

**EFFECT OF VERTICAL RECTANGULAR OPENINGS ON THE FLEXURAL
STRENGTH OF REINFORCED CONCRETE BEAM**

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**AYODELE, Olawale Alexander
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**DEPARTMENT OF CIVIL ENGINEERING,
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA**

AUGUST, 2021

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**A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL
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ABSTRACT

Effect of vertical rectangular openings on the flexural strength of reinforced concrete beam is presented. Twelve reinforced concrete beams of dimension 200mm x 230mm x 700mm with different sizes of rectangular openings, 25mm x 35mm, 50mm x 60mm and 75mm x 85mm which are placed at 150 mm from the supports, were cast. After curing, these beams were tested under centre-point loading system using universal testing machine and the flexural strength were determined. The results show that the flexural strength of the beams reduces gradually with the increase in the sizes openings. The optimum flexural strength was 13.47 N/mm^2 with opening size of 25mm x 35mm, also the maximum deflection was 14.19 mm, which do not exceed 20 mm allowable deflection provided by BS 8110. Hence, it is hereby recommended that introduction of vertical rectangular openings on reinforced concrete beam should not exceed portions of 150 mm from the supports and openings of 75mm x 85mm sizes.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

In modern constructions ducts and pipes are usually placed underneath the soffit of the beams and covered by a suspended ceiling thus creating a dead space. On each floor, the height of these ducts and pipes add dead space to the overall height of the building depending on the number and height of ducts. So concealing the pipe as conduits to pass through walls, columns, beams, and slabs reduce the story heights of buildings and weight of concrete beams as it improves the demand on the supporting frame both under gravity loading and seismic excitation which results in major cost saving (Abdul-Kareem *et al.*,2017). Utility pipes and ducts are necessary to accommodate essential services in a building. The types of services include air-conditioning, power supply, telecommunication network, computer network, sewerage and water supply (Sharmin, 2014).

In general, the influence of openings on the beam's strength and deformation depends on the openings' location and size. If the positions are selected wisely, larger openings on reinforced concrete beam structures can be provided without affecting the ultimate load. However, small openings positioned in an unfavorable place can cause a dramatic decrease in the beam's strength. For that reason, it is necessary to plan the size and location of the openings accurately. However, if the beam is pre-designed to have an opening of known size and location, this will be sufficient to ensure the safety and serviceability of the structure. These openings can be of different shapes and sizes as circular, square or rectangular, diamond, triangle and irregular shapes (Ali *et al.*,2017).

It has been noted that the classification of opening depended on the structural response of the beam; when the opening is small enough to maintain the beam-type behavior, then the opening could be termed as small opening. Otherwise, large openings are those that prevent beam-type behavior to develop (Saksena, 2013). A circular opening may be considered as large when its diameter exceeds 40% of the depth of the web, but square opening considered as large when height exceed quarter of the depth of the web.

Little researches are found on the effect of vertical openings in reinforced concrete beams (Oladipo, 2019). However, in ACI 314R-16 (2016) simplified design for reinforced concrete buildings recommends the possibility of creating vertical openings through a beam.

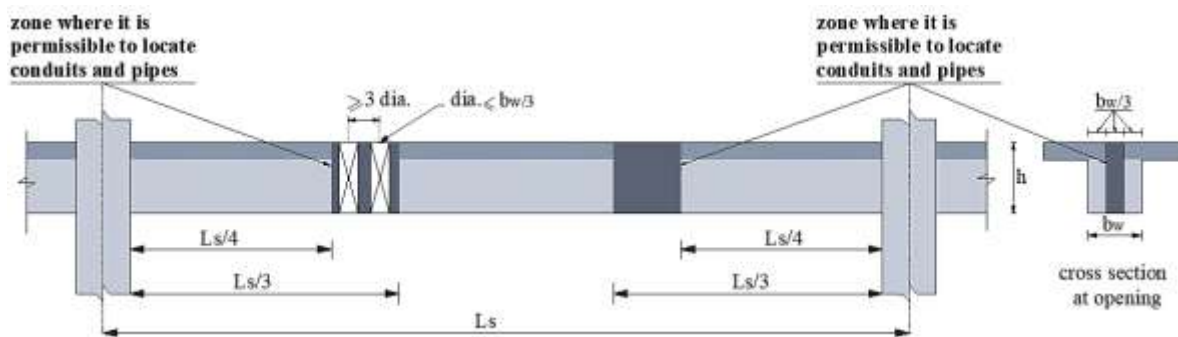


Figure 1.1: Location of conduits and pipes passes vertically through beams, *Source:* Ahmed (2020)

1.2 Statement of the Research Problem

The advancement in construction has made the need for vertical openings in beams a necessity. The architects have been working on designing more complex structures, and the ICT world turning homes into smart houses, which has caused the engineering field to work on this opening of different shapes on web (Vivek and Madhavi, 2016) and vertical openings (Oladipo, 2019), the recent researcher recommends further work on the effect of vertical rectangular

openings on beams (Oladipo, 2019) which is the focus of this research as it might fit into the modern structures.



Plate I: A typical structural building under construction with vertical circular pipe passing through a reinforced concrete beam (Abuja – 27/01/2020).

1.3 Aim and Objectives of the Study

1.3.1 Aim

The aim of this research is to study the effect of vertical rectangular openings on the flexural strength of reinforced concrete beam.

1.3.2 Objectives

The objectives of this study are to:

- i. determine the physical properties of aggregate;
- ii. determine the compressive strength;
- iii. determine the flexural strength and deflection of all cured beam specimens.

1.4 Justification of the Study

With the technical clarity on where to place and the size of rectangular openings in beam and the effect of the rectangular openings at other zones of the beam, would help engineers on field to take right decision in placing the utility pipes, plumbing pipes and networking lines on beams, it will also help to ensure the safety in engineering practices and the serviceability of the structures. (Vivek and Madhavi, 2016; Oladipo, 2019)



(a) Mechanical pipe



(b) Electrical pipe



(c) Mechanical pipe

Plate II: Typical structural buildings under construction with vertical circular pipe passing through a reinforced concrete beam. *Source:* Sumrec Estate airport road Lugbe, Abuja (27/01/2020)

1.5 Scope of the Study

The scope of this study is to research a reinforced concrete rectangular beam section (200mm x 230mm x 700mm) with vertical rectangular opening through its selected opening size of 25mm x 35mm, 50mm x 60mm, 75mm x 85mm provide at 150mm from the support and obtain the

maximum failure load, deflection with the experimental results of the same rectangular beam section. The summary of the scope is presented in Table 1.1.

