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# Experimental Investigation on Flexural Behavior of Voided RCC Beams with Voids in Both Compression and Tension Zone

* Franics C. George[1)], Prashanth Janardhan[2)] and Harish Narayana[3)]

*[1), 2)] Department of Civil Engineering, NITS, Silchar, Assam 788010, India*
*[3)] Department of Civil Engineering, NITG, Goa 403401, India*
*[2)] prashanth@civil.nits.ac.in*

## ABSTRACT

Due to various reasons cement concrete has attained the status of a major building material in the modern construction. In the past years there has been studies carried out to reduce the amount of concrete used in the structure since the reduction has both structural as well as environmental advantage. This paper aims to understand the flexural behavior of concrete beams with voids of different pattern in both compression and tension zone simultaneously. Experimental investigation is carried out using four beams out of which one is control beam and the remaining three beams are with different void condition. The beams used for this study are of size 700mm*150mm*150mm made of M20 grade concrete. Voids are created using Polyvinyl chloride (PVC) pipe of diameter 26mm. These beams were subjected to four-point loading using the universal testing machine. The results obtained shows that voided beams have more load carrying capacity than conventional Reinforced Cement Concrete (RCC) beams. The void beams with different void conditions behave in a similar way to that of conventional RCC beams. The deflection of beams also increases with the increase of voids in the beams.

## 1. INTRODUCTION

Concrete is a composite material. The major constituents of concrete are fine aggregate, coarse aggregate and the binding material cement. Since concrete is weak in tension, they are usually reinforced with reinforcement bars. In places where there is need of long beams considering the structural and architectural needs, engineers are forced to increase the depth of the beam to take care of the load and to resist deflection. With the increase in the size of the beam the self-weight of the beam also increases which finally leads to the increase in size of other members of the structure. So, in order to control the weight of beam and there by controlling the size of the other members voids can be introduced in the beam. Since large masses can attract more earthquake forces

[1)] Post Graduate Student
[2)] Assistant Professor
[3)] Assistant Professor

the introduction of voids and thereby reducing the mass of concrete can reduce the effect of earthquake on structures.

Many researchers have studied the voided beams (Mondal et al. 2011, Kumar and Jay 2013, Sivaneshan and Harishankar 2017). The introduction of polythene balls in the low stress zone of concrete did not cause much change in the load carrying capacity of the beam but resulted in the reduced weight of the concrete structure (Kumar and Jay 2013). Varghese and Jay (2015) studied the voided beam by introducing hollow circular pipes similar to that of ordinary reinforced beam. They observed increased strength and reduced deflection when compared to control beam. The hollow circular core RCC beams showed similar behavior like conventional RCC beams whereas hollow square cores showed variation in flexural strength as well as yield deformation (Manikanda and Dharmar 2015). Voided beam with PVC embedded in the neutral zone has helped to increase the load carrying capacity. This behavior exhibition by voided beam can be due to increased ductility, lower drying shrinkage and higher resistance to chloride ion penetration (Noh et al. 2019). The replacement of concrete by polythene balls in compression zone has not affected the load carrying capacity of the beam. It was also observed that the defection is less in the case of voided beams (Sivaneshan and Harishankar 2017). Even though many researchers have worked related to voided beams a detailed study with voids at different location in the beam is seldom. The objective of the study is to analyze the flexural behavior of reinforced concrete beams with voids in both compression and tension zone in different pattern.

## 2. EXPERIMENTAL DETAILS

### *2.1 Materials*

Ordinary Portland cement (OPC) of 53 grade was used as the binding material. Natural sand confirming to zone two was used as fine aggregate. Coarse aggregate having size less than 20mm was used for making the concrete. The physical properties of cement, fine aggregate and coarse aggregate are shown in Table 1.

