

# Experimental and Numerical Studies on Reinforced Concrete Hollowcore Sandwich Beams

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**ABSTRACT:** Beams are structural members which resist load by bending. Flexural action depends on compressive stress of concrete on compression side and tensile stress of steel on tension zone. In reinforced concrete (RC) beams concrete on tension zone has no effect on the flexural action. So this unutilized concrete can be removed by replacing with any lightweight material. For this study material incorporated in the concrete beam is Expanded polystyrene and Polyurethane foam, which occupy the concrete volume below the neutral axis. Specimens of solid RC beams and hollowcore RC sandwich beams with various core thickness are casted and tested for three point flexure. Then the results are compared and effects are studied. Parametric study was also conducted to know the effect of varying depth of replacement using ANSYS. These If weight of this developed hollowcore RC sandwich beams are reduced hence proving the beam to be economical. Hollowcore sandwich beams show similar behaviour in flexure as that of control beam.

**KEYWORDS:** Neutral axis, Hollowcore Reinforced Concrete Sandwich Beam, Expanded polystyrene, Polyurethane Flexural behaviour

## I. INTRODUCTION

A beam is a one dimensional horizontal flexural member which provides support to slab and vertical walls. In a beam generally two zones occur during bending compression zone at top and tensile zone at bottom. Steel is introduced in the tension zone as the strength of concrete is less in tension zone with respect to compression zone [1]. So no concrete is required at the tension zone. But the concrete on tension side acts as strain transferring media to steel and may be called as "sacrificial concrete" [4]. Hence complete removal of concrete below the tension zone cannot be allowed. Hollow core beams with partial removal of concrete on the tension zone reduce the effect of application of concrete materials to environmental impact. By structural material optimization dead load which contributes to the seismic effect in high rise structures can be reduced. Studies on structural material optimization by replacing the concrete below the neutral axis with various lightweight inert materials including Expanded polystyrene, Aerated blocks, PVC pipes, Styrofoam etc. has been conducted. The objective of this paper is to study the effect of replacement of concrete in the tension zone with inert material and to study the flexural behaviour of replaced beam by experiment and using Ansys program. To achieve the above objective experimental study was conducted and the results obtained from the experiment were compared with the finite element software ANSYS.

## II. RELATED WORK

S.Manikandan, S.Dharmar et al. [4] focussed on structural material optimization by introducing hollowcore using Expanded polystyrene in tension zone of RC beams. By material optimization they reduce the dead loads which contribute to the seismic effect in high rise structures. In addition EPS within the beam acts as vibration damper during

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earthquake and it also improves thermal insulation. Yasser, Hermanparung et al[2] replaces the concrete on tension zone by low compressive strength concrete by mixing them with Styrofoam grains.

Vanissorm Vimonasatit et al[12], T. subramani et al[1] suggested Lightweight sandwich reinforced concrete sections (LSRC) as an alternative to solid section. An experimental investigation into the strength of LSRC beams also shows promising results under flexural tests. Patelrakesh, Dubey S.K., Pathak K.K[5] studied the behaviour of partially utilized concrete of RC beam by replacing it with brick. Brick filled concrete beams acts as composite beams. They used method of initial functions for the analysis of brick filled RC composite beams.

W. Godwin Jesudhasan, Dr. G. Hemalatha[8] carried out an experimental investigation to replace the portion below the neutral axis of beam with Expanded polystyrene sheet. They found that by embedding EPS sheet in concrete, shear cracks only occur while loading and EPS embedded beam weighs less compared to conventional beams. Jain Joy, Rajesh Rajeev[7] removed unutilized concrete on the tension zone and replaced it with PVC pipe and thereby making the beam hollow. Aswathy. S. Kumar, Anup Joy[3] conducted experimental investigation on partial replacement of concrete below the neutral axis by creating air voids using polythene balls. It has been found that behaviour of reinforced concrete beams with voids in the tensile zone is similar to that of conventional beams.

P. Govindan, A.R. Santhakumar[6] stated that stresses in the beams are maximum at the top and bottom and zero at the neutral axis. So a cheap lightweight material can be used near the neutral zone for lightweight and economy. It is observed that load carrying capacity of an infilled beam is about 80%-90% of the conventional reinforced concrete beams. B.S. Karthik, Dr. H. Eramma et al[9] came with the concept of partial beam. A partial beam is a normal beam cast with two grades of concrete, one above and other below the neutral axis. It helps to achieve economy.

