



## Flexural Strength Assessment of Hollow Reinforced Concrete Filled with Polyvinyl Chloride (PVC) Pipe at Selected Positions

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### KEY WORDS

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Position

### ABSTRACT

Reinforced concrete (RC) beams are widely used in construction due to their strength and durability, but the inclusion of openings is often necessary to accommodate utilities such as pipes, ducts, and cables. This study investigates the flexural strength of hollow reinforced concrete beams with varying void placements. Six beam samples (500 mm × 100 mm × 100 mm) were cast using a 1:2:4 concrete mix and tested under four curing periods: 7, 14, 21, and 28 days. Five beams were cast with voids at different positions, and one served as a solid control. Supporting material tests, including sieve analysis, water absorption, and slump test, were also conducted to assess material suitability. The sieve analysis revealed a well-graded sand (fine aggregate) with a uniformity coefficient (Cu) of 7.00 and a curvature coefficient (Cc) of 1.02, making it suitable for structural applications. Water absorption was found to be 4.6%, indicating moderate porosity and good durability, while the slump value of 75 mm confirmed medium workability of the mix, ideal for general-purpose structural concrete. The experimental flexural strength results demonstrated that void position significantly impacts beam performance. Beams with voids located near the supports (especially at 100 mm) performed better than those with centrally placed holes. Notably, Sample 2 (holes at 100 mm) recorded the highest strength of 3.10 MPA at 28 days, even outperforming the solid control beam, suggesting that strategic void placement can enhance crack distribution and strength retention. The water cement ratio is a fundamental parameter in concrete mix design, defined as the ratio of the weight of water to the weight of cement used in a concrete mixture. The W/C ratio used is 0.5. In conclusion, the findings demonstrate that with proper material selection, adequate curing, and well-engineered void positioning, hollow reinforced concrete beams can be structurally efficient and reliable. The study supports their use in practical applications, particularly in tropical regions like southern Nigeria, and recommends further exploration through finite element modelling to refine design strategies.

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### 1.0 INTRODUCTION

Concrete is a composite building material that consists of water, fine aggregate, coarse aggregate, and cement (Pawluczuk *et al.*, 2019). Our construction firm mainly relies on conventional construction materials such as sand, granite, and cement for concrete production (Dilbas *et al.*, 2019). When choosing aggregates for concrete, the compressive aggregate strength is taken into account. The compressive strength of concrete depends on the water to cement ratio, cement to aggregate ratio, degree of compaction, the bond

between aggregate and mortar, strength, shape, and size of the aggregates (Al-Ajmani *et al.*, 2019).

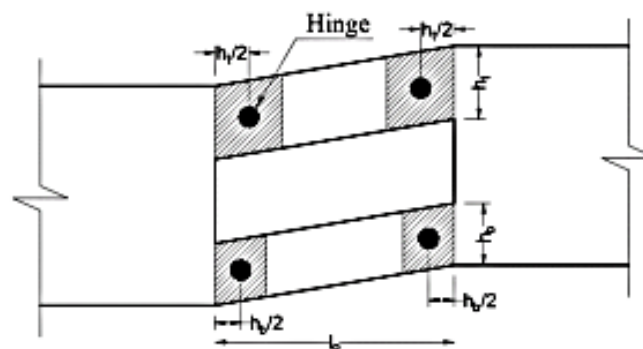
Aggregate (fine and coarse) is considered an inert filler, which accounts for 60 to 80 percent of the concrete mix and 70 to 85 percent of the concrete weight (Ferriz-Papi *et al.*, 2022). Aggregate is divided into two categories: Coarse aggregates are usually larger than 4.75 mm in size and are retained on a No. 4 sieve or bigger sieve sizes, while fine aggregates are usually lesser than 4.75 mm in size and must pass the No. 4 sieve or smaller sieve sizes. Natural sand or river sand and crushed sand constitute 35% of concrete used in the concrete construction industry (Ferriz-Papi *et al.*, 2022).

