EFFECT OF VARIOUS STRENGTHENINGS OF VERTICAL CIRCULAR OPENINGS ON FLEXURAL STRENGTH OF REINFORCED CONCRETE BEAMS

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ABSTRACT

Effect of various strengthenings of vertical circular openings on the flexural strength of reinforced concrete beam is presented. Eighteen specimens of reinforced concrete beams of sizes 200mm x 230mm x 700mm with openings at a quarter and an eighth of the total length from the support with three types of strengthening materials located at the boundaries of the openings, were cast, cured and evaluated. The three strengthening methods used were steel plate, steel pipe and strut and tie method. The flexural strength of all the hardened beams specimens were determined. The results show that strengthening circular openings at quarter and eighth point distance along its length gives an average decrease in ultimate load of 18 and 20% with strength of 13 and 12N/mm^2 respectively. With steel plate strengthening of 4mm gauge, the ultimate load capacity of the beam increases by 15 and 17% with flexural strength of 15N/mm^2 each at a distance of L/4 and L/8 respectively as compared to beams with unstrengthened openings. Using galvanized steel pipe of 2mm thickness increases the ultimate load by 9 and 11% with flexural strength of 14N/mm^2 at a distance L/4 and L/8 respectively. While the use of strut and tie method increases ultimate load by 3 and 5% with strength of 13N/mm^2 at a distance of quarter and eighth point along its length respectively. It is therefore recommended to incorporate steel plate strengthening method when vertical circular openings are to be created in reinforced concrete beams.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Percentage
kN	kilo Newton
N/mm^2	Newton per millimetre square
Pu	Ultimate load
BS	British Standard
PB	Peter’s Beams at L/4 opening from support
PB*	Peter’s Beams at L/8 opening from support
STM	Strut and Tie Method
NIS	Nigeria Industrial Standard
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
EN	European Nation
CT	Control

CHAPTER ONE

1.0 INTRODUCTION

1.1. Background to the Study

Vertical openings in Reinforced Concrete beams are becoming popular in the construction industry. An opening is a space or gap that allows the passage or access of a conduit facility. Openings in beams can either be transverse or longitudinal. In this work the opening is a transverse or vertical openings for the passage of utility. In the past, those openings are usually located near the supports where shear is predominant without considering the engineering implication as it was not designed or planned. In practical life beam openings is often used to provide conveyance for plumbing pipes, ducts for water supply systems, sewage and electrical cables, but the presence of these openings in Reinforced Concrete beams yield several problems in the beams behaviour such as; reduction in beam stiffness; lead to cracking; deflection; and reduction in the flexural strength of the beam (Lalramnghaki *et al.*, 2017).

Also, the presence of openings give rise to a high concentration of stress around the opening corners. The decrease in the beam stiffness as a result of the presence of openings changes the beam behaviour to a more complex one, which leads to a redistribution of the forces within (Mansur, 2006). The change in the beam behaviour as a result of the presence of an opening depends on several factors such as; shape and size of the opening, location of the opening, the loading type and position of the opening. However, the size of openings and the distances from the support has been found as the most important parameter that affects the behaviour of the beam (Said, 2005).

In these drawback of reduction in beam stiffness, increase in deflection and reduction in flexural strength of the beams, there is need for solutions to restore the strength of

Reinforced Concrete beams with openings to the original or high performance level. Due to this changes in the beams cross section caused by the presence of openings, strengthening of such beams may be necessary. Strengthening of beams provided with openings may increase the ultimate load capacity of the beam, the stiffness, and reduction in deflection and cracking at the opening corners. These strengthening options would resist the internal forces that the beams are subjected to. In this work the strengthened openings were compared with their counterpart the un-strengthened openings. The control beam (solid) served as a reference to assess the performance of the test specimens with un- strengthened and strengthened vertical circular openings. Longitudinal and cross section details of the beam specimens with vertical circular opening are shown in Figure 1.1

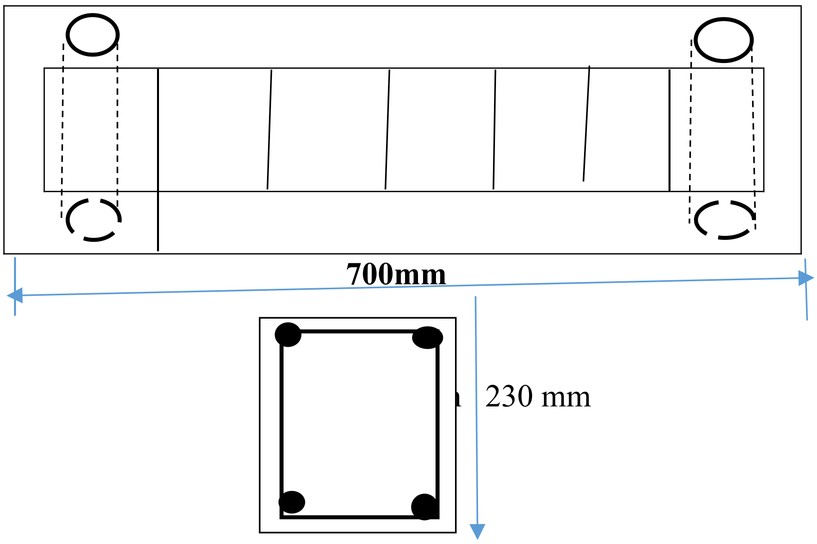

Figure 1.1: Longitudinal and cross section details of beam with vertical circular opening

1.2 Statement of the Research Problem

Openings in beams have become a necessity for accessibility of utility services such as electrical, plumbing pipes, air conditioning conduit, but the behaviour of the beam in terms of ultimate load carrying capacity, deflection and strength or stiffness is affected by these openings created on the beams according to Kin (2015). Also, openings on beams would alter the buildings function and thus, the structural strength of the buildings could be reduced as well, which may lead to safety hazard. Furthermore, the ultimate capacity of the beams due to the action of moments and shear at the region where there is an openings will be less compared to that at a normal cross section without opening; that is, some strength is lost as carried out by Surya *et al.* (2016). A number of studies have been conducted regarding the effects of strengthening of openings in the web of Reinforced Concrete beams, but very limited researches have been reported on strengthenings of beams with vertical circular openings.

1.3 Aim and Objectives of the Study

The aim of this study is to evaluate the effect of various strengthenings of vertical circular openings on flexural strength of Reinforced Concrete beams. The objectives of the study are to determine:

(i) the physical properties of the aggregates;

(ii) the compressive strength of the cubes;

(iii) the flexural strength of Reinforced Concrete beams with vertical circular openings;

(iv) the effect of various strengthening methods of vertical circular openings on flexural strength of the Reinforced Concrete beams.

1.4 Scope of the Study

The scope of this study covers the testing of eighteen specimens of rectangular Reinforced Concrete simply supported beams. All the beams that were tested have a rectangular cross section of 200mm width and 230mm depth with overall length of 700mm. The tested beams comprises of two solid beams without openings (controls) and two beams each with unstrengthened openings at a distance of a quarter and an eighth which serves as a control specimen as well, while the rest of the beams have openings strengthened with the various selected methods. The dimensions of the opening were kept the same for all the beams. The physical properties of the aggregates were determined and compressive strength of the concrete using 150mm x 150mm x 150mm cubes size.

