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Effect of Strengthening Vertical Circular Openings with Various Materials on the Behaviour of Reinforced Concrete Beams

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ABSTRACT
Opening in beam develops cracks around the region where the opening is as a result of stress concentration, this opening causes reduction in the beam strength and load carrying capacity as well. This work presents the effect of strengthening of vertical circular openings with various materials on the behaviour of Reinforced rectangular Concrete beam with dimension of 200mm x230mm x700mm.The effect of strengthening of openings was studied in terms of ultimate failure load, flexural strength and maximum deflection. It was observed that strengthening of vertical circular opening has an increase in load capacity and strength. The solid beam gives an average failure load of 251625N with flexural strength of 16.25N/mm2.The unstrengthen circular opening at L/4 and L/8 distance gives an average decrease in ultimate load of 28% and 32% with strength of 13N/mm2 and 12N/mm2 respectively. With steel plate strengthening of 4mm gauge, the ultimate load carrying capacity of the beam increases by 15% and 17% with flexural strength of 15N/mm2 each at a distance of L/4 and L/8 respectively as compared to beam with un strengthen opening. Using galvanize steel pipe of 2mm thickness increases the ultimate load by 9% and 11% with flexural strength of 14N/mm2 at a distance of L/4 and L/8 respectively. While the use of STM increases ultimate load by 3% and 5% with strength of 13N/mm2 at a distance of L/4 and L/8 respectively.
KEYWORDS: *Beam with Opening, Steel Plate, Steel Pipe, STM, Vertical Opening.*

1. INTRODUCTION

Beam openings in engineering have become a daily routine in the construction industry and this opening is of different shapes, sizes, location and are generally located close to the supports where shear is dominant without considering the engineering implication as it was not designed or planned, Lalramnghaki et, al, (2017). In practical life beam opening is quite often use to provide convenient passage for plumbing pipes and ducts for water supply system, sewage and electrical cables, but this presence of an opening in a reinforced concrete beam leads to many problems in the beam behaviour such as: (i) reduction in the beam stiffness; (ii) excessive cracking; (iii) excessive deflection; and (iv) reduction in the beam strength. Also, the presence of openings leads to a high stress concentration at the opening corners. The reduction in the beam stiffness as a result of the presence of openings changes the beam forces behaviour to a more complex one and leads to a considerable redistribution of the internal forces, Mansur (2006). The degree of change in the beam cross section as a result of the presence of an opening depends on many factors such as; shape and size of the opening; position of the opening; and type of loading. However, it was found that the size of opening and the distance from the support is the most important parameter that affects the beam behaviour, Said (2015). With all this drawback on the beam, there is need for solution to restore the strength of reinforced concrete beams with openings to the original or high-performance level. Due to this alteration of the beam 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 reduce deflection and cracking at the opening corners. Those strengthening resist the internal forces that are subjected to. The strengthened openings were compared with their counterparts, the un-strengthened openings. The control beam (solid) served as a reference to assess the performance of the test specimens with un- strengthened and the strengthened vertical circular openings. Since in every civil engineering work, safety is of paramount important, Abeer (2011). Hence, this study presented a clear understanding on the effect of various strengthening of vertical circular openings on the behaviour of reinforced concrete beam. The result of this study may be beneficial to produce an efficient strengthening of vertical circular openings. If the concept of various strengthening of vertical circular opening is commercially accepted, a strengthening process can be conducted much easier with equally satisfactory solutions.