The provision of openings in beams is a practical solution to avoid extended dropped ceilings, which leads to an economical design and significant cost savings, especially in multi-storey buildings (Mansur, 2006). The presence of openings produces changes in the behaviour of the beams. Openings might be of circular, rectangular, or undefined shape, while in most cases they are placed near the supports where shear stresses are high (Fouad *et al.*, 2020). Research on perforated beams has started early in the 1960s while trying to comprehend the theory of beams with openings considering various involved parameters.

Introducing web openings into floor beams for easy passage of utility services such as air conditioning, water supply, network cables, and electricity has advantages in minimizing story heights, self-weight dead load, and construction costs (Muhammad *et al.*, 2023). However, the presence of web openings in RC beams can result in excessive deflection under service load due to decreases in stiffness. Abrupt changes in the dimensions of a cross-section of an RC beam interrupt the normal flow of stresses and cause stress concentration on residual cross-sections. This finally leads to premature crushing of concrete around the opening. To prevent any decrease in strength and ductility of beams due to the presence of openings, sufficient reinforcement should be provided using longitudinal, transverse, and diagonal reinforcing bars (Muhammad *et al.*, 2023).

The main variables affecting the ultimate capacity and behaviour of shallow-and-deep beams with openings include the cross-section properties and shear span-to-depth ratio of beams, the type and position of loading, the size, shape, and location of openings, and the amount, type, and location of opening reinforcement (Muhammad *et al.*, 2023).

This section discusses the classification of openings in RC beams in terms of size, location, shape, and execution time. In general, several research studies divided the opening in terms of its size into small and large. However, others have mentioned another in-between size, namely medium. This considered openings with a depth exceeding 0.25 the total web depth as large. On the other hand, Mansur recommended considering the opening as large if its clear length exceeds the maximum thickness of the top and bottom chord members as shown in Figure 1 (Muhammad *et al.*, 2023).



**Figure 1:** Classification of Opening in Terms of Size (Muhammad *et al.*, 2023)

**Where:**

Small opening:  $l_o \leq h_{max}$

Large opening:  $l_o > h_{max}$

This classification was based on the formation of plastic hinges at beam failure at the four corners of the opening, as mentioned by Mansur (Ahmed et al., 2012). It is worth mentioning that the clear classification of the opening as large or small should be based on the overall beam behaviour. In other words, if the beam with a web opening follows the traditional beam theories, the opening can be classified as small as its effect is negligible (Muhammad et al., 2023). In contrast, when the beam behaves in an untraditional way and does not follow the usual theory of the beam, the opening should be classified as large and much care has to be taken to understand the new behaviour of the beam. Nevertheless, structural design engineers usually adopt one of the aforementioned classification techniques, away from investigating the actual beam behaviour, to easily distinguish between small and large openings.

Another classification of openings in RC beams is based on their shapes. Openings could have different shapes according to their applications. For example, [9] showed different opening shapes, such as circular and rectangular openings, which are the most common shapes in practice. Other several shapes, such as diamond, trapezoidal, triangular, and irregular, have been presented in different studies, as described in Figure 2. Different design approaches and recommendations have been developed to accommodate the presence of the opening in RC beams.

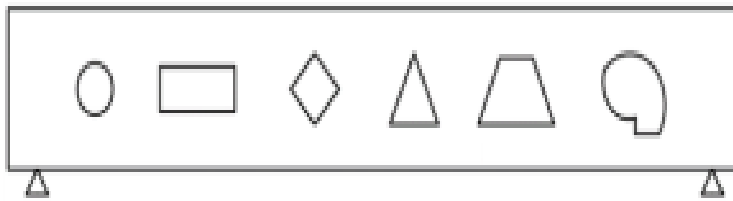


Figure 2: Classification of Opening in Terms of Shape

**Opening Execution Time**

It is worth mentioning that the opening can sometimes be fabricated after concrete casting. For example, changing the function of the building requires some new pipe connections, which might require making some openings in the existing structural elements (Muhammad et al., 2023). In such cases, strengthening of the beam using the proper technique has to be implemented. On the other hand, the pre-planned opening inside the beam has to be taken into consideration in the preliminary design stages (Muhammad et al., 2023).