Table 1 Properties of OPC

| **Property** | **Test result** |
|---|---|
| **Cement** | |
| Consistency | 32% |
| Initial setting time | 80 minutes |
| Final setting time | 350 minutes |
| Specific gravity | 3.15 |
| **Fine aggregate** | |
| Specific gravity | 2.11 |
| Water absorption | 1.214% |
| Fineness modulus | 2.87 |
| **Coarse aggregate** | |
| Specific gravity | 2.55 |
| Water absorption | 2.0% |
| Fineness modulus | 6.68 |

*2.2 Mix proportion and preparation of concrete*

The mix design for the beam was done as per IS 10262-2019. The grade of concrete used is M20. Using physical properties of materials, the mix was prepared successfully. The proportion of materials used for concrete were used in the proportion 1: 1.328: 2.68. The water cement ratio used for the mix was 0.48. The average 28-day compressive strength of cube was obtained as 28.15 N/mm$^2$.

Size of the beam was 700 mm* 150 mm* 150 mm. The beam was designed as under reinforced beam as per IS 456-2000. The depth of neutral axis is 40.5mm. Four beams were casted out of which one was control beam (under reinforced RCC beams) with two number of 8 mm diameter bars in tension side and two number of 6 mm diameter bars as hanger bars. Stirrups were provided throughout the beam with a spacing of 95 mm. Remaining three beams were casted as voided beams by introducing hollow circular PVC pipes of diameter 26 mm. Voids were created in three different patterns. In beams voids were introduced in both compression and tension zone by providing the PVC pipes such that the centre of the pipe coincides with the neutral axis of the beam. Three different patterns provided were, voids continuously throughout the beam, voids only in pure bending zone and voids throughout the length of beam with gaps in between. The nomenclature of different beams is shown in Table 2. The reinforcement details of three beams are shown in Fig. 1, 2 and 3 respectively. The beams casted were cured for 28 days and subjected to four-point loading for experimental investigation.

Table 2 Beam designation

| Beam description | Designation |
|---|---|
| Voids in both compression and tension zone for the entire length of the beam. | A1 |
| Voids in both compression and tension zone with voids only in pure bending zone. | A2 |
| Voids in both compression and tension zone with discontinuous voids along the length of the beam. | A3 |
| Conventional RCC beam casted along with set A. | CB1 |