Table 1.1: Details of beams specimen

S/n	Beam details	No of specimen	Size of opening (mm)	Distance from support (mm)
1	Control beam without openings	2	-	
2	Control beam without opening non reinforced	1		
3	Beam with opening	3	25mm x 35mm	150mm
4	Beam with opening	3	50mm x 60mm	150mm
5	Beam with opening	3	75mm x 85mm	150mm

CHAPTER TWO

2.0

LITERATURE REVIEW

2.1 Reinforced Concrete Beam

The reinforced concrete beam is frequently used in structures and machines, and its elementary stress analysis constitutes one of the more interesting facets of mechanics of materials. A beam is a member subjected to loads applied transverse to the long dimension, causing the member to bend. For example, a simply-supported beam loaded at its three points will deform into the exaggerated bent shape. Before proceeding with a more detailed discussion of the stress analysis of beams, it is useful to classify some of the various types of beams and loadings encountered in practice. Beams are frequently classified based on supports or reactions, a beam supported by pins, rollers, or smooth surfaces at the ends is called a simple beam. A simple support will develop a reaction normal to the beam, but will not produce a moment at the reaction. If either, or both ends of a beam, projects beyond the supports, it is called a simple beam with an overhang. A beam with more than simple supports is a continuous beam.

Cantilever beams and simple beams have two reactions (two forces or one force and a couple) and these reactions can be obtained from a free-body diagram of the beam by applying the equations of equilibrium. Such beams are said to be statically determinate since the reactions can be obtained from the equations of equilibrium. Continuous and other beams with only transverse loads, with more than two reaction components, are called statically indeterminate since there are not enough equations of equilibrium to determine the reactions.

In general, the influence of openings on the beam's strength and deformation relies upon the openings' location and size. If the place is selected wisely, quite large openings on RC beam structures can be provided without affecting the ultimate load. For that reason, it is necessary to plan the size and place of the openings accurately Ahmed and Ammar (2020), recommends passing the opening vertically through a beam by using the following guidelines:

- a). The vertical openings should not have diameters greater than one-third of the beam's width.
- b). The minimum distance from the opening to the closest face of the beam shall be at least 5 cm (Figure 2.1) and twice the cover provided on that face.
- c). If a set of openings is required, they must be aligned and the distance between their faces must be at least 5 cm or the opening diameter and each gap must contain at least one stirrup. Beams details with supports as shown in Figure 2.1.

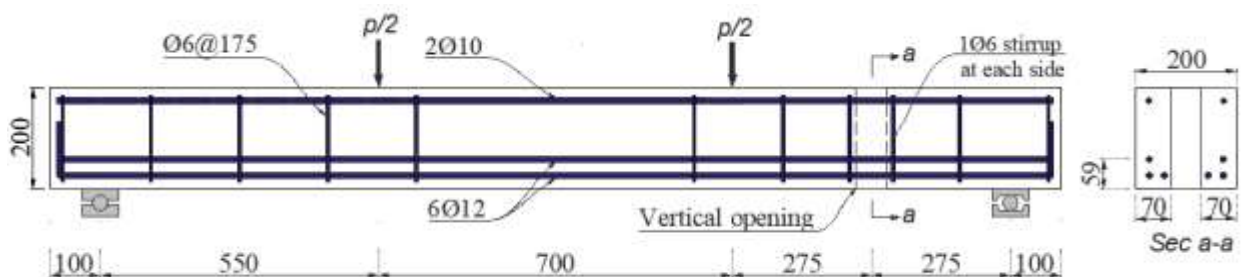


Figure 2.1: Beams details with supports, *Source:* Ahmed and Ammar (2020)

2.2 Classification of Openings

The classification of reinforced concrete beams with web openings is based on the opening's size and position. Web openings are found to have many shapes such as circular, rectangular, diamond, triangular, trapezoidal and even irregular shapes. However, circular and rectangular openings are

the most commonly used. According to Thomas *et al.* (2016), a circular opening may be considered as large when its diameter exceeds 0.25 times the depth of the web.

However, the essence of classifying an opening as either small or large lies in the structural response of the beam. When the opening is small enough to maintain the beam-type behaviour, or in other words, if the usual beam theory applies, then the opening may be termed as small but when beam-type behaviour ceases to exist due to the provision of openings, then the opening may be classified as a large opening according to Mansur and Tan (1998) recommended these criteria to classify the size of an opening as either large or small. It can be assumed that hinges form in the chord members at a distance of $\frac{h}{2}$ from the vertical faces of the opening (Somes, (1974). Where h is the overall depth of a chord member, and the subscripts t and b refer to the top and bottom chords, respectively.

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

Large opening- $l_o > h_{max}$

Mansur and Tan (1998) illustrated the selection of the size and location of web openings as for T beams, openings should preferably be positioned flush with the flange for ease in construction. In the case of rectangular beams, openings are commonly placed at mid-depth of the section. Openings should not be located closer than one half of the beam's depth D to the supports. This is in order to avoid critical region for shear failure and reinforcement congestion. Similarly, the positioning of an opening closer than $0.5D$ to any concentrated load should be avoided.

Depth of openings should be limited to 50% of the overall beam depth. When the opening becomes bigger, it is preferable to use multiple openings providing the same passageway instead of using a

single opening. When multiple openings are used, the post separating two adjacent openings should not be aforementioned less than $0.5D$ to ensure.

2.3 Studies on Beams with Openings

2.3.1 Straight shallow beams

Mansur *et al.* (1983) carried out studies on RC beams with large rectangular openings under pure torsion. It is found that torsional strength and stiffness of a beam decrease with increasing opening length or depth, but appear to be marginally influenced by its eccentricity. The beams fail by the formation of a mechanism with four hinges, one at each corner of the opening.

The study on optimum hole shapes in beams under pure bending, effective method of weight reduction for a beam in pure bending is to remove material near the neutral axis, in the form of holes was carried out by Naik *et al.* (1986). Minimizing the stress concentration around these holes is an important consideration in engineering design. One of the methods to minimize the stress concentration is to change the hole shape itself until the optimized shape with minimum stress concentration factor is reached within specified geometric constraints and loading condition.