Opening Direction Openings in RC beams could be placed in several locations. Abdulrahman and Rashid (2020) studied the effect of vertical openings in the beam's flange in terms of ultimate loads and corresponding deflections. In contrast, the effect of horizontal openings was reported in a study by Abdulrahman and Rashid (2020) describes the tested beam with a horizontal opening at mid-span. Based on the findings of each study, it can be concluded that the vertical opening has a more significant effect on the overall beam response than horizontal openings. The inside concrete core did not experience any part of the torsional capacity of the members. Fouad et al. (2020) conducted tests on RC beams conducted with normal concrete (NC) and high-strength concrete (HSC). The results verified that the hollow core affects the cracking capacity; however, the beams with hollow core (HC) attained the same torsional resistance of RC beams with solid sections.

## 2. MATERIALS AND METHODS

### 2.1 Material Characterization

The practical casting of concrete beams involved the use of several key construction materials, each selected for its suitability, local availability, and relevance to engineering standards.

#### 2.1.1 Fine Aggregates

The sand used in the process was sourced locally from Iyamho in Edo State, Nigeria. This sand played an important role, especially in forming the base and providing support during the beam casting. Its local origin ensured that the sand's characteristics were familiar and compatible with the environmental conditions of the site, contributing to cost efficiency and ease of handling.

#### 2.1.2 Coarse Aggregates

The coarse aggregate, specifically granite, was also obtained from Iyamho. Granite is a preferred choice in concrete production due to its hardness, strength, and durability. Using locally sourced granite reduced transportation costs and guaranteed freshness and quality. The granite was washed and sieved to ensure it met the standard aggregate grading and cleanliness required for structural concrete applications.

#### 2.1.3 Water

Potable tap water used for mixing and curing was obtained from the Civil Engineering Laboratory at Edo State University, Iyamho. Clean, uncontaminated water is essential in concrete production to ensure proper hydration of cement and to avoid adverse chemical reactions. Laboratory-grade potable water adheres to standard specifications, thereby enhancing the quality and strength of the concrete produced.

#### 2.1.4 Steel

For structural reinforcement, steel rebar were used. These were purchased from Auchi, Edo State, a nearby town known for access to construction materials. The reinforcement bars were properly cut and bent to specified dimensions and tied in place to resist tensile stresses within the concrete beams, in accordance with engineering design. This is shown in Figure 3.



Figure -3: Reinforcement

#### 2.1.5 Polyvinyl Chloride (PVC)

In addition, PVC pipes were utilized to create openings and voids within the beams as required. These pipes were also procured from Auchi, ensuring uniformity and compatibility with the local materials used. PVC was chosen due to its smooth finish, ease of cutting, and removal after casting, making it ideal for creating voids or services passage within concrete members. This is shown in Figure 4.



Figure 4: PVC Pipe

### 2.1.6 Cement

The cement used for the concrete mix was Dangote brand, obtained from Auchi, a nearby town. Dangote cement is known for its consistent quality and conformity to standard specifications such as NIS 444-1:2003 / BS EN 197-1, which ensures the cement has the required compressive strength, setting time, and chemical composition suitable for structural applications. Its use in the mix guaranteed a reliable hydration process and good mechanical performance of the concrete beams.

### 2.2: Mix Proportion and Engineering Properties

The concrete used for the casting was designed with a mix ratio (Table 1) of 1:2:4 (cement: sand: granite by weight), which corresponds approximately to a Grade 25 concrete (C20/25). The water–cement ratio adopted was 0.5, ensuring adequate workability and strength development. Materials used included Dangote Portland cement, which was procured from Auchi and conforms to standard cement specifications. The fine and coarse aggregates (sand and granite) were both locally sourced from Iyamho in Edo State, while potable water used for mixing and curing was obtained from the Civil Engineering Laboratory of Edo State University.

**Table 1: Mix Design Ratio**

Mix Ratio	Cement (kg)	Sand(kg)	Granite (kg)	Water (kg)	W/C
1:2:4	42.0	84.0	168.0	20.88	0.5

### 2.3 Physical Properties

#### 2.3.1 Sieve Analysis

Sieve analysis is a widely used laboratory method for determining the particle size distribution of granular materials such as soil or aggregates. At the Edo State University Laboratory, the test was conducted according to standard procedures typically outlined in ASTM D6913 or BS 1377. The process began with the careful collection of a representative soil sample. The sample was first oven-dried at a temperature of 105–110°C for at least 24 hours to eliminate moisture content, ensuring accurate weight measurements during sieving.