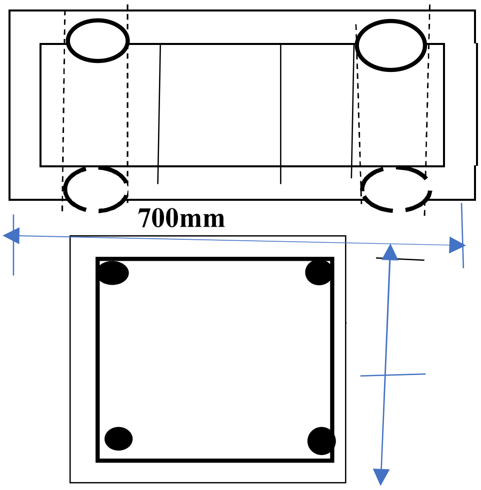


Figure 1.0: Beam details with opening and cross section

2. RELATED WORK

Jamiu, (2019), carried out an investigation on the effect of vertical circular opening on behaviour of reinforced concrete beam experimentally and using ANSYS 19.1, a total of twelve number beam was studied and he concluded that:

RC beams with openings showed a decrease in ultimate load carrying capacity compared to solid beams. The reduction in percentage of load bearing capacity was about 6% for beam with 25mm diameter opening located at 150mm from support, 32% for beam 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 beam without opening. Rectangular RC beam 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 bending zone of the beam reduces the ultimate load capacity of the RC beams by at least 35%, mode of failure is shear at the opening region, maximum compressive stress of the concrete occur at the opening region of the beam for the ultimate load and tensile stress of the longitudinal reinforcement reaches to its yield stress before reaching to the ultimate strength of the beam. The beams that bear openings far away from supports induced less stress to fail when compared with beams that bear opening 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).

khettab et al (2017). Examined the potential use of strengthening reinforced concrete (RC) deep beams that had web openings by steel plates. Experiments 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 decrease ultimate capacity about 20.5 %, 18.3%, 24.7 % and 31.7%, respectively in comparison with the reference solid beam. While strengthening those openings via steel plates was found very effective in upgrading the RC deep beam 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% & 11.88%, respectively in comparison with the unstrengthen 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% & 26.9%, respectively in comparison with the unstrengthen openings.

Research Significance

Openings adversely affect the overall stability of the structure. To overcome the instability of openings on the structural element, this work studies the incorporation of various strengthening of vertical circular openings using various materials.

3. MATERIAL AND METHODOLOGY EXPERIMENTAL WORK

Experimental Program

The test program consists of fabricating and testing of eighteen reinforced concrete beam with opening using a concrete mix with average cube compressive strength (*fcu*) equal to (18 MPa). All Beam specimens have the same dimensions (length, width and depth) equal to (700, 200 and 230mm). The variables investigated in this study are the type of opening (with or without strengthening).The specimens are divided into three groups, each of them includes four specimens, the specimens of the first group are with non-strengthened openings while the specimens of second group are strengthened, while the third are the solid with no openings, the nineteen specimen are cast as mass concrete without reinforcement and opening.

Materials Used

Material properties

The materials used in concrete mixture were Portland limestone cement (grade 42.5 Dangote 3x), natural river sand, maximum aggregate size of 20mm (3/4") with specific gravity of 2.70. The tensile strength of concrete is typically 8%-15% of the compressive strength and the Poisson ratio (v) for concrete was assumed to be 0.2, (Amiri and Masaudnia, 2011).The mix was carried out for 28 days with average cube concrete compressive strength f (cu) =18.37N/mm2, the cubes 150mm by 150mm by 150mm were cast at the same time as the specimen and cured alongside the concrete. The mix design proportion of cement, fine aggregate and coarse aggregate were (1:2:4). The water cement ratio by weight was kept in the range of 0.50. The longitudinal steel was high yield steel with nominal yield strength of 400N/mm2.the stirrups was mild steel with nominal yield strength of 240N/mm2, Rezwana, et al (2014). The steel is assumed to be an elastic-plastic material and identical in tension and compression with Poisson ratio of 0.3,Timoshenko, (1961).The main reinforcement bar was 2Ø12 at bottom and 2Ø12 at the top with stirrups of 8mm diameter at 200mm spacing.

Cement

Grade 42.5 Dangote Portland limestone cement (Dangote 3x) was chosen in this work because of its greater fineness which would have effective hydration. The cement which conforms to BS EN, 1971 is used for making concrete. The cement was uniform in colour, grey and was free from any hard lumps. Table 1: Shows the properties of the cement.