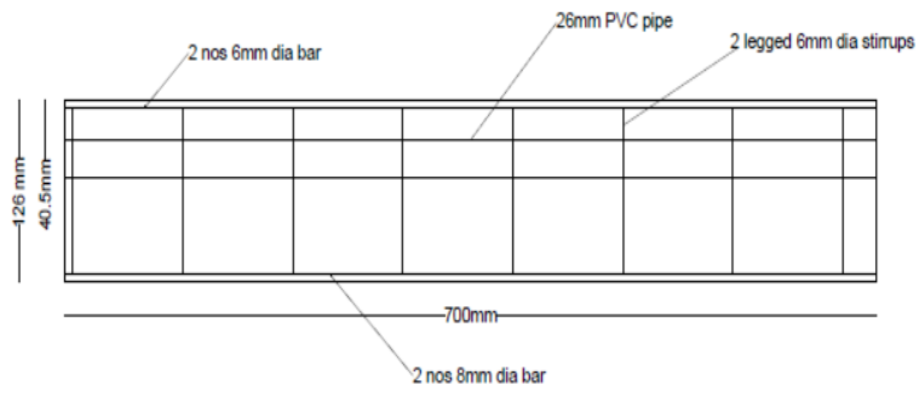

Fig. 1 Beam A1

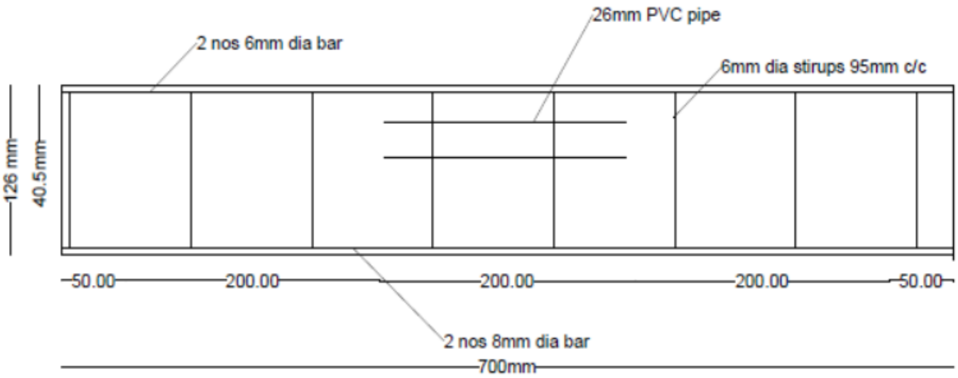


Fig. 2 Beam A2

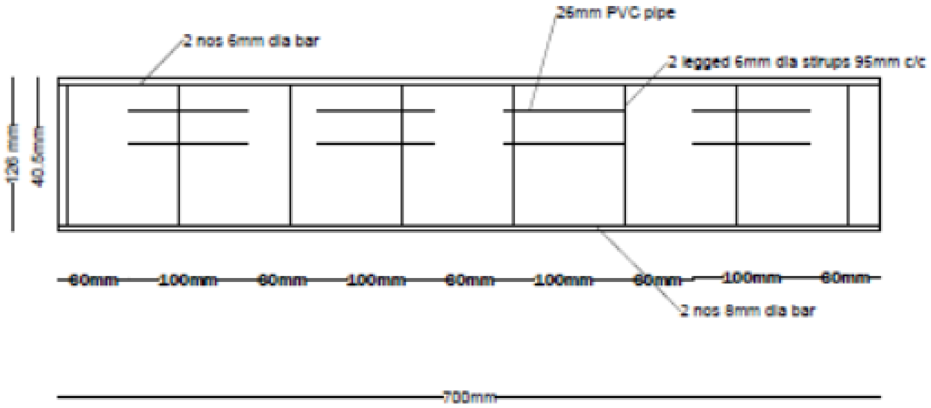


Fig. 3 Beam A3

Four-point loading test was done using computerized Universal Testing Machine (UTM). From the test conducted the load and corresponding deflection in the beam were recorded in the UTM. The effective span of the beam was 600 mm. The load and deflection recorded in the beam was closely observed from the beginning to the failure of the beam. The load at which initial crack formed was also recorded during the experiment. Using the load and deflection obtained graphs were plotted to have a better understanding of the behavior of the beams.

## 3. RESULTS AND DISCUSSION

### *3.1 Behavior of voided RCC beams*

With the increase in loads the beams started to deflect. Using the values of load and displacement obtained from the four-point loading test conducted using UTM, the load versus deflection graphs are plotted for the two sets of beams and their corresponding control beam. From the load versus deflection graph the behavior of different types of voided beams and control beams can be easily understood. Load versus deflection graphs is plotted below as Fig. 4. The plots infer that both voided beams and the control beams behave in a similar pattern. From the graph it is clear that beam A3 is taking more load while the beam A1 under goes maximum deflection. From the graph the conclusion obtained is that voids introduced in tension and compression zone of concrete within the limits, does not affect the flexural behavior of the reinforced concrete beam.