1.5 Justification of the Study

When vertical openings are introduced in beams, they reduce the flexural strength of the beams as observed by Oladipo (2019), hence, there is need to strengthen the openings. Therefore, in order to overcome the instability of beams with vertical circular openings so as to restore the strength loss in the reinforced concrete beams in relation to the weakness in the beam as a result of the introduction of openings, this work evaluates experimentally the effects in order to determine the effect of the various strengthening methods on the flexural strength of reinforced concrete beams with transverse or vertical circular opening using some selected strengthening methods. The result of this study will be beneficial to the construction industry, thereby recommending the optimal method to comfortably accommodate transverse circular openings. This will ensure the structural integrity and safety in the construction industry.

Furthermore, the production of this optimal strengthening method in commercial quantity will create job opportunities in the labour market, thus addressing part of the unemployment problems in developing nations by establishing companies of beams productions.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Reinforced Concrete Beams

Various research work have been done regarding Reinforced Concrete beams with different openings and strengthening methods, but most of the openings and strengthenings are in the web of the beams as shown on Plate I, with little or no research that focuses on the strengthenings of vertical circular openings aspect of the beams. Few of such literatures are reviewed.

Plate I: Typical beam with openings in the web (Amiri & Masoudnia., 2011)

2.2 Flexural Strength of Reinforced Concrete Beams

The flexural behaviour of Reinforced Concrete beam with a circular and rectangular openings and with a different position of loads and openings have been studied in terms of ultimate failure load, maximum deflection and failure mode. The test results show that the ultimate load carrying capacity in the shear zone with small openings at flexural zone, that the maximum reduction in ultimate load was about 1.5% as carried out by Al-Sheikh (2014). For large openings in the flexural zone, it decreased the ultimate load by about 10% and in terms of deflection of the beam, it increased by it by 11% maximum more than the control beam. In the shear zone, the maximum reduction in ultimate load was about 2.5% and for large openings excessive cracks were found around the opening decreasing the ultimate load by up to 64%. In terms of deflection, it was 57% more than the control beam.

In a solid beam that is subjected to pure bending, at the ultimate load, the beam exhibited a well-developed pattern of cracks, being initiated at the tensile face, when the extreme fibre stress exceeds the flexural tensile strength of the concrete, the cracks would propagate vertically upward and extend up to the neutral axis as noted by Salam (1977). He concluded that the provision of opening will not alter the load carrying mechanism, as long as the opening remains within the tension zone of the beam, because, concrete there would have cracked anyway in flexure at the ultimate stage. As a result, the ultimate strength of the beam will not be affected by the presence of opening. Tan & Mansur. (1996) confirmed the conclusion given by Salam (1977). He continued that the strength of a beam with openings would remain the same as that of the corresponding solid beam provided that the openings do not reduce the concrete area necessary for the development of the compressive stress block at the ultimate load.

The effect of small circular openings on the shear, flexural and ultimate strength of beams made by normal and high strength concrete have been studied. The main factors of this test are the changes of diameter, the position of opening and the type and location of reinforcement around the opening and changes in the strength of concrete. In this investigation nine beams by using normal concrete and five beams by using high strength concrete were made and tested. One beam was solid and filled with normal concrete and was used as reference for comparison with other beams and with an opening according to Amiri and Hosseinalibygie (2004). The tested beams have been loaded as simple beams with two concentrated and symmetrical load. In the beams made of ordinary concrete, when the diameter of openings exceeded 300 of depth of the beam, the reduction of ultimate strength increased and the pattern of cracking as well as mode of failure of the beam changed. The effect of concrete strength depends on the parameters, such as, diameter and the position of the openings. In order to control the cracks and restrain their width, it is better to use diagonal shear reinforcement. For increasing the ultimate shear strength of the beam, the use of diagonal reinforcement and stirrups at top and bottom of the opening is recommended. At the end, the results of tests were compared with the design equations of some codes (Aykac *et al.*, 2014).

Materials were applied by bonding it to the external surfaces of the beams with different configurations and layouts as noted by Allam (2005). Previous studies generally revealed that the strengthening of beams could significantly enhance their shear and flexural strength behaviour.

Amiri *et al*. (2011) carried out a study of three-dimensional nonlinear finite element method using ANSYS 10.0, which is a finite element analysis software, which was employed to simulate the simply supported concrete beams consisting of circular openings with varying diameters. The effects of circular opening sizes on the behaviour of such beams were investigated in his research. Two cases were carried out for verification study. Subsequently, numerous models of simply supported reinforced concrete rectangular section beams with circular and square opening were loaded monotonically with two incremental concentrated loads. The beams were simulated to obtain the load-deflection behaviour and compared with the solid concrete beam. All beams had an identical cross section of 100 mm × 250 mm and 2000 mm in length with the circular opening in seven diameters: 150, 130, 120, 110, 100, 80 and 60 mm and an equivalent square opening with 133 mm in width. The results obtained from this study showed that the performance of the beams with circular openings with diameter less than 0.48D (where D is depth of the beam web) has no effect on the ultimate load capacity of the Reinforced Concrete rectangular section beams. On the other hand, introducing the circular opening with a diameter more than 0.48D reduces the ultimate load capacity of the Reinforced Concrete rectangular section beams by at least 26%.

2.3 Flexural Strength of Reinforced Concrete Beams with Openings in the Web

An opening located adjacent to the simulated continuous support produced no reduction in strength. This opinion was observed by Mansur (1998) that as the opening moved away from the support, gradual reduction in strength occurs until it levels off to a constant value. Furthermore, his test data suggested that the position of an opening has significant effect, while an increase in the size of opening leads to an almost linear reduction in strength. This was confirmed by Weng (1998), that the maximum shear that can be applied to the beam to avoid primary crushing failure should be limited for the section above and below the opening as well as the overall section through the openings.

Hafiz *et al.* (2014) conducted a numerical study in which several openings with different shapes and sizes in the Reinforced Concrete beams were investigated by using ANSYS software. The study found that the ultimate load capacity was not affected when the diameter of circular openings was less than 44% of the depth of the rectangular Reinforced Concrete beams, however the ultimate load capacity was reduced at least 34.29% when the diameter of circular openings was more than 44% of the Reinforced Concrete beams.

A 150mm x 400mm rectangular section with a span length of 3900 mm to investigate the influence of multiple openings on strength parameters by Aykac *et al.* (2013), which was revealed from the test parameters considered in their study are, the flexural reinforcement, opening geometry, arrangement and material properties of the diagonal reinforcement around the openings, shows that the experimental results indicated that the amount of tension reinforcement and reinforcement ratio had a great effect on beam behaviour. These test results were compared to that estimated from available equations in the code they used.

2.4 Reinforced Concrete Beams with Strengthening Materials

According to Mansur and Tan (1999), strengthening of beams provided with openings depends mainly on whether those openings are pre-planned or post-planned. In the case of pre-planned openings, both the upper and lower chords are designed and reinforced to resist the internal forces that they are subjected to. The design of such chords depends on the position of opening and the type of loading. Also, special steel reinforcement is provided around the opening edges and extended with enough length beyond the opening corners to resist the stress concentration. Both the reinforcement provided for the upper and lower chords and the special reinforcement provided around the opening are considered as internal strengthening. On the other hand in the case of post-planned opening created in an existing beam, external strengthening will be necessary for the upper and lower chords and also for the opening corners and edges to protect it against stress concentration. The materials used for strengthening were either traditional steel plates or fibre composites.