Mansur *et al.* (1991) carried out an experimental investigation on reinforced-concrete continuous beams with openings. Variables considered are number of spans, the size of opening, and its location along the span. Failure of the beam occurs by the formation of a mechanism, and the two opening ends represent the most vulnerable locations for the development of plastic hinges. The strength and stiffness of the beam decrease with an increase either in the length or depth of opening. The effect of web openings in slender beams was investigated by Thevendran and Shanmugam (1991) and the presence of web openings not only reduces the ultimate strength of beams, but also

the lateral buckling capacity. Based on the energy approach, a numerical method was developed to predict the critical lateral-buckling loads of slender, doubly symmetric beams containing unreinforced web openings. The critical loads evaluated numerically are compared with the values obtained experimentally. The study shows good agreement between the numerical and experimental values.

Strut-and-tie model for the analysis of a reinforced concrete beam that contains geometric discontinuities in the form of a transverse circular opening in the web. A comparison of the theoretical predictions concerning the ultimate strength, mode of failure, and the proportion of the applied shear carried by the chord members above and below the opening shows good agreement with test results. The truss model explains clearly the role of diagonal reinforcement in relieving the concrete distress at the throat section by transferring across the discontinuity a significant amount of applied shear as studied by Mansur and Tan (2001).

Reinforced concrete beams with openings un-strengthened and strengthened with FRP sheets. The effect of this strengthening technique on deflection, strain, cracking, and ultimate load was investigated. An experimental investigation on the behaviour and strength of reinforced concrete beams with shear openings was carried out. The presence of an un-strengthened opening in the shear zone of a reinforced concrete beam significantly decreases its ultimate load carrying capacity. An un-strengthened opening with height of 0.6 the beam depth may reduce the beam capacity by 75%. Abdalla *et al.* (2003) investigated the application of CFRP sheets greatly decreases beam deflection, cracks around opening, and increases the ultimate load carrying capacity of the beam. The use of FRP sheets to strengthen the area around openings may retrieve the full capacity of the beam for relatively small openings.

Maaddawy and Ariss (2012) conducted studies on RC beams with web openings strengthened in shear with externally bonded CFRP composite sheets. The test parameters were the width and depth of the opening and the amount of the CFRP sheets used for shear strengthening. Test results showed that the inclusion of web openings drastically reduced the beam shear capacity and stiffness. External strengthening with CFRP sheets around the opening was found to be very effective in improving the beam shear resistance and stiffness. Increasing the opening width or depth reduced the gain in the shear capacity. Doubling the amount of the vertical CFRP sheets from one to two layers increased the shear capacity but the additional shear capacity gain was not in proportion to the added amount of the CFRP.

Aykac *et al.* (2013) investigated the influence of multiple web openings along the length of an RC beam on its flexural behavior. Diagonal reinforcement around openings effectively prevented premature failure of some specimens due to *Vierendeel* action. Longitudinal rebar's and full-depth stirrups adjacent to openings and short stirrups in the chords prevented beam-type and frame-type shear failures. The length of the plastic failure mechanism increased in the presence of multiple openings compared to beams with a single opening. The beams were simply supported at the ends and subjected to six-point bending. The test results were compared to the estimates from available equations.

2.3.2. Straight deep beams

Mansur and Alwis (1984) investigated the behavior of reinforced fiber concrete deep beams with rectangular openings in the web. The major parameters of the study were the volume fraction of fibers, opening location, shear span to effective depth ratio and the amount of web reinforcement. Test results indicate that the amount of web reinforcement, either in the form of discrete fibers or as continuous reinforcement. Available strength equations for non-fiber concrete deep beams are shown to provide a reasonable prediction of the ultimate strength for fiber reinforced concrete.

The stress distribution in deep beams with and without web openings. The general form of stress diffusion has been established and the critical zones have been identified. The critical tensile and shear stresses have been evaluated and their sensitivity to various span-to-depth ratios and opening positions along the span has been established. Based on stress flow pattern and contour lines of principal tensile stresses, failure mechanisms have been predicted and recommendations have been made for the design of reinforced concrete deep beams (Haque *et al.*, 1986).

The study to estimate the influence of web openings in reinforced concrete deep beams. Test variables included are concrete strength, shear span-to-depth ratio, and the width and depth of the opening. Test results indicated that the strengths at diagonal crack and at peak were closely related to the angle of the inclined plane joining the support and the corner of the web opening. Also, the influence of concrete strength on the ultimate shear strength remarkably decreased in deep beams with openings and also study on reinforced concrete deep beams with openings. The main variables considered were the opening size and amount of inclined reinforcement. An effective inclined reinforcement factor combining the influence of the amount of inclined reinforcement and opening size on the structural behavior of the beams tested is proposed by Yang *et al.* (2008). It was

observed that the diagonal crack width and shear strength of beams tested were significantly dependent on the effective inclined reinforcement factor that ranged from 0 to 0.318 for the test specimens. As this factor increased, the diagonal crack width and its development rate decreased, and the shear strength of beams tested improved. Beams having effective inclined reinforcement factors of more than 0.15 had higher shear strengths than that of the corresponding solid beam. Predictions obtained from the proposed formulas have a consistent agreement with test results.

Maaddawy and Sherif (2009) examined the potential use of externally bonded carbon fiber reinforced polymer (CFRP) composite sheets as a strengthening solution to upgrade reinforced concrete deep beams with openings. Test parameters included the opening size, location, and the presence of the CFRP sheets. The structural response of RC deep beams with openings was primarily dependent on the degree of the interruption of the natural load path. Externally bonded CFRP shear strengthening around the openings was found very effective in upgrading the shear strength of RC deep beams. The strength gain caused by the CFRP sheets was in the range of 35–73%.

Evaluation of the influence of circular openings in reinforced concrete deep beams with low shear span-to-depth ratio in flexure under four-point loading. Campione and Minafo (2012) says comparative analysis of the experimental results shows that the effect of the hole depends on its position in the beam; the benefit of the presence of reinforcement depends on its arrangement. An analytical model is proposed to predict the shear strength and corresponding deflection of deep beams with openings and the results are also compared with a non-linear finite element analysis showing good agreement.

Reinforced concrete deep beams with large openings, reinforcement detailing of deep beams based on strut-and-tie models can be complex and very often, these models may not predict the failure mechanism of deep beams due to localized damages. Sahoo *et al.* (2012) studied the performance of two RC and two steel fiber-reinforced concrete (SFRC) deep beams with large openings under monotonically increased concentrated loads. The RC specimen with strengthened boundaries exhibited a ductile mode of failure and had significantly higher ultimate strength than predicted by STMs. The SFRC specimens with 1.5% volume fraction of fibers reached much higher strength than the design load and exhibited significant post peak residual strength and a ductile mode of failure.