### III. RESEARCH SIGNIFICANCE

In reinforced concrete beams less stressed concrete in and near neutral axis can be replaced with lightweight material. By structural material optimization the dead load which contributes seismic effect in highrise structures can be reduced. This study aims to propose a reinforced concrete beam having improved crack pattern, dynamic behaviour and load deflection curve comparable with that of conventional reinforced concrete beam by replacing concrete below the neutral axis with lightweight inert material.

### IV. EXPERIMENTAL INVESTIGATION

#### Variable Parameters

The primary variables considered in the work includes i) Expanded Polystyrene and Polyurethane foam as replacement materials ii) Effect of varying thickness of replacement

#### Materials used

##### Cement

Ordinary Portland cement of 53 grade is used

Table-1 Physical properties of cement

Physical property	Results obtained
Standard Consistency(%)	38
Initial setting time(min)	35
Specific gravity	3.15
Finess(%)	2

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### Aggregate

MSand is used as fine aggregate. The coarse aggregate of 20mm size is used.

Table-2 Test results of aggregates

Physical property	Results obtained
Specific gravity of Fine aggregate	2.73
Specific gravity of Coarse aggregate	2.81

### Water

Ordinary potable water was used for mixing.

### Replacement Material

Expanded polystyrene of density 30kg/m<sup>3</sup> and Polyurethane of density 62.5kg/m<sup>3</sup> is selected for the study

Table-3 Test results of Replacement material

Physical properties	Results obtained
Water absorption of Expanded polystyrene	50%
Water absorption of Polyurethane	32%

### Mix proportion

A mix M30 grade was designed as per IS 10262:2009 and the same was used to prepare the test specimens. The design mix proportion is shown in Table

Table -4 Mix proportion for M30

Cement	Fine aggregate	Coarse aggregate	Water Cement ratio
1	1.44	2.66	0.43

### Test specimens

A total of 9 specimens were cast. All specimens are of length 1m and cross section 150mm×200mm. Hollowcore sandwich beams and control beams were cast using M30 grade concrete with a water cement ratio of 0.43. Thickness of cover concrete was selected as 20mm. Steel bars used are of Fe500 grade. Longitudinal reinforcement provided in all the specimens are of 10mm dia. Minimum shear reinforcement is provided for both the beams. Stirrups provided are of 6mm dia.

#### Depth of Replacement Offered

Depth of Neutral Axis,

$$X_u = \frac{0.87 \times f_y \times A_{st}}{0.36 \times f_{ck} \times b}$$

$$= \frac{0.87 \times 500 \times 2 \times \frac{\pi}{4} \times 10^2}{0.36 \times 30 \times 150}$$

$$= 42 \text{ mm}$$

$$d' = [2 \times \text{cover} + \text{diameter of bar}]$$

$$= [2 \times 20 + 10]$$

$$= 50 \text{ mm}$$

$$\text{Maximum Depth of replacement} = D - [X_u + d']$$

$$= 200 - [42 + 50]$$

$$= 108 \text{ mm}$$

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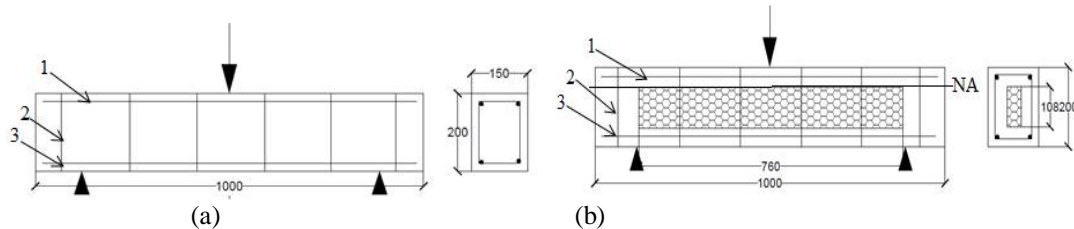


Fig.1.Specimens(a)Control beam(b)Beam with replacement below neutral axis(10.8cm)