2.4.1 Strengthenings of openings using strut and tie method

Cheng *et al.* (2009) carried out a study which was conducted on Reinforced Concrete deep beams with large openings. The 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. Their study investigates the performance of Reinforced Concrete beams with vertical circular openings strengthened with four selected method of strengthening under loading conditions to examine the behaviour of the strengthened beam in terms of load capacity, deflection and crack pattern.

Likewise Mansur *et al.* (2001) examined the 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 effect of openings with various position in deep beams using the strut and tie model approach both experimentally and analytically was examined by Nishitha and Kavitha (2015). They concluded that the ultimate load obtained from the finite element evaluation by using a software has only 5% variation compared to that obtained from experimental.

2.4.2 Strengthenings of openings using steel plates

Numerical analysis for Reinforced Concrete beams with circular openings in flexural and shear zones strengthened by steel plates was carried out by Ahmed and Abdulwahab (2018**)** a 3D finite element modelling (ABAQUS 6.12) software was used to simulate five different specimens of Reinforced Concrete beams. Their results showed that when the openings were strengthened by steel plates, the ultimate load carrying capacity increased, but the deflection was decreased when compared to the openings without strengthening. In addition, the model reliability was verified with good agreements between the experimental and numerical results.

Mohamed *et al.* (2010) investigated the efficiency of internal strengthening of Reinforced Concrete beams with rectangular openings in the shear zone by using steel plates; external strengthening by using external steel plates or external CFRP laminates.

They concluded that the use of steel plates or CFRP laminates will be a satisfactory method in the case where it is required to provide new openings in existing beams.

Hayder *et al.* (2017) examined the potential use of strengthening Reinforced Concrete deep beams that had web openings by steel plates. their experiment were conducted to test thirteen deep beams under two point loading with square, circular, horizontal and vertical rectangular openings. Two openings, one in each shear span, were placed symmetrically about the midpoint of the inclined compressive strut. It was concluded that the structural behaviour of deep beams that had openings was primarily dependent on the interruption degree of the inclined compressive strut. Constructing square, circular, horizontal and vertical rectangular openings led to a decrease in ultimate capacity for about 20.5, 18.3, 24.7 and 31.7%, respectively in comparison to the reference solid beam. While strengthening those openings with steel plates was found very effective in upgrading the Reinforced Concrete deep beams shear strength. The strength gained in beams that had strengthened square, circular, horizontal and vertical rectangular openings was about 9.3, 13.2, 8.8 and 11.88%, respectively in comparison with the unstrengthened openings. Furthermore, adding studs to the strengthening plates caused a strengthening gain in square, circular, horizontal and vertical rectangular openings to be about 16.9, 17.8, 14.3 and 26.9%, respectively in comparison with the unstrengthened openings.

2.4.3 Strengthenings of openings using steel pipes

Lalramnghaki *et al*, (2017) studied the behaviour of reinforced concrete beams with circular opening in the flexural zone strengthened by steel pipes. The results show that there is about 10% deviation which occurs while comparing analytical and experimental results. They concluded that by increasing the thickness of the galvanized iron pipes used in strengthening the ultimate load carrying capacity of the beam increases.

Suresh and Angeline (2014) discusses the use of steel fibres and steel plates to strengthen the opening region in reinforced concrete beams tested under two point loading. The test specimens of cross section 150 x 300mm and length 2000mm were used. The experimental programme included the testing of fourteen reinforced concrete beams, two Reinforced Concrete beams without opening (one without fibres and another strengthened with fibres), four Reinforced Concrete beams with openings of different sizes in the shear zone, four steel fibre reinforced concrete beams with openings of different sizes in the shear zone and four steel fibre reinforced concrete beams with openings of different sizes in the shear zone strengthened with steel plates. Solid beam without opening was considered as the control beam. The behaviour of reinforced concrete beams with and without openings at ultimate load, deflection and cracking patterns were evaluated. The presence of duct openings in the shear zone reduces the load carrying capacity by 55 to 70 % for the beams with openings. The experimental results shows that strengthening the duct openings with steel fibres increases the load carrying capacity and the ductility characteristics of the beam. For Steel fibre reinforced concrete beams with openings of different sizes strengthened using steel plates, stiffening the duct openings with steel plates of 4mm thickness increases the load carrying capacity and there is a considerable increase in the deflection of the beam before failure. Crack formation is delayed in the case of beam strengthened using steel plates**.**

An experimental study was carried out by Said (2005), who tested nine Reinforced Concrete beams in order to investigate the efficiency of external strengthening of beams when provided with large openings within their shear zones.

Firstly three beams were considered, one of these beams was solid without any openings (control beam). The second beam was provided with one opening within the shear zone but without any strengthening which was also considered as a control beam whereas the third beam was provided with an opening at the same location and having the same dimensions. However, the third beam was internally strengthened with steel reinforcement along opening edges.

Secondly, six beams were provided with openings at the same location and having the same dimensions like the second and the third beams. The six beams were externally strengthened with steel plates or Carbon Fibre Reinforced Plastics (CFRP) sheets along the opening edges. It was found that both type of material used for strengthening and its configuration scheme significantly affected the efficiency of the strengthening in terms of beam deflection, steel strain, cracking, ultimate capacity and failure mode of the beams. Test results revealed that the efficiency of external strengthening of beams with openings increased significantly when the strengthening was applied to both inside and outside edges of the beam openings than that in the case of strengthening the outside edges only. Finally, theoretical analysis was performed for all tested beams with openings in order to calculate the ultimate shear force sustained by such beams. Equations presented by the Egyptian code in addition to empirical formulas found in the literature were used to perform the theoretical analysis. Good agreement was observed between the theoretical results and the experimental ones.

Kumar and Latha (2017) investigated the behaviour of Reinforced Concrete beams with circular openings in the flexure zone with and without steel plates. They reported that the load carrying capacity increased by 40 to 55% when the flexure zone was strengthened by steel plates as compared to the one without steel plates.

2.5 Behaviour of Reinforced Concrete Beams with Vertical Openings

Oladipo (2019) carried out a study that evaluates the effect of vertical circular opening on the behaviour of reinforced concrete beams experimentally, while using ANSYS 19.1 software to simulate the specimen to correlate the experimental result. A total of twelve beams were studied and he concluded that the Reinforced Concrete beams with openings show a decrease in ultimate load carrying capacity compared to solid beams. The reduction in the percentage of load bearing capacity was about 6% for beams with 25mm diameter opening located at 150mm from support, 32% for beams with 25mm diameter opening located at 350mm from support, 28% for beam with 50mm diameter opening located at 150mm from support and 35% for beam with 50mm diameter opening located at 350mm from support when compared with solid beams without opening. Rectangular Reinforced Concrete beams with vertical circular opening of diameter more than one - third of the beam width (without special reinforcement in opening zone) with the opening practically located at the bending zone of the beams reduces the ultimate load capacity of the Reinforced Concrete beams by at least 35%. The beams that have openings far away from supports induced less stress to fail when compared with beams that have openings closer to the support. The most critical position of vertical circular opening to reach the ultimate strength in beams made of normal concrete is near the mid-span and also the best place for the location of opening in these beams is one-third of a distance between the place of applied load and support, (close to the support).