Table1: Properties of Cement

S/N	Characteristics	Value
1	Grade cement	42.5
2	Bulk density	1507
3	Initial setting time	65mins
4	Final setting time	160mins
5	Fineness modulus	6%

Fine aggregate

Natural sand was used as fine aggregate. The sand was sieved with sieve size 4.75mm and retained on sieve no.0075 to get rid of coarse aggregate according to BS EN 12620(2002). Which was free from clay or any organic matter or chemical. It has 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 sand complies with BS EN 882, zone II (1992) as shown in Table 2: Also, physical properties of fine aggregate are shown in Table 3:

Table 2: Grading of fine aggregate

BS Sieve size (mm)	Passing (%)
12.7	100
9.52	100
4.75	93.8
2.36	81.1
1.18	61.1
0.60	37.6
0.30	17.1
0.15	8.7

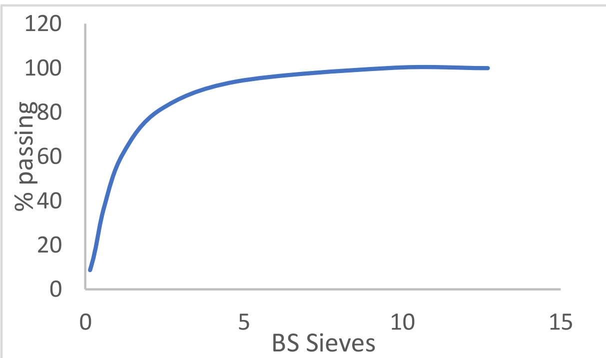


Table3: Physical properties of fine aggregate

Properties	Test results	BS specification limit
Grading Zone	Second	----
Fineness Modulus	2.25	----
Specific gravity	2.57	
Materials finer than sieve No. 200,%	2%	Not greater than 5%
size	Passing 4.75mm	

Coarse aggregate

Coarse aggregate with 20mm nominal (3/4") size was used, sourced from the market, hard and clean, free from organic impurities, free from clay and silt, free from oil coating. The grading of the coarse aggregate complies with the British standard. The preliminary tests such as Aggregate Crushing Value (ACV), Aggregate Impact Value (AIV) and particle size distribution of aggregates were carried out prior to concrete making specify by requirements of British Standards Institution. The grading coarse and particle size curve are shown in table 4 and table 5

Table 4: Grading of coarse aggregate

Sieve size (mm)	Passing (%)
50	100
37.5	100
19.05	90.2
9.52	9.5
4.76	1.2

Table 5: Physical properties of coarse aggregate

Properties	Test Results	BS EN Specification Limits (2002)
Specific Gravity	2.70	----
Bulk Density	1650 kg/m^3	----
ACV	26	23-30
AIV	17	17-21
Materials Finer Than Sieve No. 200,%	3%	Not Greater Than 3%

Mixing Water

Ordinary tap water was used for casting and curing all the specimens which was obtained from the teaching hospital construction site at Baze University, Abuja. According to the Nigerian Industrial Standard (NIS 87, 2004) water play a major role in the strength and workability of concrete when properly used as the water to cement ratio. The water used for mixing and curing 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.

Materials Used for Strengthening Openings

Steel plates and steel pipe (galvanize GI Pipe) of 4mm and 2mm thickness were used for strengthening the opening regions, these materials were used to strengthened the concrete that was removed due to the construction of the openings, shear connectors were welded to the materials for proper bonding and anchorage between the concrete, also 8mm diameter bar was used to fabricate the STM specimen used to strengthen the opening region. The strengthening materials were placed in the reinforcement cage into the formwork before concreting the beam.

