls and PVC pipes.
(4)Conducting two point loading test using 50t loading frame.
(5) Analytical study is done using ANSYS.
(6)Study on the obtained experimental and analytical results.

MATERIAL TESTS

TABLE I
MATERIAL TEST RESULTS

Test	Material	Equipment Used	Values Obtained
Specific Gravity	Ordinary Portland Cement	Le-Chatelier Flask	3.15
Specific Gravity	Fine Aggregates	Pycnometer	2.7
Specific Gravity	Coarse Aggregates	Vessel	2.94
Workability	M25 Concrete	Slump Cone Apparatus	100mm

MIX DESIGN

TABLE II
M25 MIX PROPORTIONING

Cement (Kg/m^3)	374.30
Fine aggregate (kg/m^3)	751.03
Coarse aggregate (Kg/m^3)	1280.31
Water (li/m3)	149.72
Water cement ratio	0.40
Mix ratio	1:2.006:3.420

EXPERIMENTAL INVESTIGATION

A. Experimental Procedure

A total of fourteen specimens were cast and tested; two of the specimens are control specimens and the others are specimens with partial replacement of 4%, 8% & 16% below neutral axis. Details of specimens cast are shown in Table III below.

TABLE III
DETAILS OF SPECIMENS CAST

SL.No:	Number Of Beams	Percentage Of Concrete Replaced	Designation Used	Material Adopted
1	2	0	CS	No Replacement
2	2	4	PB1	Polyethylene Balls
3	2	8	PB2	Polyethylene Balls
4	2	16	PB3	Polyethylene Balls
5	2	4	PP1	PVC Pipes
6	2	8	PP2	PVC Pipes
7	2	16	PP3	PVC Pipes

CS- Control Specimen
PB- Polyethylene Balls
PP- PVC Pipe

Dimension of all the specimens are 150mm x 200mm x 1250mm, with an effective span of 990mm.Main reinforcement provided is 3# 12mm diameter bars, 2# 8mm diameter bars are provided as anchor bars and stirrups are provided as 8 mm diameter bars @ 130mm c/c. Two point loading using 50t loading frame was used for testing the specimens.

The depth of neutral axis is calculated by considering M25 grade concrete and Fe 415 steel with an effective cover of 20mm. 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. Here the section is designed as a balanced section, and neutral axis depth is 90.74mm from the top.

B. Test Procedure

Beams were tested using a 50t loading frame. Dial gauge was used to determine the deflection at the center of the beam. The behaviour of the beams was keenly observed from beginning to failure. The strength of the beam was tested as a two point loading system using a hydraulic jack attached to the loading frame.

The appearance of the first crack, and the development and the propagation of cracks due to increase in the load were also recorded. The loading was continued after the initial crack formation and was stopped when the beam was just on the verge of collapse. 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 and the ultimate cracking load was noted.

Fig.1 Experimental setup of beam specimen

EXPERIMENTAL RESULTS

A. Load Carrying Capacity

Ultimate strength of beams under two point loading was confirmed through recording the maximum load indicated by the dial gauge, whereas the cracking load was specified with the development of the first crack on the beam. It was found that there is a high variation in the load carrying capacity of the control specimen and that of beams with partial replacement.

TABLE IV
ULTIMATE LOAD OF ALL SPECIMENS

Beam Specimen	Ultimate Load (kN)
CS	392.40
PB1	445.47
PB2	700.80
PB3	509.68
PP1	471.45
PP2	739.04
PP3	560.65

Table IV shows the ultimate load of all the beam specimens, from the Fig.2 & Fig.3 it is clear that compared to control specimen (CS) the partially replaced specimens i.e. PB1, PB2, PB3, PP1, PP2 & PP3 have higher values. For both, specimens partially replaced using polyethylene balls and PVC pipes it can be clearly seen that PB3 & PP3 there is a decrease in the value. Therefore it can be said that partial replacement upto a range of 8% can be done and beyond that replacement leads to a decrease in the load carrying capacity.