Hafiz *et al.* (2014) studied the effect of using circular openings with different sizes located at the shear zone on the load-deflection curves using Finite Element (FE) software. In addition, the effect of the shape of the openings on the ultimate failure load has been studied by using rectangular openings with equivalent area to the circular openings. They concluded that there was only small effect on the ultimate failure load and maximum deflection when Reinforced Concrete beams incorporated circular openings with diameters of less than 44% of the depth of the beams in comparison to the solid control beams. However, a reduction of minimum 34% have been recorded when the diameter of the openings was more than 44% of the depth of the beams. In addition, the results demonstrated that the utilisation of rectangular openings with equivalent area to the circular openings caused a decrease in the ultimate failure load by about 10% relative to the circular openings.

Effects of circular openings on the behaviour of Reinforced Concrete beams was examined by Rezwana *et al.* (2014). The Reinforced Concrete beams model solid65, solid45 and link8 representing linear and nonlinear behaviour of concrete, steel plate and reinforcing bars were prepared. A circular opening of diameter less than 44% has no effect on ultimate load capacity while a circular opening of diameter more than 44% reduces the ultimate load capacity up to 34.29%. It was concluded that circular openings offer greater strength than square opening with a difference of 9.58% in the ultimate load of the Reinforced Concrete beams.

A study of three-dimensional nonlinear finite element method using ANSYS 14.0 software was carried out by Saksena and Patel (2013a), the finite element analysis software, has been employed to simulate the simply supported reinforced concrete beams consisting of circular openings with varying diameters at different locations. The effects of circular opening size on the behaviour of such beams were investigated in their research. Numerous models of simply supported reinforced concrete rectangular section beams with circular opening were loaded monolithically with two incremental concentrated loads, while the beams were simulated to obtain the load-deflection behaviour and compared with the solid concrete beam. All beams had an identical cross section of 150 mm × 200 mm and 2000 mm in length with the circular opening in three diameters: 110 and 90 mm at different locations, such as L/8, L/4 and L/2 distance from the support (where L is the span of the beam). A total of seven models were simulated in ANSYS. The results obtained from the study showed that the performance of the beams with circular openings at centre of the span has lesser effect on the ultimate load capacity of the Reinforced Concrete rectangular section beams (Saksena and Patel, 2013b). On the other hand, introducing the circular opening of diameter of 45% of depth near the support reduces the ultimate load capacity of the Reinforced Concrete rectangular section beams by at least 32% when compared to the solid beam

Ali *et al.* (2017) studied the structural behaviour of Reinforced Concrete beams with circular openings of different sizes and locations modelled using ABAQUS FEM software. Seven Reinforced Concrete beams with the dimensions of 1200 mm × 150 mm × 150 mm were tested under three point loading. Group A consists of three Reinforced Concrete beams incorporating circular openings with diameters of 40, 55 and 65 mm in the shear zone. However, Group B consists of three Reinforced Concrete beams incorporating circular openings with diameters of 40, 55 and 65 mm in the flexural zone. The final Reinforced Concrete beam did not have any openings, to serve a control beam for comparison. The results show that increasing the diameter of the openings increases the maximum deflection and the ultimate failure load decreases relative to that of control beam. In the shear zone, the presence of the openings caused an increase in the maximum deflection ranging between 4 and 22% and a decrease in the ultimate failure load of between 26 and 36% compared to that of control beam. However, the presence of the openings in the flexural zone caused an increase in the maximum deflection of between 1.5 and 19.7% and a decrease in the ultimate failure load of about 6 and 13% relative to the control beam. In his study, the optimum location for placing circular openings was found to be in the flexural zone of the beam with a diameter of less than 30% of the depth of the beam. Their experimental results show that the presence of flange openings reduces the shear capacity of the beam by 12% for beams containing one opening and about 18 - 20% for beams containing two openings in comparison with the reference beams. Also results indicated that the use of CFRP sheets to upgrade the reinforced concrete T- beams with flange openings has significant effect on the overall behaviour, such as, the ultimate load, crack width and deflection. The ultimate load capacity of the strengthened beams was increased by about 70 - 80 % in comparison with beams containing openings.

2.6 Effect of Various Strengthenings on Vertical Circular Openings on the Flexural Strength of Reinforced Concrete Beams

Oladipo (2019) carried out a study evaluating the effect of vertical circular opening on the behaviour of Reinforced Concrete beams experimentally and using ANSYS 19.1 software to simulate the specimen to correlate the experimental result with that of the numerical. His studies show that the reinforced concrete beams with openings shows a decrease in the ultimate load carrying capacity compared to the solid beams. The reduction in percentage of load bearing capacity was about 6% for beams with 25mm diameters openings located at 150mm from the support, 32% for beams with 25mm diameters openings located at 350mm from the support, 28% for beams with 50mm diameters openings located at 150mm from the support and 35% for beams with 50mm diameters openings located at 350mm from the support when compared with the solid beams without openings. The beams that bear openings far away from supports induced less stress to fail when compared with beams that bear openings closer to the support.

In the study presented herein, an experimental evaluation on the effect of various strengthening of vertical circular openings on the flexural strength of Reinforced Concrete beams is documented.

CHAPTER THREE

3. 0 MATERIALS AND METHODS

3. 1 Materials

The materials used in this work include:

i. coarse aggregates;

ii. fine aggregates;

iii. ordinary portland cement (OPC);

iv. iron bar;

v. Water.

These materials are further described below:

3.1.1 Fine aggregate

Natural sand was used as fine aggregate. Fine aggregate includes the particles that passes through 4.75 mm sieve and retained on 0.075 mm sieve to get rid of coarse aggregate according to BS EN 12620 (2002). The fine aggregate was free from clay or any organic matter or chemical with a specific gravity of 2.57 and fineness modulus of 2.25. Moreover, sieve analysis was also conducted on the fine aggregates, in order to identify the gradation of the aggregates and more so, to see if it is suitable for various civil engineering purposes. The grading of the fine aggregate comply with the requirements of BS 882 - 2 (1992)

3.1.2 Sieves analysis of fine aggregate

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 and their properties are prescribed by BS 410 (1986). The weights of the sample retained on the sieve after shaking and their percentage were calculated using the expression below:

Weight of aggregate retained = weight of sieve of aggregate - weight of sieve

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

3.1.3 Coarse aggregate

Coarse aggregate with 20mm nominal (3/4”) size was used, sourced from the market. The coarse aggregate includes the particles that are retained on 4.75 mm sieve. The grading of the coarse aggregate complies with the British standard, and particle size distribution of aggregates were carried out prior to concrete making as specified by requirements of BS EN 12620 (2002)

3.1.4 Aggregate crushing value test (ACV)

The cylinder of the test apparatus was placed 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 of 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 a uniform rate as much as possible so that the required force of 400 kN is reached in 10 min ± 30 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. The aggregate crushing value (ACV) is expressed as a percentage to the first decimal place, of the mass of fines formed to the total mass of the test specimen using the following equation:

$$ACV = \frac{M_2}{M_1} \text{x } 100 \qquad (3.2)$$

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).