Plate 1: materials used for strengthening the openings

Casting of Beam and Cubes specimen

The beam mould is fabricated with steel with dimension of 200mm x 230mm x 700mm while the mould of 150mm x 150mm x150mm size was used to produce the test samples in accordance to BS EN 12390 (2002)

Curing of Beam and Cubes Specimen
The samples were completely immersed in water for curing age of 28days in accordance to BS EN 12390(2002)

Experimental Investigation
General
The experimental study consists of casting of eighteen rectangular reinforced concrete beams including beams with and without opening. Circular openings are provided at the shear zone. All the beams cast are tested to failure. The beams are indicated by the label: SOLID, CT1, CT2, PB1, PB1* PB2, PB2*, PB3, PB3*. All beams had the same geometrical dimensions. The behaviour of beams with transverse circular opening under strengthening is carried out. Beams without circular opening are provided (SOLID), two beams with opening at L/4 distance and two beams with opening at L/8 distance from the support without strengthening(CT1 and CT2) all serve as the control beam. The rest are provided with strengthening materials. These beams are tested using 2000kN testing machine under single point loading in the loading frame, the ultimate failure load of the beam and deflection have been recorded and results were compared with the control beam without opening and control beam with unstrengthen opening.
SOLID: Control specimen without opening.
CT1: Beam with two transverse circular opening without strengthening at L/4
CT2: Beam with two transverse circular opening without strengthening at L/8
PB1: Beam with two transverse circular opening with Steel plate strengthening at L/4.
PB1*: Beam with two transverse circular opening with steel plate strengthening at L/8
PB2: Beam with two circular opening with Steel pipe strengthening at L/4.
PB2*: Beam with two opening with steel pipe strengthening at L/4
PB2*: Beam with two transverse opening with steel pipe at L/8
PB3: Beam with two transverse opening with STM at L/4
PB3*: Beam with two transverse opening with STM at L/8

Plate 2: Flexural strength testing machine of 2000kN capacity

Specimens.
The beams consist of eighteen numbers, all the tested beams were rectangular in cross-section having dimension of 200mm width, 230mm height with overall length (L) of 700mm. the beam were cast using steel formwork. 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 galvanize 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.

Mixing, compaction and curing of concrete.
Before mixing, all quantities are weighted and packed in a container, through hand mixing was done. Compaction was done with the help of 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 metal trowel. The curing was done in an open tank to prevent the loss of water which is essential for the process of hydration and hence for hardening.

Plate 3: Cast Beam with Strengthened

Openings

Plate 4: Curing of Beam Specimen

Test Setup

The beams were tested 28days after the casting to investigate the effects of the strengthened openings on the flexural behaviour of the concrete beam using an academic Testing Machine of 2000kN maximum capacity. All the specimens were tested for flexural strength under single point flexural load. The specimens were arranged with simply supported conditions. Loads were applied digitally till the ultimate failure of the specimens occurred.

Plate 5: Experimental Setup

4. RESULT AND DISCUSSION

Engineering Properties of the Hardened Concrete (Compressive Strength Test)

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 tabulated result for the compressive strength test is given in table 6. The compressive strength test of the specimen is 18Mpa or 18 N/mm^2

Table 6: Compressive Strength Test

specimen	weight (kg)	ultimate failure load (kN)	compressive strength N/mm^2	average compressive strength (N/mm2)
C1	8.01	387.21	17.21	
C2	8.042	461.92	20.53	18.42
C3	8.212	389.41	17.37	

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 can be said to be fit for use in concrete production (Mamlouk and Zaniewski 2006).