Where,

1 = anchor bars (10 mm dia)

2 = shear reinforcement (6 mm dia)

3 = Longitudinal reinforcement(10mm dia)

Fig.1 show the selected specimens for the study. Concrete below the neutral axis is replaced with Expanded polystyrene and Polyurethane for a thickness of about 10.8cm

### Test setup

All the specimens were tested for flexural strength under three point loading. Hollowcore sandwich beams and control beams were tested in universal testing machine having capacity 1000kN. The specimens were arranged with simply supported conditions, centred over bearing blocks adjusted over an effective span of 760mm. The load was applied at midpoint of the beam specimen, increased at a uniform rate till the ultimate failure. Deflection of the beam was measured by a dial gauge placed at mid span. For each load increment the deflection and crack were observed and tabulated.

### Test results and observations

The following observations were made during the progress of tests.

Table-5 Beam test results

Specimen	BC	SBT	SBP
Firstcrack Load(kN)	55	52	54
Ultimate Load(kN)	111	107	109

Table-5 shows the firstcrack load and ultimate load of the tested specimen obtained from experiment. 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 replacement below the neutral axis. The solid control beams are designated as BC. Beam section with 10.8cm replacement of Polyurethane below neutral axis is designated as SBP, Beam section with 10.8cm replacement of Expanded Polystyrene below neutral axis is designated as SBT. The first crack loads and ultimate load showed almost equal to all beams

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Table-6 Load Deflection values of beam specimen

Load(kN)	Deflection(mm)		
	BC	SBT	SBP
10	0.3	0.44	0.49
20	0.55	0.59	0.6
30	0.81	0.84	0.82
40	1.05	1.1	1.03
50	1.3	1.49	1.44
60	1.55	2.12	2.1
70	1.95	2.45	2.34
80	2.5	2.85	2.79
90	3.35	4.2	3.9
98		4.53	4.4
99			4.75
100	4.4		

Table-6 shows the load deflection values obtained from experiment. It was found that there is not much difference in the load carrying capacity of solid control beam section and that of Hollow core sandwich beams. However the hollow section decrease in load capacity and increase in corresponding deflection for the same properties when compared with solid control beams.

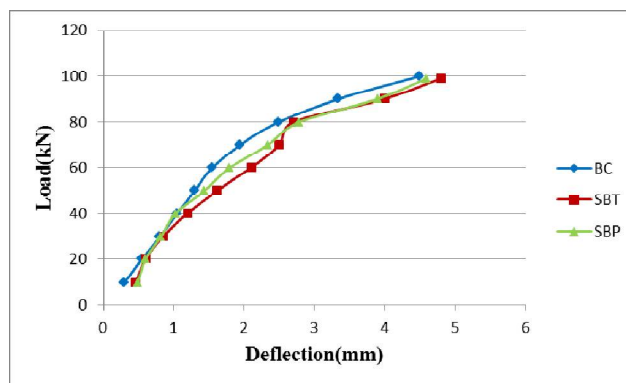


Fig.2. Load deflection curve

Fig.2 shows the load deflection curve for the tested specimen. Initially load will be directly proportional to deflection. Due to further increase in 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. The load values and corresponding deflection of solid control beam and beam with replacement at the neutral axis upto a safe load of 100kN. From the graph it is clear that control beam and beam with replacement shows similar behaviour.

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## IV. ANALYTICAL INVESTIGATION

ANSYS 14.5 was employed to simulate the flexural behaviour of the beam by finite element method.

### Material Properties

Table-7 Material properties

Material	Density(kg/m <sup>3</sup> )	Young's modulus(N/mm <sup>2</sup> )	Poisson's ratio
M30 concrete	2500	29219	0.15
Fe500 steel	7850	200000	0.3
Expanded polystyrene	30	3000	0.12
Polyurethane	62	105.45	0.44

### Modal Analysis

Modal analysis is a technique to study the dynamic characteristics of a structure under vibrational excitation. Natural frequencies, mode shapes and mode vectors of a structure can be determined using modal analysis. Modal analysis allows the design to avoid resonant vibrations. Here, we are using ANSYS WORKBENCH 14.5 in which modelling of beam with fixed ends is done in geometry component system, material is selected from engineering data library and simulation & analysis is performed in modal analysis system from where we obtained natural frequency and mode shapes for all specimens.