Investigating the effects of the opening shape and location on the structural behavior of reinforced concrete deep beams, while keeping the size of the opening unchanged as carried out by Alsaeq (2013). The results conclude that the opening location has much effect on the structural strength than the opening shape also placing the openings near the upper corners of the deep beam may double the strength, and the use of a rectangular narrow opening, with the long sides in the horizontal save up to 40% of structural strength of the deep beam.

2.3.3 Curved beams

The investigation of behaviour and performance of reinforced concrete horizontally semi-circular curved beams with and without openings, unstrengthen and strengthened externally by CFRP laminates or internally by steel reinforcement (Ali and Hemzah 2014) observed that the beams were tested under the action of two point loads at top face of mid-spans with three supports at bottom face. The results showed that the presence of opening has a great effect on the behavior and ultimate load capacity of semi-circular curved beams, while the strengthening of these opening

by internal steel reinforcement or external CFRP laminates will increase the ultimate load capacity and affect post-cracking behavior and mode of failure of these beams.

Investigation on the behavior and performance of reinforced concrete curved ring beams with and without openings, unstrengthen and strengthened externally by CFRP laminates or internally by steel reinforcement.

2.3.4 Vertical openings in reinforced concrete beams

The experimental results showed that the presence of a vertical opening slightly reduced the ultimate load capacity. In addition, it has an insignificant effect on increasing the maximum deflection at the service loads. On the other hand, it is found that the circular shape of openings exhibited a lower effect on reducing the ultimate load capacity than square openings as study by Ahmed and Ammar (2020)

Oladipo (2019) reveal that reinforced concrete beam with vertical circular openings of diameter greater than 33.3% of beam width reduced its flexural strength by at least 20%; maximum compressive stress of concrete occurs at the openings region of the beam; and the difference in ultimate load capacity of finite element (FE) beam models and experimental beam specimen is 3.5%, to predict the behaviour of RC beams diameter of vertical circular opening in RC beam should not exceed 33.3% of the beam width and its location from beam support should not exceed $L/6$ as show in Figure 2.1. In this paper, we shall consider how the flexural strength of reinforced concrete beam respond structurally when a rectangular opening is created through its depth.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials that were used in this study and whose preliminary tests were conducted to specification of codes of practice, are as follow:

- i. Coarse aggregate;
- ii. Fine aggregate;
- iii. Ordinary Portland cement (OPC);
- iv. Water;
- v. Iron bar.

3.1.1 Fine aggregate

Fine aggregate includes the particles that all passes through 4.75 mm sieve and retain on 0.075 mm sieve.

3.1.2 Sieves analysis

Sieve analysis is a simple operation of dividing a sample of aggregate into fractions, each consisting of particles of the same size. In practice, each fraction contains particles between specific limits, these being the opening of standard test sieves. The test sieves used for concrete aggregate have squared openings. The weights of the sample retained on sieve after shaking and their percentage were calculated using the expression below: Weight of aggregate retained= (weight of sieve of aggregate) - weight of sieve

$$\text{Percentage aggregate weight retained} = \frac{\text{weight of aggregate retained}}{\text{total weight of aggregate used}} \times 100 \quad (3.1)$$

3.2 Coarse Aggregate

Coarse aggregate includes the particles that retain on 4.75 mm sieve.

3.2.1 Aggregate crushing value test

Place the cylinder of the test apparatus in position on the baseplate and add the test specimen in three layers of approximately equal depth, each layer being subjected to 25 strokes from the tamping rod distributed evenly over the surface of the layer and dropping from a height approximately 50 mm above the surface of the aggregate. Carefully level the surface of the aggregate and insert the plunger so that it rests horizontally on this surface. Take care to ensure that the plunger does not jam in the cylinder. Place the apparatus, with the test specimen prepared plunger in position, between the platens of the testing machine and load it at as uniform a rate as possible so that the required force of 400 KN is reached in $10 \text{ min} \pm 30 \text{ s}$. Release the load and remove the crushed material by holding the cylinder over a clean tray of known mass and hammering on the outside of the cylinder with the rubber mallet until the particles are sufficiently disturbed to enable the mass of the specimen to fall freely on to the tray.

Transfer any particles adhering to the inside of the cylinder, to the baseplate and the underside of the plunger, to the tray by means of a stiff bristle brush. Weigh the tray and the aggregate and determine the mass of aggregate used (M_1) to the nearest gram, Sieve the whole of the test specimen on the tray on the 2.36 mm test sieve until no further significant amount passes during a further period of 1 min. Weigh and record the masses of the fractions passing and retained on the sieve to the nearest gram (M_2 and M_3 respectively). If the total mass of the two individual fractions (M_2 plus M_3) differs from the initial mass (M_1) by more than 10 g, discard the result and repeat the complete procedure using a new test specimen in accordance to BS812-110 (1990).

Calculate the aggregate crushing value (ACV) expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the test specimen from the following equation:

$$ACV = \frac{M_2}{M_1} \times 100 \quad (3.2)$$

Where: M_1 is the mass of the test specimen (in g);

M_2 is the mass of the material passing the 2.36 mm test sieve (in g).

3.2.2 Aggregate impact value test (AIV)

The impact machine shall rest without wedging or packing upon the level plate, block or floor, so that it is rigid and the hammer guide columns are vertical. The cup shall be fixed firmly in position on the base of the machine and the whole of the test sample placed in it and compacted by a single tamping of 25 strokes of the tamping rod. The hammer shall be raised until its lower face is 380 mm above the upper surface of the aggregate in the cup, and allowed to fall freely on to the aggregate.

The test sample shall be subjected to a total of 15 such blows each being delivered at an interval of not less than one second. The crushed aggregate shall then be removed from the cup and the whole of it sieved on the 2.36-mm IS Sieve until no further significant amount passes in one minute. The fraction passing the sieve shall be weighed to an accuracy of 0.1 g (Weight B). The fraction retained on the sieve shall also be weighed (Weight C) and, if the total weight (B+C) is less than the initial weight (Weight A) by more than one gram, the result shall be discarded and a fresh test made in accordance to BS812-112 (1990).

$$\text{Aggregate impact value} = \frac{B}{A} \times 100 \quad (3.3)$$

Where: B = Weight of fraction passing 2.36-mm IS Sieve

A= Weight of oven-dried sample.

3.3 Cement

Cement is a substance used for binding and hardening other materials. Water and cement set and harden through a chemical reaction known as hydration. The process of hardening is described as curing. The cement that will be used is Ordinary Portland cement with grade 42.5 N.