3.1.5 Aggregate impact value test (AIV)

The impact machine rested 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 was 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 is 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 is subjected to a total of fifteen blows each at an interval of not less than one second. The crushed aggregate is then removed from the cup and the whole is sieved on the 2.36mm BS sieve until no further significant amount passes in one minute. The fraction passing the sieve is weighed to an accuracy of 0.1 g (Weight B). The fraction retained on the sieve is also 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 is discarded and a fresh test can be conducted. Thus,

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

Where: B = Weight of fraction passing 2.36mm BS Sieve

A= Weight of the oven-dried sample.

3.1.6 Cement

Portland Limestone cement (Dangote 3x) with a strength class of C42.5 was chosen in this work because of its greater fineness which would have effective hydration. The cement which conforms to BS EN 12269 (2000) is used for making concrete. Cement is a substance used for binding and hardening other materials. Water and cement set and harden through a chemical reaction know as hydration. The process of hardening is described as curing.

3.1.7 Water

Portable tap water was used for casting and curing all the specimens. The water used for mixing and curing of concrete was clean, tasteless and odourless and free from injurious amounts of oils, acids, alkali, salts, sugar, organic material or other substances that may be deleterious to concrete or steel. However, the water conforms to the requirements for concreting and curing according to BS EN 13946 (2003).

3.1.8 Formwork

In this experiment steel mould were used for the formwork, which were fabricated to accommodate the actual size of the concrete beam of size 200mm x 230mm x 700mm and the formwork were braced such that the angle iron braces were placed at 200mm interval and were also braced at all edges to hold the form together firmly so as to prevent bulging during the tamping of the concrete when it is been poured in the formwork. The moulds were cleaned and oil was applied to avoid adhesion of concrete for easy removal. The fabricated formwork is shown in Plate II

Plate II: Steel moulds fabricated for the test

3.1.9 Description of beams specimens

The beam size that were used for this research work was 200mm x 230mm x 700mm with four of 12mm diameter bars, that is two bars each at the top and bottom which handles the tension and compression reinforcement and 10mm diameter bars as stirrup at 150mm c/c spacing, the concrete cover to reinforcement was 20mm minimum. The circular openings of 75mm diameter was created by a circular polyvinyl chloride (PVC) pipe inserted in the beam before casting of the concrete which was retracted after the concrete was set for some minutes while the plates and galvanized pipe was left permanent as the means of strengthening the holes. The openings were at two different positions, at the shear zone and above the support. For the purpose of this study eighteen reinforced concrete beams sample were cast. Table 3.1 shows the description of the beams specimens.

Table 3.1: Details of beams specimens

Beam specimens	Number of specimens	Openings diameter	Distance of opening	Strengthening materials
SOLID	2	-		-
CTI	2	75	L/4	-
CT2	2	75	L/8	-
PB1	2	75	L/4	Steel plates
PB1*	2	75	L/8	Steel plates
PB2	2	75	L/4	Steel pipe
PB2*	2	75	L/8	Steel pipe
PB3	2	75	L/4	Strut tie method
PB3*	2	75	L/8	Strut tie method
M.C	1			

3.1.10 Flexural strength test setup

The Flexural strength test were determined using a testing machine of 2000kN capacity on the reinforced concrete beams by the single-point loading method.The bending strength test conducted on the concrete beams conforms to the requirements of the BS 12390 -5 (2009), using the centre-point loading method. A mix proportion of 1:2:4 by volume of cement, sand and granite aggregates with water-cement ratio by weight was kept in the range of 0.50 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 a tamping rod. After the setting of the concrete beams had taken place, the formwork was carefully detached. Also after curing for 28days, 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 centred 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.

3.1.11 Steel reinforcement

Steel reinforcement bars were 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 the elongation of steel due to high temperatures (thermal expansion coefficient) nearly equals to that of concrete. Thermo Mechanically treated bars were used in this research work because of its strength, ductility, welding ability, bending ability, economical and safety in use. Steel bars of 12mm diameter (H12) were used as compression and tension reinforcement and 10mm diameter bars (H10) were used as shear reinforcement. The steel is assumed to be an elastic-plastic material and identical in tension and compression with Poisson ratio 0.3 (Timoshenko and Gere, 1997). Plate III shows the steel reinforcement bars.

Plate III: Beam reinforcement bars

3.1.12 Compressive strength of hardened concrete cubes

Compressive strength is the ability of a material or structure to carry the load on its surface without any crack or deflection. Compressive strength test were conducted in accordance to BS1881-116 (1983) specification. Concrete cubes were removed from the curing tank at the age of 28days. The mass (m) and volume (v) of concrete cubes were determined as shown in Plate IV

The unit weight was calculated, thus;

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

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

$$\text{Compressive strength} = \frac{Load\ (p)}{Area\ of\ cube\ (A)}$$

(3.5)

Plate IV: Weighing of concrete cubes

3.1.13 Concrete mix ratio

Concrete mix design is the process of finding right proportions of cement, sand and aggregate for concrete to achieve a target strength 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 0.50 is considered for casting the beams. Hand –mix method was used in mixing the concrete.

3.1.14 Materials used for strengthenings of vertical circular openings

The materials used for strengthening the vertical circular openings include:

(i) Steel plates of 4mm thickness;

(ii) Steel pipe (galvanized GI Pipe) of 2mm thickness;

(iii) 8mm diameter bar for fabricating the Strut Tie Method.

The strengthening materials were placed in the reinforcement cage in the formwork before concreting the beam. The strengthening materials are shown in Plate V

(a) (b)

Plate V: Materials used for strengthening the specimens (a) Steel plate and pipe (b) Strut and tie model

3.1.15 Mixing, compaction and curing of concrete

Before mixing, all quantities were weighted and packed in a container, while using hand mixing. Compaction was done with the help of a tamping rod in all the specimens and care was taken to avoid displacement of the reinforcement cage and the strengthening materials inside the formwork after which the surface of the concrete was levelled and smoothened by a metal trowel. The mixing and curing was done in an open space and tank to prevent the loss of water which is essential for the process of hydration and hence for hardening as shown in Plate VI.

(a) (b)

Plate VI: Materials: (a) Aggregate (b) Beam specimen curing tank

CHAPTER FOUR

4. 0 RESULTS AND DISCUSSIONS

4. 1 Results

The results obtained and presented are as follows:

(i) Aggregate crushing values;

(ii) Aggregate impact values;

(iii) Sieve analysis test;

(iv) Specific gravities test;

(v) Bulk density;

(vi) Compressive strength;

(vii) Flexural strength test.

4.1.1 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.

4.1.2 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 given in Table 4.1. From Table 4.1 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 25.63 which is less than the limiting value of 40 (Shetty, 2005).

Table 4.1: Aggregate crushing values

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	

4.1.3 Aggregate impact value

This is a property of aggregates used in measuring 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 research is presented in Table 4.2.

Table 4.2: Aggregate impact values

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	

4.1.4 Particle size distribution of the fine and coarse aggregates

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 presented 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 fine modulus obtained in this study is lower that the limiting value of 3.2, the fine aggregate is fit for use in concrete production (Mamlouk and Zaniewski, 2006).