Once the shaking process was completed, the mass of soil retained on each sieve was carefully collected and weighed. The weight retained on each sieve was then used to calculate the cumulative percentage passing each sieve size. These values were plotted on a semi-logarithmic graph to form the particle size distribution curve. From this curve, key particle sizes were determined, specifically D10 (the particle size at which 10% of the sample is finer, D30 and D60 where obtained from the curve.

### 2.3.2 Water Absorption Capacity

The water absorption test is a crucial laboratory procedure used to determine the porosity and durability of concrete or block samples. At Edo State University Laboratory, the test was conducted according to standard guidelines such as BS 1881: Part 122 or ASTM C642, depending on the type of material being tested. The process began by selecting a representative solid sample often a concrete cube, block, or cylinder free from visible cracks or surface irregularities. The sample was first oven-dried at a temperature of 105–110°C for at least 24 hours to ensure that all moisture was completely removed. Thereafter, the water absorption capacity was determined.

### 2.4 Specimen

The specimen design was done as specified in the Standard. Loading assumptions were taken in order to make the case study near to the reality. The simply supported beam had 500mm span, 100mm width, and 100mm depth. Concrete strength was 25MPa. The main bars were Y12, while the shear reinforcements used were Y8 with strength of 410N/mm<sup>2</sup> (Figure 5).

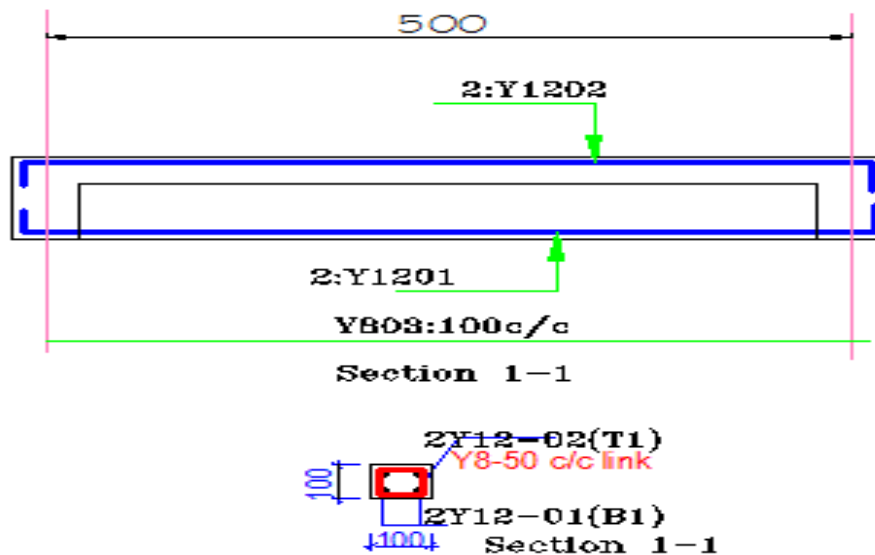


Figure 5: Beam details

### 2.5 Test Procedure (Flexural Strength and Failure Patterns)

The experimental investigation was conducted to assess the flexural strength and failure patterns of reinforced concrete beams with varying hole spacing, using standard methods. The study followed the ASTM C293 standard, which outlines the procedure for testing the flexural strength of concrete using a simple beam with centre-point loading. The entire process involved the casting, curing, and flexural testing of multiple reinforced concrete beams under controlled laboratory conditions. The concrete beams were cast in moulds with uniform internal dimensions of 500 mm length, 100 mm breadth, and 100 mm height. Each beam was reinforced with two 12 mm diameter main bars at the tension face, tied together with 8 mm stirrups spaced at 100 mm centre-to-centre. For the purpose of this study, circular holes were introduced in the tension zones of the beams using PVC pipes, which were inserted during casting and later removed after the concrete had set. The hole spacing varied for different sample groups: Sample A had holes spaced at 50 mm from each end, Sample B at 100 mm, Sample C at 150 mm, Sample D at 200 mm, while Sample E had no holes and served as the control sample. Concrete was mixed manually in batches, starting with dry mixing of cement, sand, and granite, followed by the gradual addition of water to achieve a consistent and workable mix (Figure 6). The fresh concrete was poured into the moulds in

layers and compacted using tamping rods and light vibration to remove air pockets. For each of the five sample groups, four beams were cast, resulting in a total of 24 beam specimens.