3.4 Formwork

In this study steel moulds were used as formwork (Plate III) which were fabricated to accommodate the concrete beam size of 200mm x 230mm x 700mm. The formwork was braced such that the angle iron brace is placed at 200mm interval. The edges were also braced to prevent bulging during the taping of the concrete when poured.



Plate III: Steel moulds fabricated in the laboratory

3.5 Steel Reinforcement

Steel reinforcement bars are used to improve the tensile strength of the concrete since concrete is very weak in tension but is strong in compression. Steel is only used as rebar because elongation of steel due to high temperatures (thermal expansion coefficient) nearly equals to that of concrete. Thermo mechanically treated bars will be used in this research because of its strength, ductility, welding ability, bending ability, economical and the safe in use. Steel bars of 12mm diameter (Y12) will be use as compression and tension reinforcement and 10mm diameter bars (Y10) were used as shear reinforcement as shown in Plate IV.

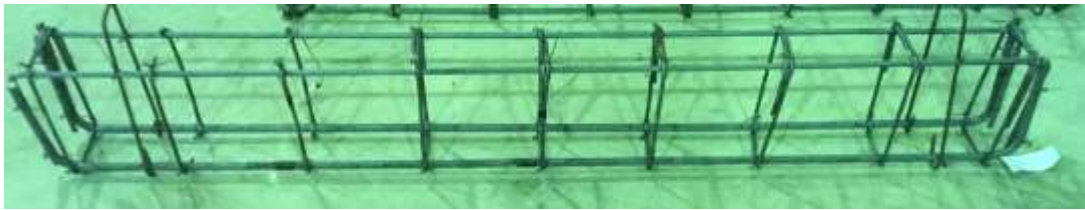


Plate IV: Longitudinal reinforcement and stirrups

3.6 Concrete Mix Ratio

Concrete mix design is the process of finding right proportions of cement, sand and aggregate for concrete to achieve target strength required in structure. So concrete mix design can be stated as Concrete Mix = Cement: Sand: Aggregates. The mix proportion of 1:2:4 by volume of cement, sand and granite aggregates with water-cement ratio of 0.45 will be considered for casting the beams. Hand –mix method was use in mixing the concrete.

3.7 Description of Specimen

The beam size to be use for the research will be 200mm x 230mm x600mm with 4 numbers of 12mm diameter bars which handles the tension and compression reinforcement and 10mm diameter bars as stirrup at 150mm c/c, the concrete cover to reinforcement will be 20mm

minimum. The rectangular opening size, 25mm x 35mm, 50mm x 60mm, 75mm x 85mm at 150mm distance to the supports. For the purpose of this research 12 numbers of beams sample were casted while 3 will be the control beam (2 reinforced without opening while 1 is without reinforced control beam) as shown in Table 3.1 and 9 beams with varying rectangular opening sizes spaced at 150mm interval from supports.

Table 3.1: Details of beams specimen

S/n	Beam details	No of specimen	Size of opening (mm)	Distance from support (mm)
1	Control beam without openings	2	-	
2	Control beam without opening non reinforced	1		
3	Beam with opening	3	25mm x 35mm	75mm
4	Beam with opening	3	50mm x 60mm	75mm
5	Beam with opening	3	75mm x 85mm	75mm

The bending strength test conducted on the concrete beams satisfied the requirements of British Standards Institution (1983), using the Centre-point loading method as shown in Figure 3.1. A mix proportion of 1:2:4 by volume of cement, sand and granite aggregates with water-cement ratio of 0.45 were used for casting the beams. In order to study the effect of parameters related to opening in the beam, the amount of shear and flexural reinforcements, their strength and the stirrups spacing, along all beams were considered constant.

Reinforcement bars were placed in the lubricated formwork and filled with concrete in three layers, each layer compacted with 25 blows using tamping rod. After the setting of the concrete beams had taken place, the formwork was carefully detached. After the curing of the beams were subjected to flexural strength tests on a flexural testing machine. During testing, each of the samples were placed in position in the flexural testing machine, correctly centered with the longitudinal axis of the beam at right angle to the supporting and load-applying rollers. This ensured that the top and bottom surfaces of the beam were parallel so that the loading was uniform across the width of the beam.



Figure 3.1: Centre-point load bending test

3.7.1 Compressive strength test

Compressive strength is the ability of material or structure to carry the load on its surface without any crack or deflection. Compressive strength test will be conducted in accordance to BS1881-116 (1983) specification. Concrete cubes will be removed from the curing tank at each curing day and cleaned. The mass (m) and volume (v) of concrete cubes were determined.

The unit weight was calculated, thus;

$$\text{Unit weight} = \frac{\text{Mass (m)}}{\text{Volume(v)}} \quad (3.4)$$

The cubes were subjected were to load by the compression testing machine. The failure load will be recorded. The compressive strength of the concrete will be calculated, thus;

$$\text{Compressive strength} = \frac{\text{Load (p)}}{\text{Area(A)}} \quad (3.5)$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

The results obtained and presented are as follow:

- i) Aggregate crushing value;
- ii) Aggregate impact value;
- iii) Sieve analysis test;
- iv) Specific gravities test;
- v) Compressive strength;
- vi) Flexural strength test.

4.2 Physical Properties of the Aggregates

The physical properties of the aggregates investigated in this study are aggregate crushing value, aggregate impact value, particle size distribution, specific gravity and the bulk density.

4.2.1 Aggregate crushing value

Aggregate crushing value is the relative measure of the resistance of an aggregate sample to crushing under a gradually applied compressive load. Aggregate sample subjected to crushing finer than 2.36mm is usually expressed in percentages of the original weight before crushing and this percentage is called the aggregate crushing value. The result of the aggregate crushing value for the coarse aggregate used in this study is presented in Table 4.1. from the table its value can be observed that the aggregate is fit for use even for concrete used for road and pavements as the aggregate crushing value for the coarse aggregate is less than the limiting value of 40 (Shetty, 2005).

Table 4.1: Aggregate crushing value

SN	Description	A	B	C
1	weight of material in mould	1500	1520	1491
2	weight of material passing sieve 2.36mm	392	384	380
3	Aggregate crushing value (ACV)	26.13	25.26	25.49
	Average ACV		25.63	

4.2.2 Aggregate impact value

This is a property of aggregates used in meaning the resistance of the aggregate to failure by impact, aggregate impact value is usually a measure of the toughness of the aggregate. the aggregate impact value for the coarse aggregate used in this study is presented in Table 4.2.