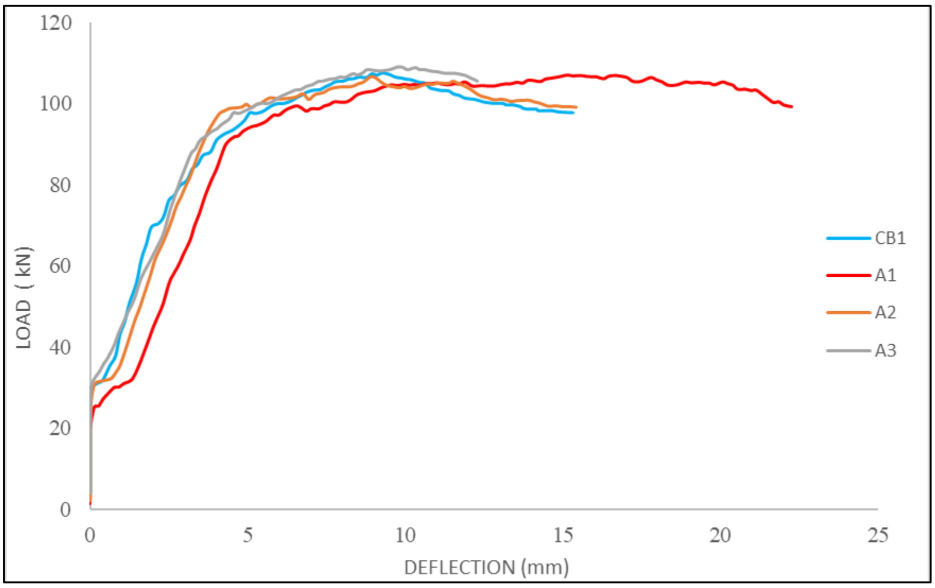


Fig. 4 Load versus deflection graph of control beam and voided beam

From the investigation carried out using four point loading it was found that the maximum load carrying capacity is shown by beam A3. The ultimate load carrying capacity of the beams are A1=106.9 kN, A2=106.6 kN, A3=109.1 kN and CB1=107.3 kN. Even though A3 showed higher strength, the magnitude of difference with other beams is quite small. Also, all the beams showed same failure pattern. Hence, it can be concluded that the flexural behavior of voided beams is exactly same as that of regular RCC beams. Therefore, voided beams can be considered as a substitution for conventional RCC beams. Interestingly it has seen that voids in compression zone also does not affect the flexural behavior of voided beams and can be subjected to further studies.

*3.2 Crack Pattern*

With the increase in load the beam started to deflect. In the initial stages of loading, voided beams as well as control beams showed no crack formation. With the increase in load cracks started to appear in similar pattern in all the beams. The failure pattern in control beam as well as in voided beams were observed as flexure shear failure. The failure pattern also thus ensured that the behavior of voided beams is exactly similar to that of conventional RCC beams.

Fig. 5 Crack Pattern in voided beam

*3.3 Concrete saving*

The introduction of voids in beams resulted in saving of concrete. The amount of concrete saved depends upon the volume of voids created. The decrease in volume of concrete is proportional to the volume of voids created. Therefore, the amount of concrete saved will be more in the case of A1 beams. The percentage of weight reduced for different voided beams compared to the control beam is given in Table 3. The decrease in amount of concrete further reduces self-weight and cost of construction. The reduction in self weight has another important advantage of using it in earthquake zone. Even though amount of concrete saved is more in the case of beams A1, the maximum deflection was also observed for A1. Hence, the voids in the beam have to be selected based on minimum deflection and maximum ultimate load carrying capacity which in the present study is for beam A3.

Table 3 Percentage of concrete saving in voided beam compared to control beam

| Beam | Weight reduced (%) |
|---|---|
| A1 | 2.36 |
| A2 | 0.67 |
| A3 | 1.35 |

## 4. CONCLUSIONS

To understand the flexural behavior of voided RCC beams, six voided beams were casted with different void patterns along with two conventional RCC beams. These beams after casting and curing for 28 days was subjected to four-point loading for determining and comparing their behavior with conventional RCC beam. Based on the results obtained following conclusions were obtained.

- The flexural behavior of voided RCC beams with voids in compression zone and voids in both compression and tension zone is similar to that of conventional RCC beams.
- The crack development pattern of voided beams also followed similar to conventional RCC beams.

- The strength of voided beams A3 was slightly greater than that of conventional RCC beams.
- The more voids in beam will increase the deflection of the beam.
- The amount of concrete saved will increase with the increase in dimension of the beams.

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