Figure 2: Particle size distribution curve for coarse aggregate

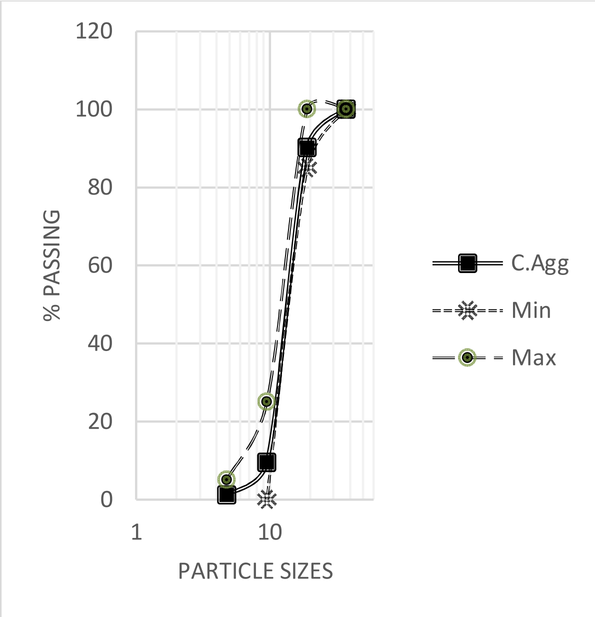


Figure 3: Particle size distribution for fine aggregate

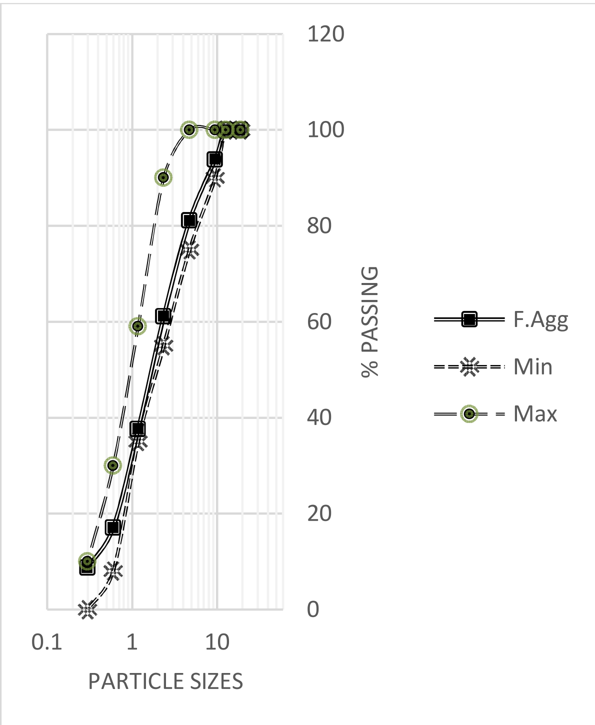
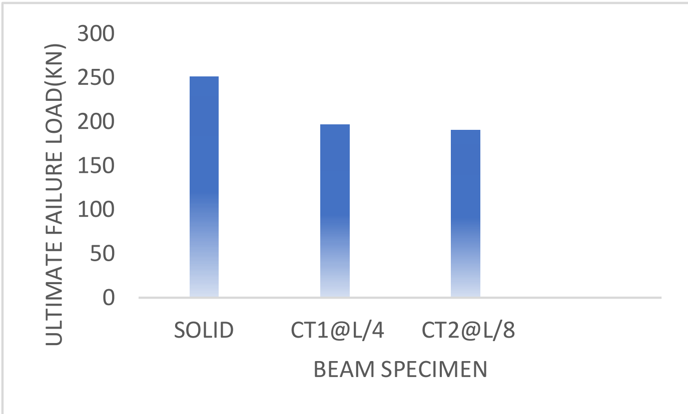


Table 7. Result of Flexural Strength Obtained

Beam Specimen	Distance of Opening from Support	Ultimate Failure Load(Pu) kN	Maximum deflection (mm)	Flexural Strength (Fs) N/mm2
SOLID		251.625	0.443	16.25
CT1	L/4	196.96	0.347	13.03
CT2	L/8	190.84	0.336	12.62
PB1	L/4	232.31	0.409	15.37
PB1*	L/8	228.92	0.403	15.15
PB2	L/4	217.21	0.383	14.37
PB2*	L/8	214.74	0.378	14.18
PB3	L/4	201.86	0.336	13.36
PB3*	L/8	200.17	0.352	13.24
M.C		88.06	0.155	5.83

Figure 4: Ultimate Load Graph of the Control Beams



Testing beams CT1@L/4 and CT2@L/8 (Control) revealed the behaviour of un-strengthened beams with openings in comparison to that of a solid beam without opening. Figure 4 shows the effect of vertical circular opening on the beam load carrying capacity, the ultimate bearing capacity of CT1@L/4 and CT2@L/8 decreases by 28% and 32% as a result of the unstrengthen opening of diameter 75mm as compared to the solid beam without opening which has an average ultimate failure load of 251625N. This openings on the beam reduces the ultimate load capacity of the member.