Figure of the

6: Casting Process Beams

### 3. RESULTS AND DISCUSSIONS

#### 3.1 Sieve Analysis Result

The results obtained from the sieve analysis (Figure 7) provided three important particle diameters:  $D_{10} = 0.15$  mm,  $D_{30} = 0.40$  mm, and  $D_{60} = 1.05$  mm. These values were derived from the particle size distribution curve plotted using the cumulative percentage passing versus sieve size on a semi-logarithmic graph. These specific diameters are critical in soil classification and are used to calculate key gradation parameters that indicate the soil's engineering suitability. Using the standard formulas, the Coefficient of Uniformity ( $C_u$ ) and Coefficient of Curvature ( $C_c$ ) were computed. The uniformity coefficient, calculated as, indicates that the soil is well-graded. A  $C_u$  value greater than 6 for sands (or 4 for gravels) suggests a wide range of particle sizes, which is beneficial for soil stability, compaction, and reduced permeability. Well-graded soils are typically desirable for most geotechnical applications due to their improved strength and reduced void ratio.

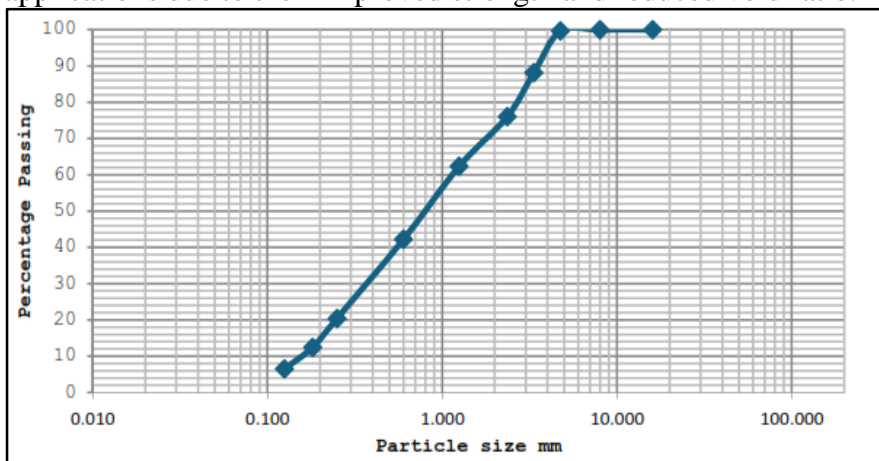


Figure 7: Sieve Analysis Result

The coefficient of curvature was found using the formula. This value falls within the acceptable range of 1.0 to 3.0, confirming that the soil has a balanced distribution of intermediate particle sizes. A suitable  $C_c$  value, when combined with a high  $C_u$ , confirms that the soil does not have any gaps or irregularities in the size distribution, further reinforcing the classification of the soil as well-graded. The sieve analysis results indicate that the soil tested at Edo State University Laboratory has a favourable gradation profile. With  $C_u = 7.00$  and  $C_c = 1.02$ , the material meets the criteria for well-graded sands as defined by the Unified Soil Classification System (USCS). Such soils are typically suitable for use in subgrade, base, and embankment construction due to their strength, compaction potential, and stability under load.

### 3.2 Water Absorption Capacity Result

In the water absorption test conducted (Table 2), the sample absorbed 23 grams of water, and the calculated water absorption was 4.6%. This result indicates the ability of the material to retain moisture, which directly relates to its porosity and long-term durability. Materials with high water absorption tend to have more interconnected pores, which can lead to reduced strength, increased permeability, and greater susceptibility to environmental degradation.