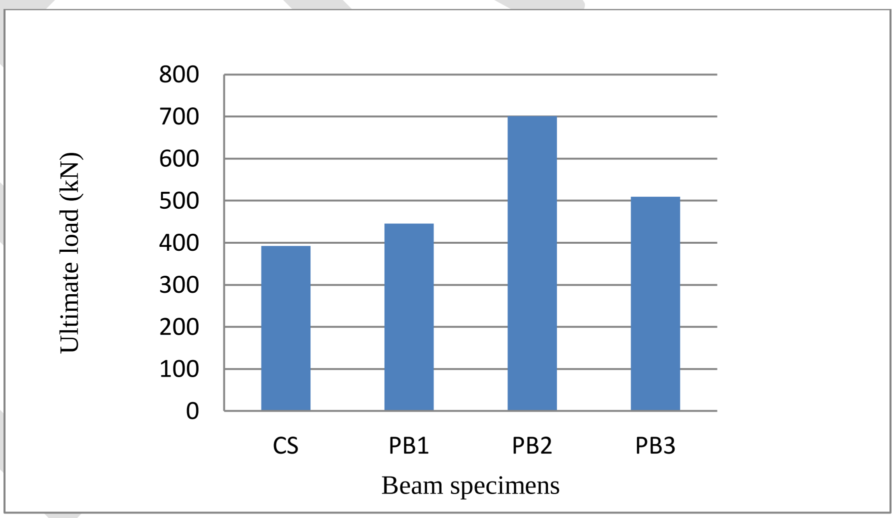

Fig.2 Ultimate load of different percentage of polyethylene balls

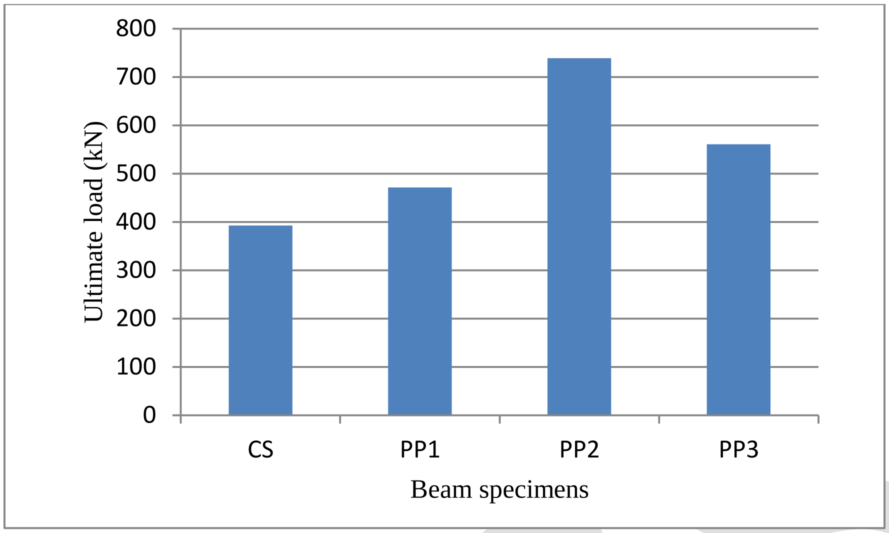

Fig.3 Ultimate load of different percentage of PVC pipes

B. Load Vs Deflection Graph

Due to increase in the load, deflection of the beam starts, upto a certain level the load vs. deflection graph will be linear i.e. load will be directly proportional to deflection. Due to further increase in the load, the load values will not be proportional to deflection, since the deflection values goes on increasing, strength of the material also increases and material loses elasticity undergoing plastic deformation. Hence from the graph we can predict strength of the material by knowing the deflection at the corresponding load values. The load vs deflection curves is shown in Fig. 4&Fig. 5.