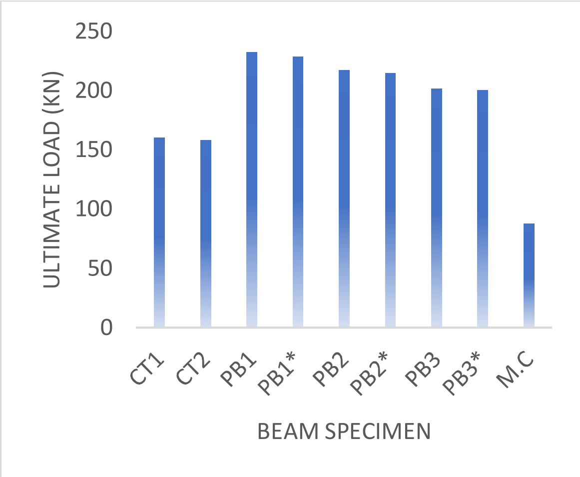


Figure 5: Effect of Strengthening Materials on the Load Carrying Capacity Beam

Figure 5 revealed the significant and noticeable effect of strengthening on the Load capacity of the member, it can be clearly seen that after the openings has been strengthen (PB1-PB3*) the ultimate load also increases as compared to the un-strengthened opening CT1 and CT2 respectively. The use of Steel Plate of 4mm gauge (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 the unstrengthen opening(CTI and CT2). Using galvanize steel pipe of 2mm gauge (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 strut tie method (PB3 and PB3*) it increases the ultimate load by 3% and 5% at a distance of L/4 and L/8 respectively as compared to the control.

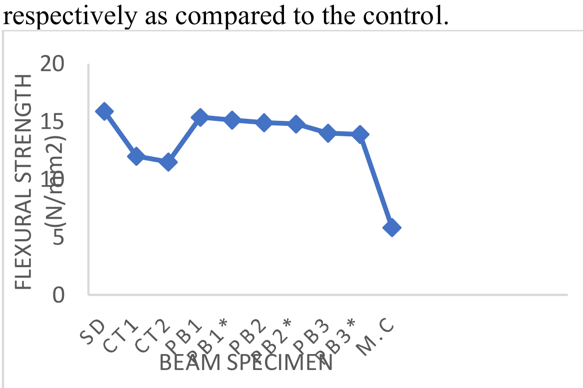


Figure 6: Flexural strength Graph

Figure 6 revealed the relationship between the strength of the beam specimen, it can be observed that the SOLID (SD) beam without opening gain more strength of 16N/mm2 as compared to CT1 and CT2 which has a strength of 13N/mm2 and 12N/mm2 respectively, this is due to the presence of openings. Observing beam PB1 and PB1* the strength rise to 15N/mm2 at a distance of L/4and L/8 respectively as compared to the unstrengthen opening. Beam PB2 and PB2* also increase in strength by 14.4N/mm2 and 14.2N/mm2 respectively, while STM also increases the strength of the beam by13.4N/mm2 and 13.2N/mm2 respectively. The mass concrete has the least strength of all the beam specimen due to lack of reinforcement.

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 drawn:

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

Using the strengthening techniques, the result showed a noticeable increasing effects on the ultimate load capacity of the beam.

The use of Steel plate increases the ultimate load capacity of the beam by 15% and 17%, galvanize steel pipe increases the ultimate load by 9% and 11%, while the use of STM also increases the ultimate load by 3% and 5% at a distance of L/4 and L/8 from the support respectively as compared to the unstrengthen opening.

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

Using steel plate and steel pipe for strengthening appear more effective, easy and convenience than STM in beam strengthening.

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