Table 4.2: Aggregate impact value

SN	Description	A	B	C
1	Mass of sample before test	1430	1439	1428
2	Mass of sample retained on No 7 sieve	1172	1185	1194
3	Mass of sample passing No 7 sieve	258.0	254.0	234.0

4	Aggregate impact value (AIV)	18	17	16
	Average AIV		17	

4.2.3 Particle size distribution

The particle size distributions of aggregates (fine and coarse) are usually determined with the aid of sieve analysis. The result of the sieve analysis for the coarse and the fine aggregates used in this study are tabulated in Table 4.3 and 4.4 respectively. The particle size distribution curve for the fine and coarse aggregate are plotted in Figure 4.1 and 4.2 respectively. From both figures, it can be seen that the grading curve for the aggregate (fine and coarse) are within the grading limit and as such both the fine and coarse aggregate are fit for the purpose of this study (Shetty, 2005).

From the sieve analysis test conducted on the fine aggregate, the fineness modulus of the fine aggregate which was obtained as the ratio of the sum of the cumulative percentage retained on the standard sieve set and an arbitrary number (in this study 100) is 3.01. This implies that the fine aggregate can be said to be a coarse sand and since the fineness modulus obtained in this study is lower than the limiting value of 3.2, the fine aggregate can be said to be fit for use in concrete production (Zaniewski and Mamlouk, 2006).

Table 4.3: Sieve analysis test result of coarse aggregate

Sieve size (mm)	Weight Retained	% Retained	Cum. % retained	% passing	Specification	
					Minimum	Maximum
50	0	0	0	100	100	100
37.5	0	0	0	100	100	100
19.05	600	9.8	9.8	90.2	85	100
9.52	4965.2	80.7	90.5	9.5	0	25
4.76	511.3	8.3	98.8	1.2	0	5

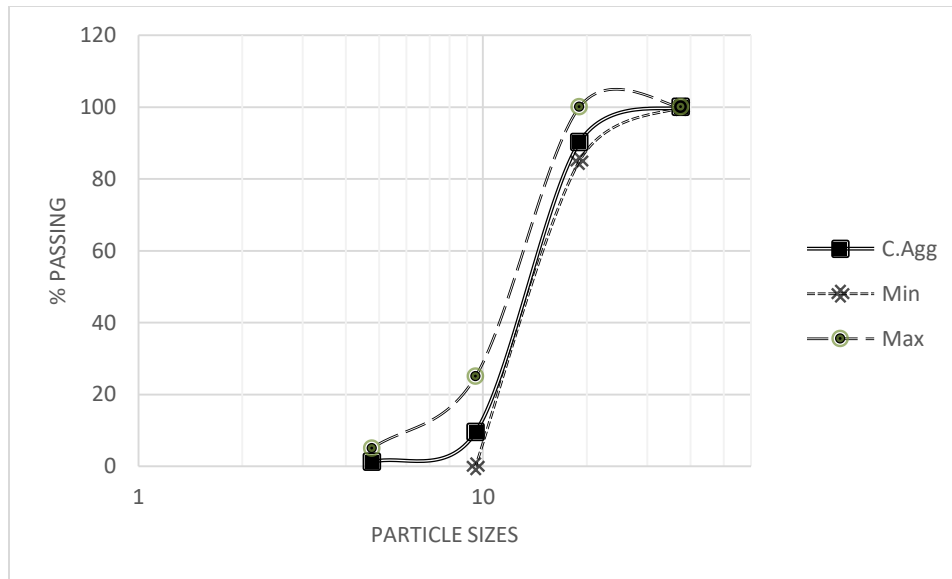


Figure 4.1: Particle size distribution curve of coarse aggregate

Table 4.4: Sieve analysis test result of fine aggregate

Sieve size(mm)	Weight Retained	% Retained	Cum. % retained	% passing	Specification	
					Minimum	Maximum
19.05	0	0	0	100	100	100
12.7	0	0	0	100	100	100
9.52	0	0	0	100	100	100
4.75	54	6.2	6.2	93.8	90	100
2.36	111.2	12.7	18.9	81.1	75	100
1.18	175	20	38.9	61.1	55	90
0.6	206	23.5	62.4	37.6	35	59
0.3	179.1	20.5	82.9	17.1	8	30
0.15	73.8	8.4	91.3	8.7	0	10

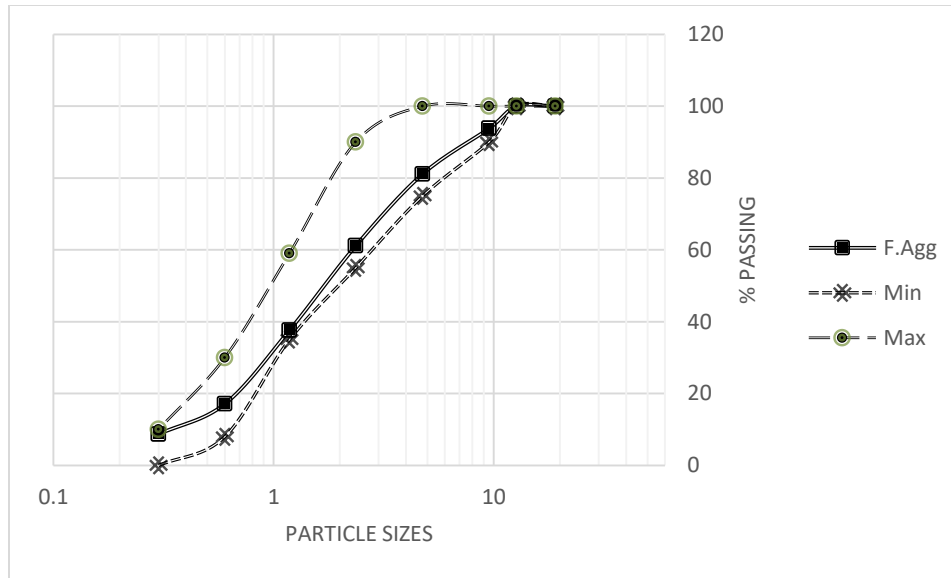


Figure 4.2: Particle size distribution of fine aggregate

4.2.4 Specific gravity

The specific gravity of aggregates is one of the most important aggregate properties in concrete technology. It is the backbone upon which many concrete design models is built. The result of the specific gravity test conducted on the aggregates (fine and coarse) is in Table 4.5 and 4.6 for fine aggregate and coarse aggregate respectively. From the tables, the specific gravity for fine aggregate and coarse aggregates are 2.57 and 2.7 respectively. The result of the specific gravities obtained are within the range specified for aggregate suitable for concrete production (Petersson *et al.*, 1998).