**Table 2: Water Absorption Test**

Water Absorption (%)	
Dry Weight of Aggregate	500 g
Wet Weight of Aggregate	523 g
Water Absorbed	23 g
Water Absorption (%)	4.60%

A water absorption value of 4.6% is considered moderate. According to ASTM C90, for concrete masonry units, the maximum acceptable water absorption is typically around 8% for average density concrete blocks. For paving blocks and high-strength concrete, standards such as IS 15658 recommend absorption values below 6%, and ideally below 5% for good durability in wet conditions. Therefore, the test result of 4.6% meets most international standards and indicates that the material is of good quality and moderate porosity.

Compared to established standards, the observed water absorption of 4.6% is within acceptable limits. For example, BS 1881 recommends that good-quality concrete should have water absorption less than 5%, which aligns with the test result. Similarly, Neville (2011) in *Properties of Concrete* suggests that low absorption values (typically under 5%) are associated with dense and durable concrete, capable of withstanding aggressive environmental exposure. Studies by other researchers have also provided similar benchmarks. For instance, Olutoge et al. (2012) reported water absorption values between 4.5% and 6.2% for concrete blocks containing agricultural waste ash, classifying values below 5% as excellent. In another study, Adewole et al. (2015) observed that concrete blocks with absorption rates less than 6% generally exhibited better compressive strength and reduced water permeability. Thus, the 4.6% water absorption obtained in this test places the material within the range of high-quality construction units, comparable to findings from other academic studies and technical standards. It suggests good resistance to moisture ingress and durability under service conditions, especially in tropical or moderately wet climates like that of southern Nigeria.

### 3.3 Slump Test Result

From Table 3, with a slump of 75 mm, the concrete is considered to have moderate consistency, which makes it suitable for general-purpose applications such as reinforced beams, slabs, or columns where moderate ease of placement is required without excessive segregation.

**Table 3: Slump Test Result**

Slump (mm)	75
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The mix is workable enough for placement by hand or with light equipment, while still dense and cohesive enough to maintain structural integrity. The slump result of 75 mm falls well within the recommended range for structural concrete, as noted in standards such as BS EN 206 and in literature by Neville (2011), who states that slump values between 50–100 mm are optimal for most reinforced concrete works. Additionally, Shetty (2005) in *Concrete Technology* classifies such mixes as being of "medium workability," suitable for normal reinforced structures without the need for excessive vibration. In similar

experimental studies, such as those by Olutoge et al. (2012) and Adewole et al. (2015), concrete mixes designed for strength and durability often reported slump values in the 60–90 mm range, balancing both workability and minimal risk of bleeding or segregation.

### 3.4 Flexural Strength Test Result

The flexural strength test was conducted (Figure 8) on six samples of reinforced concrete beams (five) which were hollowed at various positions, while one served as a control sample with no hole. The test results represent strength values (in MPa) obtained at 7, 14, 21, and 28 days of curing.