Table 4.3: Sieve analysis 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

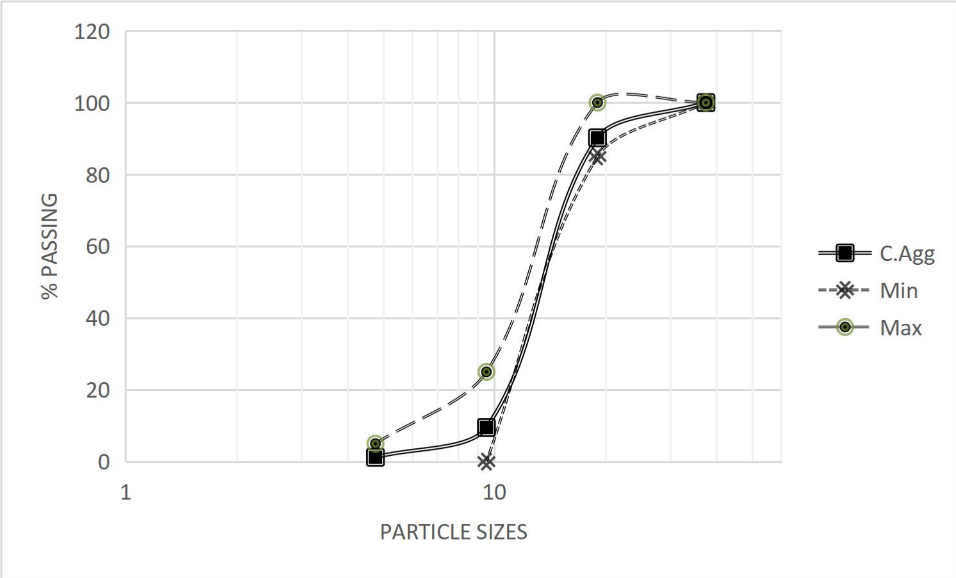

Figure 4.1: Particle size distribution curve of coarse aggregate

Table 4.4: Sieve analysis 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

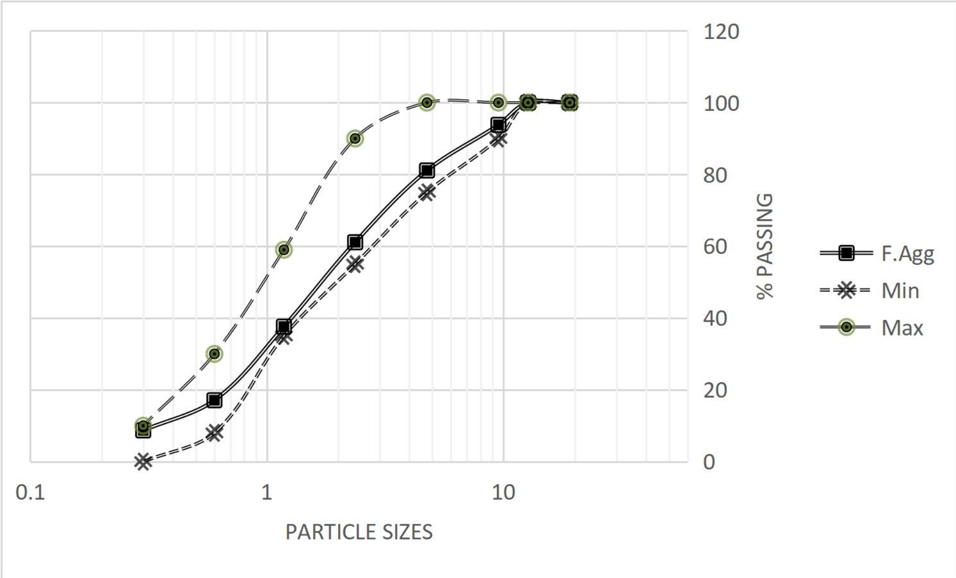

Figure 4.2: Particle size distribution of fine aggregate

4.1.5 Specific gravities of coarse and fine aggregates

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 are built. The results of the specific gravity tests conducted on the aggregates (fine and coarse) are presented in Table 4.5 and 4.6 for the fine and coarse aggregate respectively. From the tables the specific gravity for the fine and coarse aggregates are 2.57 and 2.7 respectively. The result of the specific gravities obtained are within the range specified for aggregates suitable for concrete production.

Table 4.5: Specific gravity of fine aggregate

SN	Description		Test No	
			A	B
a	weight of empty bottle	(gm)	60	60
b	weight of bottle + water	(gm)	771	771
c	volume of bottle	(b-a)	711	711
d	weight of bottle + sample	(gm)	652	649
e	weight of sample	(d-a)	592	589
f	weight of bottle + sample + water	(gm)	1134	1129
g	water added	(f-d)	482	480
h	water displaced	(c-g)	229	231
i	temperature of water		20	20

	Specific gravity	e/h_k	2.59	2.55
	Average specific gravity		2.57	

Table 4.6: Specific gravity of coarse aggregate

S/N	Description		Test No	
			A	B
1	weight of empty bottle	(gm)	60	60
2	weight of bottle + water	(gm)	771	771
3	volume of bottle	(b-a)	711	711
4	weight of bottle + sample	(gm)	632	640
5	weight of sample	(d-a)	572	580
6	weight of bottle + sample + water	(gm)	1135	1132
7	water added	(f-d)	503	492
8	water displaced	(c-g)	208	219
9	temperature of water		20	20
10	Specific gravity	e/hk	2.75	2.65
	Average specific gravity		2.70	

4.1.6 Properties of cement

For the purpose of this study, the properties of cement investigated are setting time and fineness of cement which are summarized in Table 4.7

Table 4.7: Cement properties

Characteristics	Value
Grade	C42.5
Bulk density	1507
Initial setting time	65mins
Final setting time	160mins
Fineness modulus	6%

4.1.7 Setting time of cement

The result of the setting time of the cement used is presented in Table 4.8. From the table, the initial setting time and the final setting time of the cement sample used are 65 minutes and 160 minutes respectively.

Table 4.8: Setting time of cement

SN	Time (min)	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		

4.1.8 Fineness of cement

The fineness of cement is an important property of cement that affects the strength gaining process and rate of generation of the heat of hydration of cement in the presence of moisture. The result of the fineness of the cement and cube compressive strength used is presented in Table 4.9 and 4.10. From the tables, the fineness modulus of the cement sample is 6% and average compressive strength of cube is 18.42 N/mm^2.

Table 4.9: Fineness modulus of cement sample

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

Table 4.10: Average compressive strength of hardened concrete cubes at 28days

Specimen	Weight (kg)	Ultimate failure load (kN)	Compressive strength N/mm^2	Average compressive strength (N/mm^2)
C1	8.01	387.21	17.21	
C2	8.042	461.92	20.53	18.42
C3	8.212	389.41	17.37	

4.1.9 Flexural strength of beams specimens

The beams specimens cast are 700mm long, 200mm wide and 230mm deep. The beams are supported on two simply supported edges of the flexural strength machine. The controls (solid) sample has no opening along its cross section. The other controls samples have openings (without strengthening) on both sides of the supports, such that, the openings have a distance (x) from each support. Table 4.11 shows the result of the flexural strength evaluated, the distance of the opening from the supports and the flexural strength of each beams specimen. The test results indicates that the use of strengthening material have beneficial effects on the strength and load carrying capacity of the beam. Table 4.11 shows the ultimate failure load (P_u), and flexural strength (Fs) for all the beams specimen, it can be observed that the solid reference or control beam with no opening deformed less than the beams with unstrengthen circular openings. The test results also showed that providing a 75mm diameter circular opening with unstrengthened openings caused a reduction in the ultimate load carrying capacity of the beam as compared to that of the solid beam. When opening is located at L/4 distance, the average ultimate load carrying capacity of the unstrengthened beams is 196.96 kN as compared with that of the solid or control beams. When the opening is located at L/8 distance, the average ultimate load carrying capacity of the beam is 190.84 kN as compared to the solid (control) beam.