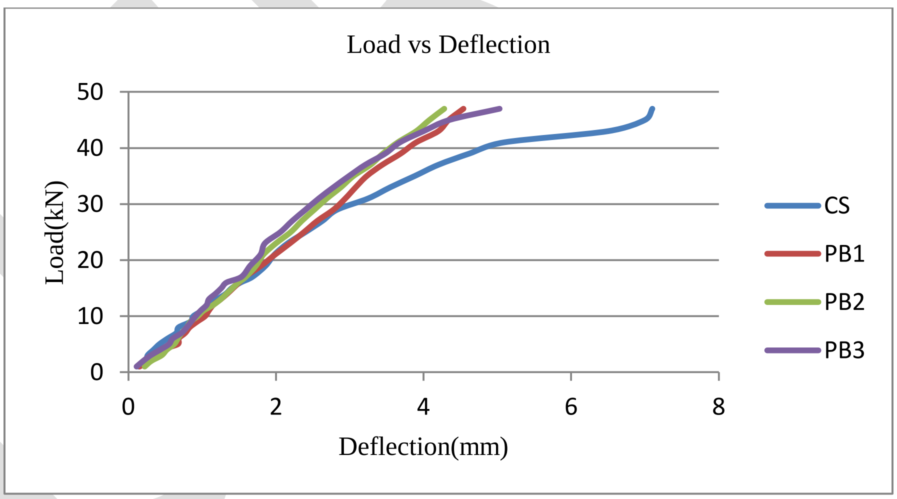

Fig.4 Load vs deflection of beams replaced using polyethylene balls

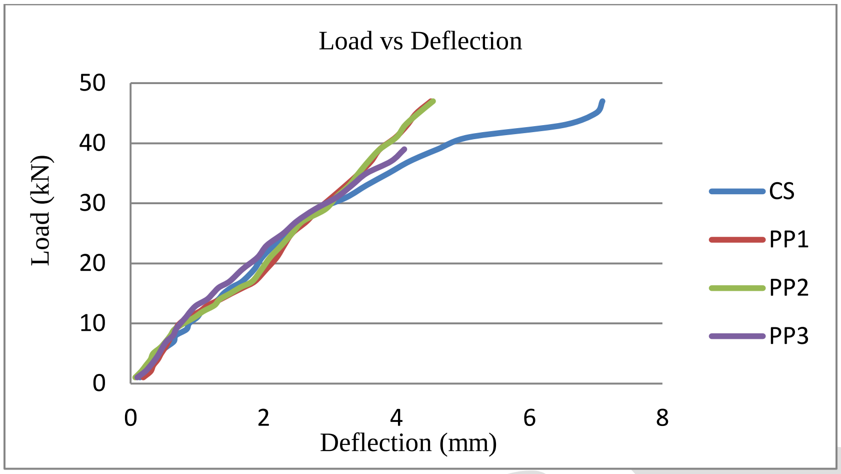

Fig.5 Load vs deflection of beams replaced using PVC pipes

C. Crack Pattern

Mainly shear cracks were developed from the supporting points and widened up as the load increased. At failure, the concrete in the compression region crushed. The cracks continued to widen as the load increased, and failure occurred soon after depicting a typical sudden type of shear failure. The crack pattern of replaced beams is similar to that of control specimen.

ANALYTICAL INVESTIGATION

ANSYS 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. FEA is a numerical method of deconstructing a complex system into very small pieces called element. The software implements equations that govern the behaviour of these elements and solves them all. These results 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. Size of reinforced concrete beam-150mm x 200mm; size of loading and support steel plates- 25mmm x 150mm, 5mm thick; steel reinforcement details; 3# 10mm diameter at bottom and 2# 8mm diameter bar at the top.

B. Modelling Procedure

1) Element Types and Real constants

TABLE V
ELEMENT TYPES FOR MODEL

Material types	Element types
Concrete	SOLID 65
Steel reinforcement	LINK180
Steel plates at supports and loading	SOLID 186
PVC pipe	BEAM ELEMENT 186
Polyethylene balls	SOLID 168

TABLE VI
REAL CONSTANTS FOR ELEMENTS

Real Constant Set	Element Type	Constants	
1	LINK 180	Cross sectional area (m^2)	3.39×10^{-4}
		Initial strain	0
2	LINK 180	Cross sectional area (m^2)	1×10^{-4}
		Initial strain	0

2) Material Properties

TABLE VII
MATERIAL PROPERTIES OF ELEMENTS

Material	Young's Modulus	Poisson's Ratio
M25 concrete	25000	0.15
Fe 415 steel	2×10^5	0.30
Polyethylene balls	3500	0.34
PVC pipes	3300	0.40

C. Meshing

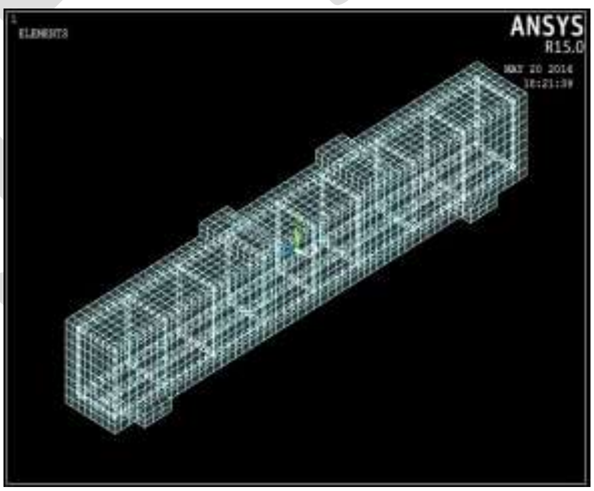

Fig.6 Meshing diagram of CS

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 constrained in the UY and UZ directions.

E. Analysis

The finite element model for this analysis is a simply supported beam under two point loading condition. For the purpose of this model, static analysis type is utilized.

ANALYTICAL RESULTS

A. Load Vs Deflection Graph

Load deflection values were obtained, and using these graphs is plotted as shown in Fig.7& Fig.8.