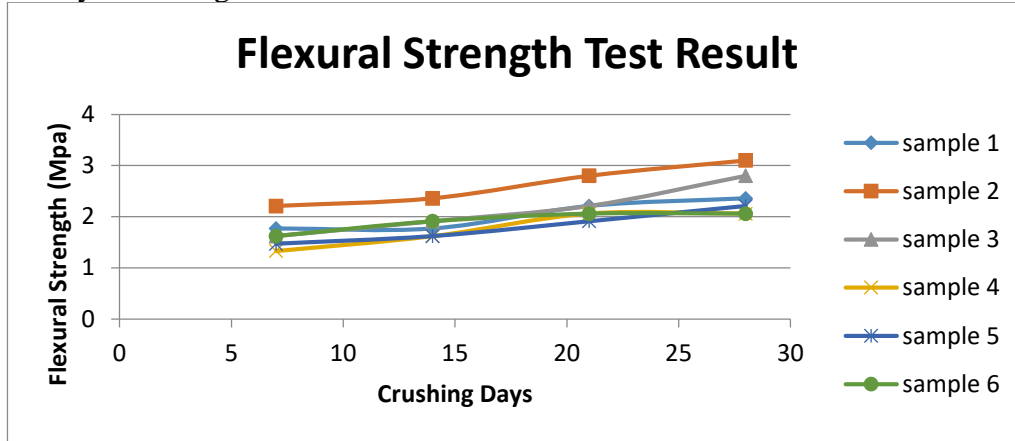


Figure 8: Flexural Strength Test Result

Sample 1, with holes placed at 50 mm from both ends, recorded flexural strengths of 1.77, 1.77, 2.21, and 2.36 MPa, respectively. While strength gradually increased with curing time, the initial 7- and 14-day values were the same, indicating delayed strength gain possibly due to stress concentration near the supports. Sample 2, with holes at 100 mm from both ends, showed the highest strength among all samples: 2.21 to 3.10 MPa over 28 days. This placement of voids appears to have the least negative impact on the bending zone, allowing better strength development and crack resistance. Sample 3, with holes at 150 mm from both ends, started lower at 1.62 MPa but reached 2.80 MPa at 28 days. The trend suggests improved structural efficiency over time but slightly delayed strength gain compared to Sample 2. Sample 4, with holes at 200 mm from the ends, reached a maximum of 2.06 MPa and then plateaued between days 21 and 28, indicating premature weakening possibly due to the holes being closer to mid-span stress zones. Sample 5 had a single central hole (250 mm) and followed a steady but lower strength development path, ending at 2.21 MPa.

This suggests that placing a hole at the mid-span (maximum moment region) reduces bending resistance due to direct interruption of the tension zone. Lastly, Sample 6 (control sample) with no hole reached a maximum of 2.06 MPa, a value lower than Sample 2 and 3, implying that some hole positions may, counter aid crack redistribution and enhance flexural strength.

According to BS EN 12390-5 (Testing hardened concrete, Flexural strength of test specimens), normal flexural strength for plain concrete beams ranges from 2.0 to 5.0 MPa, depending on mix design and curing conditions. The 28-day strengths obtained in this study ranged from 2.06 MPa to 3.10 MPa, which falls within the lower to moderate range of standard values. Sample 2, reaching 3.10 MPa, compares favourably with the expected strength of high-performance concrete under standard curing. The effect of void positioning is consistent with the findings of Akintayo and Aina (2014), who reported that voids located closer to supports have a lesser effect on bending strength than those positioned near the mid-span. Similarly, Abdulkadir and Adamu (2019) found that central openings significantly reduced flexural capacity, which aligns with the results of Sample 5 in this study. Neville (2011) also confirms that stress concentration around holes increases crack

initiation under flexural loading. Interestingly, Sample 2 (holes at 100 mm) outperformed the solid control beam (Sample 6), which agrees with experimental findings by Muthuramu et al. (2021), who observed that strategically placed voids can improve crack dispersion and stiffness due to better internal stress distribution. From the results, it is evident that the location of voids within reinforced concrete beams has a significant effect on flexural strength.

Beams with holes placed near the supports (Sample 2 and 3) developed higher strength than those with central or no holes. This suggests that void positioning can be optimized without severely compromising performance an important consideration for lightweight or material-efficient structural designs. The results align with both standards and published literature, supporting the feasibility of using hollow beams with thoughtful engineering.

## CONCLUSION

The sieve analysis showed that the soil sample is well-graded, with  $C_u = 7.00$  and  $C_c = 1.02$ , indicating a wide and balanced distribution of particle sizes. Such grading enhances strength, compaction, and stability, making the soil appropriate for use in subgrade and embankment works. The water absorption test revealed a value of 4.6%, which falls within the acceptable limits set by international standards like ASTM C90 and BS 1881. This moderate absorption level reflects a concrete mix that is sufficiently dense and durable, with good resistance to moisture-related deterioration. The slump test result of 75 mm indicates medium workability, confirming that the mix is suitable for general reinforced concrete applications, with ease of placement and minimal risk of segregation or bleeding. The flexural strength and crack pattern tests show that hole position greatly influences beam performance. Beams with holes near the supports (Samples 1 and 2) had better strength and fewer critical cracks, with Sample 2 performing the best (3.10 MPa). In contrast, beams with central holes (Samples 4 and 5) showed early, wider cracks and lower strength. Surprisingly, Sample 2 outperformed the solid control beam, suggesting that well-placed voids may improve crack control. Holes in beams should be avoided near midspan, especially under flexural load-dominated conditions.

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