Table-9 Modes and Frequency of Beams

Mode No	Frequency(Hz)		
	BC	SBP-F	SBT-F
1	472.69	405.29	431.42
2	588.73	515.4	548.67
3	996.01	827.08	885.2
4	1150.5	962.53	1024
5	1350	1171	1247.4
6	1736.4	1505.5	1601.5

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Table-9 shows the natural frequencies and shapes of the first six modes of vibration. Beam with polyurethane shows lesser natural frequency compared to others as it has lower modulus of elasticity. Higher the natural frequency more will be the stiffness. As beam with polyurethane has lower natural frequency it offers better performance during earthquake.

## VI. PARAMETRIC STUDY USING ANSYS

### Thickness - Total deformation Relation

Correlation between total deformation and thickness is analyzed using ANSYS 14.5. Optimization of parameters was conducted and thickness range is given from 1cm to 10.8cm. Software automatically selected five different samples from the given range and total deformation was found out..

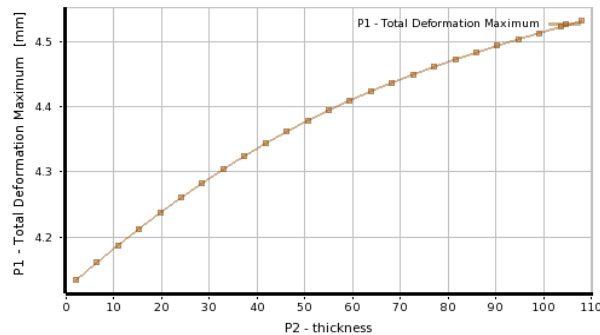


Fig.4. Response chart between Total Deformation and Thickness Obtained from ANSYS

Fig.4 shows the relation between thickness and total deformation obtained from software. It is seen that there is not much variation in deformation values and we can conclude that concrete below neutral axis has no significant role and it can be replaced

### Thickness-Frequency Relation

Correlation between Frequency and thickness for Hollowcore sandwich beam replaced with polyurethane is analyzed using ANSYS 14.5 as it has the lowest natural frequency compared to others. Optimization of parameters was conducted and thickness range is given from 1cm to 10.8cm. Software automatically selected five different samples from the given range and Frequency was found out.

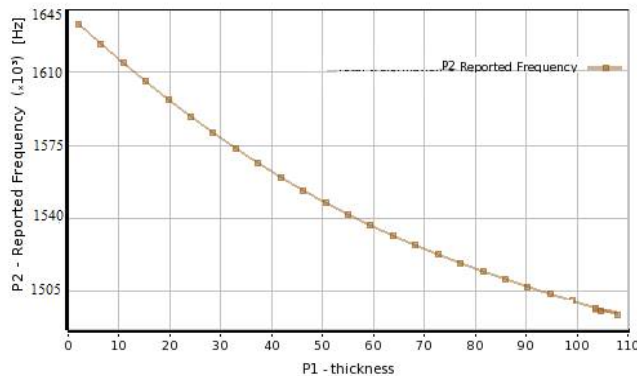


Fig.5. Response chart between Total Deformation and Thickness Obtained from ANSYS

Fig.5 shows the relation between thickness and frequency obtained from software. From the above figure it is clear that with increase in the thickness of the core layer there is a decrease in natural frequency for each mode. This means the damping effect of the sandwich has been increased.

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## VII. CONCLUSION

Based on the observations of the experimental investigation and numerical analysis following conclusions can be drawn:

1. Flexural strength, deflection at yield of reinforced concrete beams with region below the neutral axis replaced with inert materials is similar to that of conventional reinforced concrete beams.
2. From the parametric study, it is seen that there is not much variation in deformation with the increase in thickness of replacement.
3. As the thickness of the replacement increases, there is a decrease in natural frequency for each mode. Thus the damping effect of the sandwich has been increased.
4. It has been observed that the replacement of concrete in tension zone does not require any extra labour or time.

It can be concluded that even though both Polyurethane and Expanded polystyrene shows comparable flexural strength, Polyurethane is found to be a more effective replacement as it offers better damping property.

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