Table 4.11: Average failure loads and flexural strength of concrete beams specimens

Beam	Distance	Strengthening	Ultimate	Flexural

specimen	of opening from support	material	failure load(Pu) kN	strength (fs) N/mm^2
SOLID			251.625	16.65
CT1	L/4	unstrengthen	196.96	13.03
CT2	L/8	unstrengthen	190.84	12.62
PB1	L/4	steel plate	232.31	15.37
PB1*	L/8	steel plate	228.92	15.15
PB2	L/4	galv.steel pipe	217.21	14.37
PB2*	L/8	galv.steel pipe	214.74	14.18
PB3	L/4	Strut tie metho	201.86	13.36
PB3*	L/8	Strut tie metho	200.17	13.24
M.C			88.06	5.83

On testing the control beams with openings at L/4 and L/8 (without strengthenings) CT1 and CT2 respectively revealed the behaviour of un-strengthened beams with openings in comparison to that of solid beam without openings. Figure 4.3 shows the effect of vertical circular openings on the beams load carrying capacity, the ultimate load bearing capacity of the controls (CT1) at L/4 and (CT2) at L/8 decreases by 18 and 20% as a result of the unstrengthened openings of diameter 75mm as compared to the solid beam without openings, which has an average ultimate failure load of 251.625 kN. These openings on the beam reduce the ultimate load capacity of the beam.

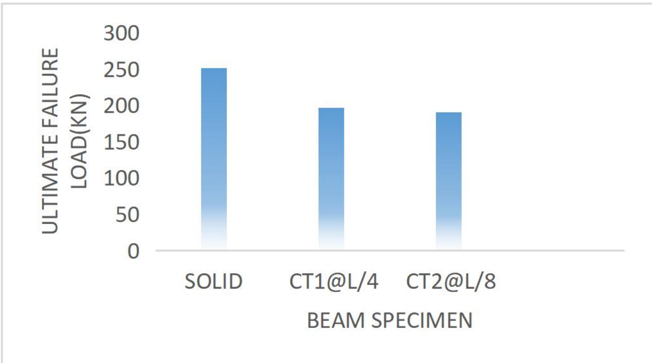

Figure 4.3: Ultimate load of reinforced concrete beams specimens without openings

The eighteen beams specimens chosen in the current experimental programme were aimed to achieve the objectives of this work through a comparison between the behaviour of the various beams, that is, solid beams without opening, beams with unstrengthen openings and beams with strengthened openings. Testing the control beams (CT1 and CT2) revealed the behaviour of un-strengthened beams with openings in comparison to that of a solid beam.

Also, testing beam PB1-PB3* revealed the behaviour of strengthened beams with opening in comparison to a solid beam and un-strengthened beam with opening. Furthermore, testing beams PB1-PB3* revealed the efficiency of the different schemes of strengthening for the beams with openings. This was achieved by comparing the behaviour of those beams PB1-PB3* to that of the solid beam and un-strengthened beam with opening. Such behaviour of all the tested beams is presented below. Also, necessary comparisons will be made between different beams in order to achieve the objectives of the study presented above. Figure 4.4 revealed the significant and noticeable effect of strengthening on the load capacity of the member. It can be clearly seen that after the openings have been strengthened (PB1-PB3*) the ultimate load increases as compared to that of the controls of the un-strengthened openings (CT1 and CT2) respectively.

Using steel plate of 4mm thickness (PB1 and PB1*) as strengthening material, increases the load bearing capacity of the beam by 15% at a distance of L/4 and 17% at a distance of L/8 respectively, as compared to that of unstrengthened openings (CTI and CT2). Using galvanize steel pipes of 2mm thickness (PB2 and PB2*), the ultimate load increases by 11% at a distance of L/4 and 9% at a distance of L/8, while using the strut tie method (PB3 and PB3*), it increases the ultimate load of the beam by at least 3 and 5% at a distance of L/4 and L/8 respectively as compared to that of the control beams.

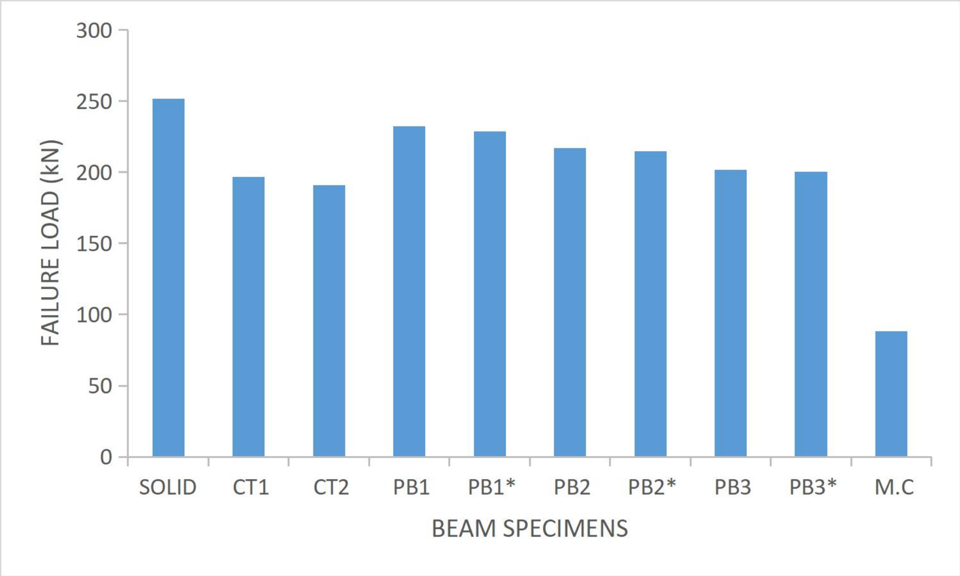

Figure 4.4: Average failure load of reinforced concrete beam specimens

Figure 4.5: Failure pattern in mass concrete after experiment

4.1.10 Crack and failure patterns of the beams

The crack mechanisms and failure pattern of the beams were observed in Figure 4.5, 4.6 and 4.7

Figure 4.6: Crack pattern of reinforced concrete beam (strengthened openings)

Figure 4.7: Crack pattern of reinforced concrete beam without openings (control beam)

For the solid beam without any opening, the first crack was observed at the bottom support, as the applied load kept increasing more cracks appeared towards the point load. Then at an average load capacity of 251.625 kN, the beam finally failed due to bending at the point of the load application. Different behaviour was observed for the unstrengthened beams with openings. In this case, the first crack was observed at the bottoms of the beam where the bending moment is maximum. As the load increases the cracks tend towards the opening corners and the beam finally failed at an average failure load of 196.980 kN and 190.840 kN at an opening distance of L/4 and L/8 respectively. In the case of the cracking behaviour of the strengthened beams with openings. PB1-PB2* cracking behaviour was similar to that for the un-strengthened beams with openings.

However, cracks were observed in the case of beams with circular strengthening at a higher values of applied load than that of unstrengthened beams. It was also noted that the crack propagation could not be observed along the beams with strengthened openings due to the existence of materials around the openings used for the strengthening of the beams.