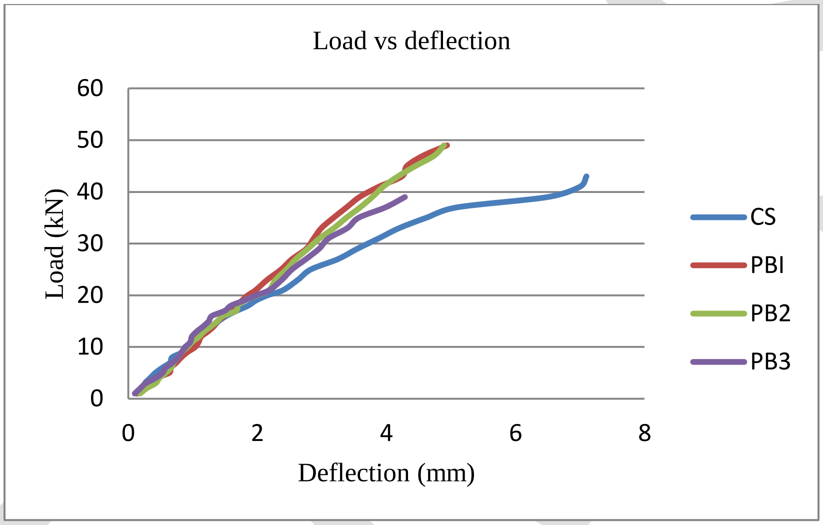

Fig.7 Load vs deflection of beams replaced using polyethylene balls

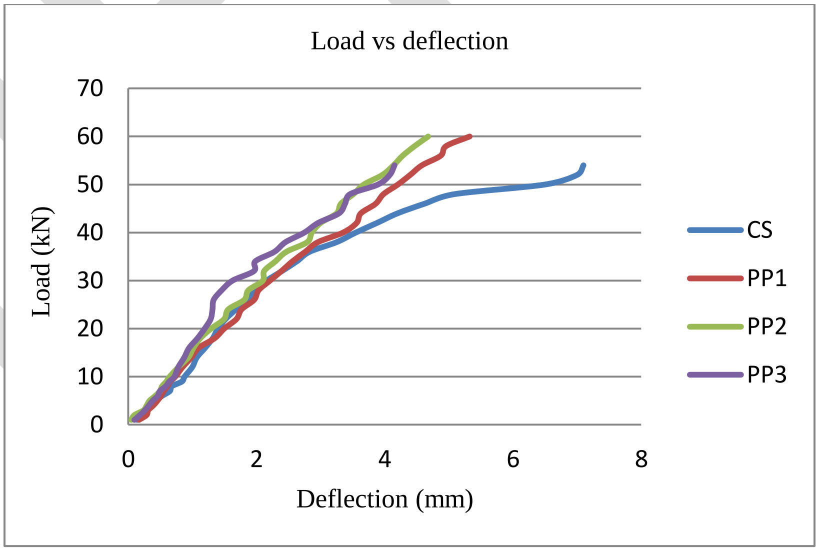

Fig.8 Load vs deflection of beams replaced using PVC pipes

EVALUATION & DISCUSSION

A. Load-deflection relationship

From Fig's 4, 5, 7 & 8, it is found that the load deflection relationship of control beam and that of partially replaced beams, obtained from experimental and analytical evaluation are found to be similar.

B. Concrete Saving

Concrete is one of the most versatile building materials. Material cost is a main component to be considered while construction, mainly this varies from 25 to 75%. Therefore, in order to control the cost, it is necessary to pay maximum attention for controlling the material cost. It should be made sure that the right quantities of materials are consumed with less wastage. This issue can be minimized by avoiding concrete below the neutral axis without bearing significant strength.

C. Labour Reduction

Labours are one of the major resources in construction industries. From the study it is clear that the total volume saving in concrete is directly proportional to the percentage reduction in labour. When the volume of concreting works reduce, the need for labour also get decreased simultaneously, which in turn minimize the production cost.

D. Cost Reduction

In current days the entire field is filled with competition, and it is necessary that a business concern should have utmost efficiency and minimum possible wastages to reduce the cost of production. From the study conducted, we can conclude that by partial replacement below neutral axis in beams, significant amount of concrete can be saved without affecting the strength.

E. Applications

From the results evaluated, it is observed that the reinforced beam with region below the neutral axis replaced with voids can be applied to various fields of constructions such as:

- Raft foundations
- Piers
- Similar other works.

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CONCLUSIONS

Behaviour of reinforced concrete beams with region below the neutral axis with voids created using polyethylene balls and PVC pipes is similar to that of control specimen. 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 pipes and balls. 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.

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