Table 4.5: Specific gravity of fine aggregate

SN	Description	Test No	
		A	B
1	weight of empty bottle	60	60
2	weight of bottle + water	771	771
3	volume of bottle	711	711
4	weight of bottle + sample	652	649
5	weight of sample	592	589

6	weight of bottle + sample + water	1134	1129
7	water added	482	480
8	water displaced	229	231
9	temperature of water	20	20
10	Specific gravity	2.59	2.55
Average SG		2.57	

Table 4.6: Specific gravity of coarse aggregate

SN	Description	Test No	
		A	B
1	weight of empty bottle	60	60
2	weight of bottle + water	771	771
3	volume of bottle	711	711
4	weight of bottle + sample	632	640
5	weight of sample	572	580
6	weight of bottle + sample + water	1135	1132
7	water added	503	492
8	water displaced	208	219
9	temperature of water	20	20
10	Specific gravity	2.75	2.65
Average SG		2.7	

4.3 Properties of cement

For the purpose of this study, the properties of cement investigated in this study are setting time and fineness of cement.

4.3.1 Setting time of cement

The result of the setting time of the cement used in this study is presented in Table 4.7. As shown in Table 4.7, the initial setting time and the final setting time of the cement sample used in this study are 65 minutes and 160 minutes respectively.

Table 4.7: Setting time of cement

S/n	Time (m)	Penetration(mm)
1	0	40
2	15	40
3	30	39
4	45	38
5	60	38
6	65	36
Initial Setting Time = 65 Min		
7	75	34
8	85	30
9	95	25
10	105	21
11	115	16
12	125	12
13	135	9
14	145	3
15	155	0
Final Setting Time = 160 Min		

4.3.2 Fineness of cement

The fineness of cement is an important property of cement that affects the strength gaining process and the rate of generation of the heat of hydration of cement in the presence of moisture. The result of the fineness of the cement used in this study is tabulated in Table 4.8, which shows that the fineness of the cement sample is 6%.

Table 4.8: Fineness of cement sample

SN	Weight of Sample (g)	Weight of residue	Average
1	100	6	6
2	100	8	
3	100	4	

4.4 Compressive Strength of Specimen Beam

For the purpose of determining the strength of the concrete produced in this study, concrete cubes were cast and compressive strength test was carried out on the cast cubes. The result of the compressive strength test is presented in Table 4.9, reflecting the compressive strength test of the specimen to be 17.37 N/mm²

Table 4.9: Compressive strength test

Specimen	Weight (kg)	Ultimate failure load (kN)	Compressive strength N/mm ²	Average compressive strength
C1	8.01	387.21	17.21	17.37
C2	8.042	461.92	20.53	
C3	7.812	323.41	14.37	

4.5 Flexural Strength of Beam Specimen

The beam specimen cast for the purpose of this study is 700mm long, 200mm wide and 230mm high. The beams are supported on two simply supported edges of the flexural strength test machine. The control sample has no opening along its cross section. The test samples on the other hand have openings on the both sides of the supports such that the openings have a distance (x) from each support. Table 4.10 shows the dimension of the openings under investigation, the distance of the opening from the supports and the flexural strength of each beam specimen.

From Table 4.10, the average failure load on the control sample (i.e. the beam specimen without vertical rectangular openings) is 251.63 kN, the beam specimen with an opening of 25x35x230mm³ has average failure load of 203.55 kN. As the opening increases to 50x60x230mm³, the failure load reduces. Such trend continues as the opening increases in the case

of 75x80x230mm³. It can be said that the failure load of the beam specimen reduces as the vertical rectangular opening increases as shown pictorially in Figure 4.3. Flexural strength reduces with the increase in the sizes openings of the beam as presented in Table 4.11 and Figure 4.4.

Table 4.10: Average ultimate failure load test on the beam specimen

S/n	Specimen	Opening sizes (mm ²)	Distance from the support (mm)	Ultimate load (kN)	Average ultimate load (kN)
1	CT1	-		253.3	251.63
2	CT2	-		249.95	
3	C1	25x35	150	217.35	203.55
4	C2	25x35	150	184.98	
5	C2	25x35	150	208.32	
6	B1	50x60	150	195.6	202.40
7	B2	50x60	150	209.33	
8	B3	50x60	150	202.27	
9	A1	75x80	150	193.25	201.48
10	A2	75x80	150	226.86	
11	A3	75x80	150	184.32	

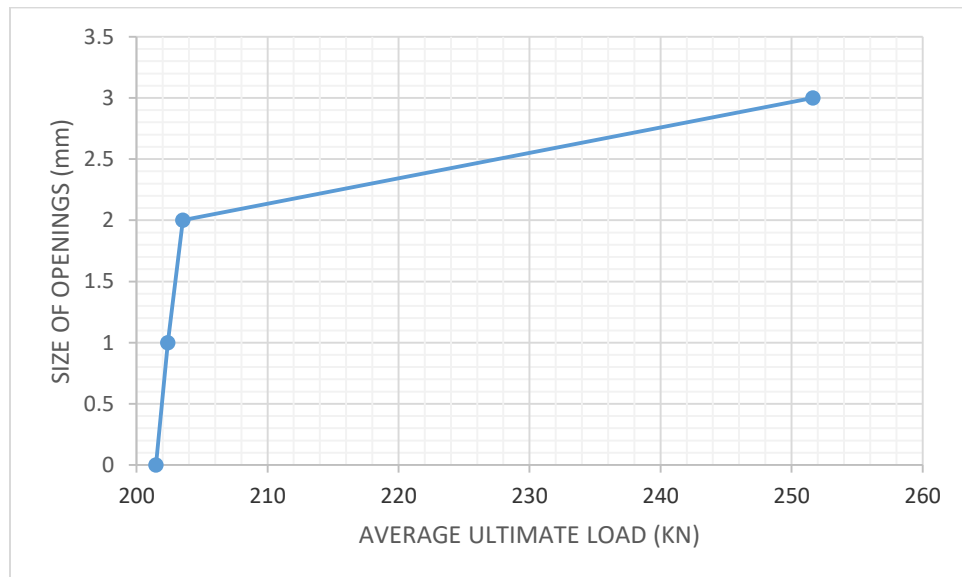


Figure 4.3: Graph of opening against average ultimate load

Table 4.11: Flexural strength beam specimen

S/n	Sample	Opening sizes (mm)	Average ultimate load (kN)	Deflection(mm)	Flexural strength (N/mm ²)
1	CT	0	251.63	0.44	16.65
2	C	25 x 35	203.55	0.48	13.47
3	B	50 x 60	202.40	0.71	13.39
4	A	75 x 80	201.48	14.19	13.33