However, the first crack which was observed for those beams was a flexural crack formed on the bottom face of the beam and at the mid-span. Also in beams PB1-PB2* a different mode of failure was observed due to the strengthening scheme provided for these beams. Such a scheme provided enough anchorage for strengthening of the openings. Also such strengthening scheme increased the stiffness of the lower and upper chords against the vertical shear forces. The strengthening scheme provided for the beams transformed the failure mode to a flexural mode of failure rather than a shear mode of failure.

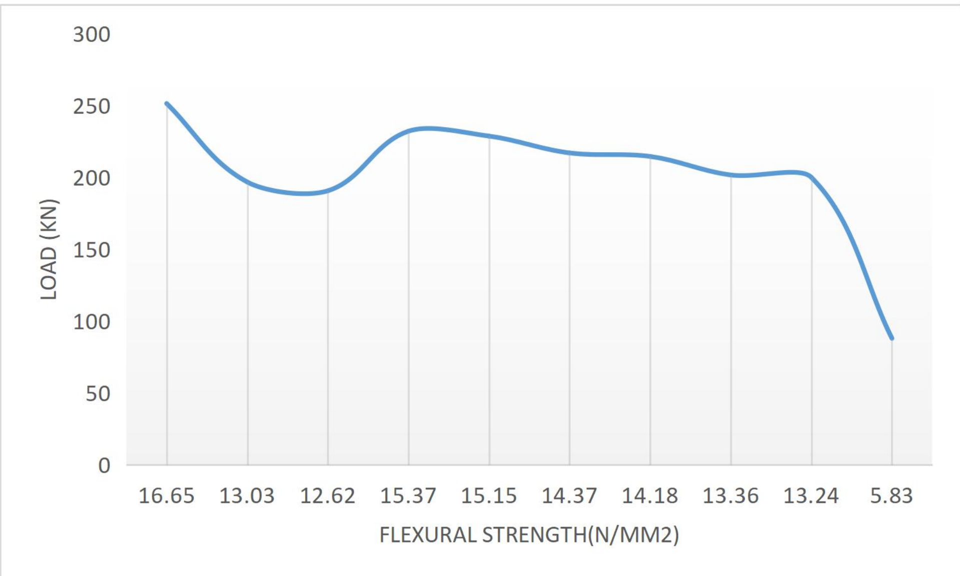

Figure 4.8: Average failure load and flexural strength of reinforced concrete beams specimens

Figure 4.8 revealed the relationship between the load and flexural strength of the beams specimens. It was observed that the solid (control) beam without openings gained more strength of about 16.65 N/mm^2 as compared to the other controls with openings but without strengthenings, that is, CT1 and CT2 which have a strength of 13 and 12 N/mm^2 respectively; this is due to the presence of the openings. On observing beam PB1 and PB1* the strength rose to 15 N/mm^2 at a distance of L/4and L/8 respectively as compared to the unstrengthened openings. Beam PB2 and PB2* also increased in strength by 14.4 and 14.2 N/mm^2 at a respective distances of L/4 and L/8, while PB3 and PB3* increased the strength of the beam by 13.4 and 13.2 N/mm^2 at a distances of L/4 and L/8 respectively. The mass concrete has the least strength of all the beams specimens due to lack of reinforcement or strengthening.

4.1.11 Efficiency of various strengthenings methods

The ultimate failure load (P_u) and the corresponding flexural strength are presented in Table 4.11 for all tested beams specimens.

Examining the results presented in table it is clear that the presence of an opening within the shear and above the support reduced the ultimate load capacity of the beam and the strength of the beam were reduced as well. The reduction in the ultimate failure load of the beam was about 18 % and 20% due to the presence of a 75mm diameter openings located at L/4 and L/8 distances from the supports for the controls (CT1 and CT2) respectively. It can be generally observed from the results presented in Table 4.11 that strengthening of such beams opening significantly enhanced the ultimate load capacity of the beam. However, such enhancement in the ultimate capacity depends on the type of strengthening as well. For instance, in the case of strengthening using steel plate, galvanize steel pipe of 4 and 2mm thicknesses, strut and tie method to strengthen the entire openings (Beams PB1-PB3*), the enhancement in the beam strength was 15.37, 15.15, 14.37 and 14.18 N/mm^2 respectively in comparison to that of the un-strengthened beams which is 12.77 and 12.36 N/mm^2.

The enhancement in the ultimate load capacity of the beams was as a result of the contribution of the steel plate, steel pipe and the strut and tie model which gives additional strength to the openings. The enhancement in the ultimate load capacity of the beams was 15, 16 and 3% for beams PB1, PB2 and PB3 at a distance of L/4 respectively in comparison to the un-strengthened beam CTI and 9, 11 and 5% for beams PB1*, PB2* and PB3* at a distance of L/8 as compared to the unstrengthened beam CT2. A comparison between the ultimate load capacities of beams PB1-PB2* revealed that the use of steel plates and galvanized steel pipes to strengthen openings improves the ultimate load capacity of the beam.

CHAPTER FIVE

5. 0 CONCLUSION AND RECOMMENDATIONS

5. 1 Conclusion

The potential use of selected materials for strengthening circular opening in beams was examined in the current study. Based on the result of this experimental investigation, the following conclusion can be made:

The preliminary results were obtained as follows: Average compressive strength of concrete cube is 18Mpa, AIV 17%, ACV 27%, Specific Gravity for Fine and Coarse aggregates are 2.57 and 2.70 respectively, fineness of Ordinary Portland Cement is 6% with 65mins and 160mins Initial and Final Setting time.

Using the strengthening techniques, the result showed a significantly increasing effects on the ultimate load capacity of the beam. The use of Steel plates increases the ultimate load capacity of the beam by 15 and 17%, galvanized steel pipe increases the ultimate load by 9 and 11%, while the use of the Strut and Tie Method (STM) also increases the ultimate load capacity by 3 and 5% at a distance of L/4 and L/8 from the support respectively as compared to the unstrengthen opening where L is the span of the beam.

Using the three strengthening methods in beams strengthening with vertical openings increases the flexural strength of the beams as compared to the control beams with unstrengthened openings.

Using steel plates and galvanized steel pipes for strengthening appear more effective, easy and convenient than STM in beams strengthening; also, if transverse opening is continued the steel plates and galvanized steel pipes should be used for strengthenings.

5. 2 Recommendations

From the experimental study carried out, the following recommendations were made:

i. The strengthening materials restore the full usage of the structural element, in this case beams effectively without compromising engineering performance and standard which is good for safety and durability.

ii. Steel plates strengthening method should be incorporated when vertical circular openings are to be created in reinforced concrete beams.

iii. Further studies should be carried out using Finite Element (FE) analysis to correlate the experimental results of this work.

5. 3 Contribution to Knowledge

The study established that the vertical circular openings have serious effect on the flexural strength of Reinforced Concrete beams. After strengthening with the various materials, the use of steel plates increases the ultimate load capacity of the beams by 15 and 17%, galvanized steel pipes increases the ultimate load capacity of the beams by 9 and 11% while the strut and tie methods increases the ultimate load capacity of the beams by 3 and 5% at a distance of L/4 and L/8 respectively from the support, where L is the span of the beam which is simply supported beams.

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