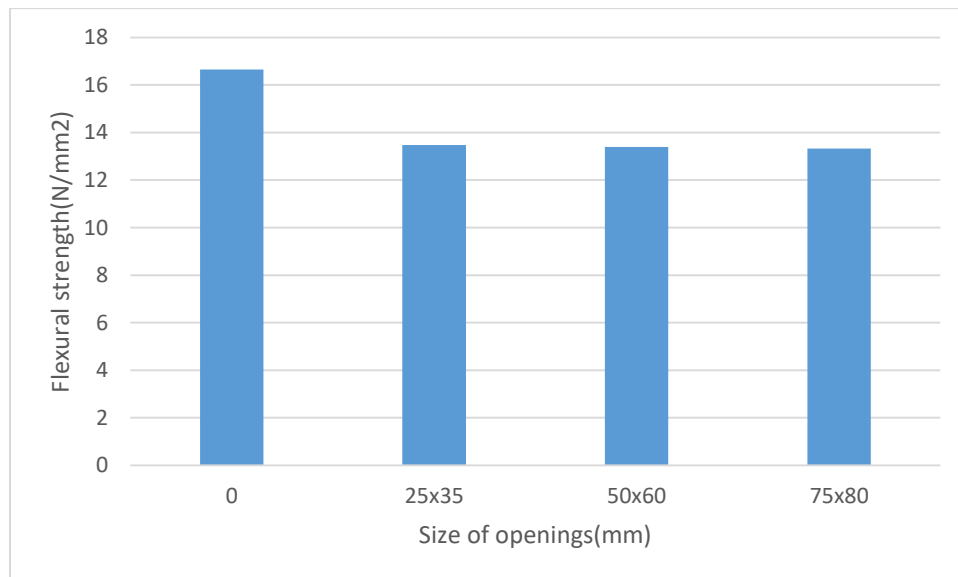


Figure 4.4: Graph of opening against flexural strength

4.5.1 Deflection of beams specimen

Deflection of the beams were calculated and the result are presented in Table 4.11 and Figure 4.5, also shows the deflection-openings relationship.

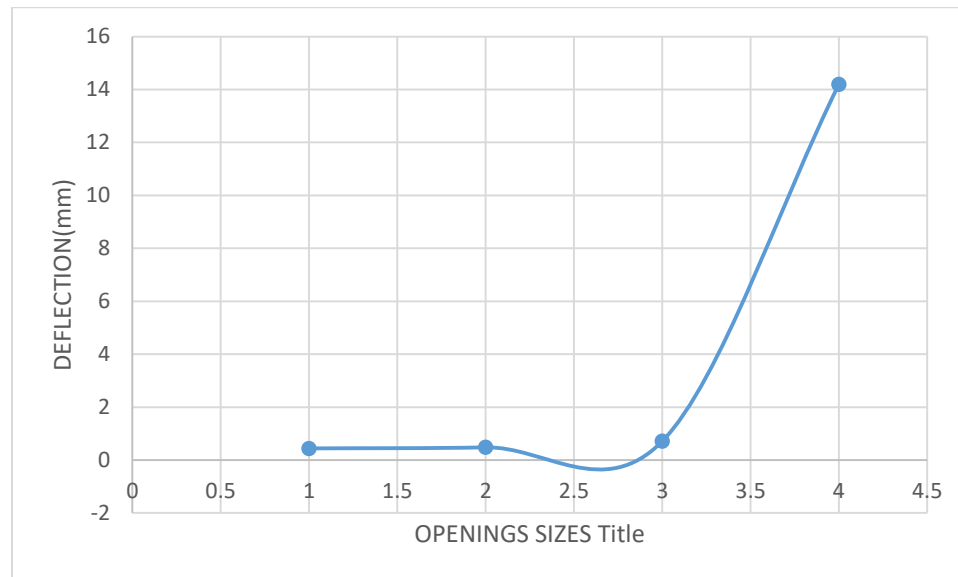


Figure 4.5: Graph of deflection against openings sizes

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study on the effect of vertical rectangular openings on the flexural strength of reinforced concrete beam was carried out, conclusion made and presented.

The openings introduced into the reinforced concrete beams decreased the ultimate load carrying capacity compared with solid beams (control) from 251.63 kN to 201.48 kN.

The flexural strength (13.47 N/mm^3 , 13.39 N/mm^3 and 13.33 N/mm^3) of the beams specimen varies with sizes of vertical rectangular openings ($25 \times 35 \times 230 \text{ mm}^3$, $50 \times 60 \times 230 \text{ mm}^3$, $75 \times 80 \times 230 \text{ mm}^3$) at 150mm. At this portion of the beam, the flexural strength reduces with the increase in sizes of the openings.

The reduction in the percentage of load bearing capacity of the specimen when the sizes of openings ($25 \times 35 \times 230 \text{ mm}^3$, $50 \times 60 \times 230 \text{ mm}^3$, and $75 \times 80 \times 230 \text{ mm}^3$) increase are 19.11%, 19.56%, and 19.93% , when compared with solid beam that has no opening.

The maximum deflection of the beams with the vertical rectangular openings was 14.19mm, this does not exceed the allowable deflection provide by BS 8110 (1983).

5.2 Recommendations

The following recommendations can be suggested from the conclusion of the study:

- a) Vertical rectangular openings in reinforced concrete beams reduces the flexural strength, openings of this sizes and beams should not exceed 150mm from the ends supports;
- b) To maintain minimal deflection such sizes of beam and sizes of openings can be adopted;
- c) Further researches can be carried out to determine the effect of other vertical openings (triangular and irregular shapes) on flexural strength of reinforced concrete beams.

5.3 Contribution to Knowledge

The study shows that vertical rectangular openings on reinforced concrete beam effect the flexural strength of the beam. Openings of sizes: 25x35x230mm³, 50x60x230mm³ and 75x80x230mm³ reduce the flexural strength of the by 13.47 N/mm³, 13.39 N/mm³ and 13.33 N/mm³ respectively at 150mm to the support as compared to the beam without openings (16.65 N/mm²). This presents guide in introducing rectangular opening in the beams where unavoidable in order to prevent early structural failure.

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