Original Research Article

EFFECT OF BIG SERVICE OPENINGS ON BENDING STRENGTH OF REINFORCED CONCRETE SLENDER BEAM

ABSTRACT

The focus of this research is to investigate the effect of big service openings on the ultimate load of reinforced concrete slender beams. A total number of ten beams were cast using 20.8 N/mm² concrete strength. The cross-sectional dimensions of the beams are 100mm x 150mm and 1000 mm length, with effective span of 750 mm. The tested beams consisted of two control beams. The experimental beams consisted of eight beams, four of the beams were with 40 mm service openings (with two beams having openings at the centre and two beams having openings at the supports) and the other four beams had 50 mm service holes (with two beams having openings at the centre and two beams having openings at the supports). The reinforced concrete beams were cured by covering it with wet cloths and tested at 28th day. The control beams and experimental beams are subjected to point loads at the beam centre. The average actual ultimate load for the experimental beams with 40 mm service openings at the supports (TII) and centre were (TIII) were 49.48 kN and 63.28 kN respectively, while the average actual ultimate load for the experimental beams with 50 mm openings at supports (TIV) and centre (TV) were 42.85 kN and 62.26 kN respectively. The average actual ultimate load for the control beams (TI) was 63.88 kN, while the estimated ultimate loads for control and the experimental beams was 63.88 kN. The openings placed at the supports of beams have more reducing effect on the ultimate load, when compared with the openings placed at the centre of the beams.

Keywords: Slender beam, Concrete, Compressive strength, Control beam, Service openings

1. INTRODUCTION

Openings and drilled ducts are often provided in concrete structural elements to allow access for services, such as pipes for plumbing and electric wiring. The provision of such openings may result in the loss of strength, stiffness and ductility. These openings can either be large or small depending on the schematic layout of the building. The web openings of the beam result in the decrease of flexural and shear strengths, flexural stiffness, and the increase of the deflection. The reinforcement at the opening is needed to ensure the proper strength and stiffness of the beams (Mansur *et al.*, 1985). Therefore to prevent adverse effects of the provision of openings in beams, these openings must be considered adequately during the design or construction stages. This is especially true for unbraced structures, since loss of stiffness leads to redistribution of internal forces and moments.

Construction of modern buildings do ensure a network of pipes and ducts necessary to accommodate essential services like water supply, sewage, air-conditioning, electricity, telephone, and computer network. Usually, these pipes and ducts are placed underneath the beam soffit and, for aesthetic reasons, are covered by a suspended ceiling, thus creating a dead space. Passing these ducts through transverse openings in the floor beams leads to a reduction in the dead space and results in a more compact design (Mansur and Tan, 1999). For small buildings, the savings thus achieved may not be significant, but for multi-story buildings, any saving in story height multiplied by the number of stories can represent a substantial saving in total height, length of air-conditioning and electrical ducts, plumbing risers, walls and partition surfaces, and overall load on the foundation (Mansur and Tan, 1999).

British Standard Institution (BS EN 1992-1-1, 2004) defines a deep beam as a member whose span is less or equal to 3 times the overall section depth. Hence slender beam can be said to be beam whose span is greater than 3 times the overall section depth (Olanitori and Tifase, 2019). Mansur and Tan (1999), considered circular and square (or rectangular) in shape opening as small if $d \leq 0.25\ h$ (where d is depth of square or rectangular openings or the diameter of a circular opening and h is the beam height) and otherwise, it is classified as large opening. Research work into the behaviour of deep beams with ducts has been carried out extensively; however, research into the behaviour of slender beams with big service openings is rare and attracts little or no attention. Hence, the focus of this research is to investigate the effect of big service openings on the strength characteristic of slender beams.

LITERATURE REVIEW

In his work, Aziz (2016) noted that for beams with service openings when compared with the ones without service openings, their the ultimate strengths were decreased by 12%, 22% and 41% for beams containing opening at distance L/2, L/3 and L/6 from the edge respectively. This means that moving of opening locations from the centre towards the supports, lead to decrease in the carrying capacity of the ultimate load.

When the opening is small enough to maintain the beam-type behaviour, or in other words if the usual beam theory applies, then the opening may be termed as small opening. Those that prevent beam-type behaviour to develop are termed large opening. The presence of large openings in reinforced concrete beams requires special attention in the analysis and design phase because of the reduction in both strength and stiffness of the beam and excessive cracking at the opening due to high stress concentration (Vivek and Madhavi, 2016).

Lee *et al*. (2010) noted that there was increase in the load carrying capacity of the beam for reinforced concrete T-section deep beams strengthened externally with CFRP sheets. In order to reduce the effects of service openings on the strength characteristics of beams, Suresh and Prabhavathy (2014), used steel fibres and steel plates to strengthen the service openings. From the test results, Suresh and Prabhavathy (2014) noted that the presence of service openings in the shear zone reduces the load carrying capacity by 55 to 70 % for the beams with openings. Also, the experimental results show that strengthening the duct openings with steel fibres and steel plates increase the load carrying capacity and the ductility characteristics of the beam.

From their work, Olanitori and Tifase (2017), noted that the decrease in the flexural strength of the beam with small service hole at the centre was between 39.62% and 42.64%, while that of the beam with the small hole at supports is between 6.0% and 14.67%. Hence, it was recommended that small service holes should be located near the supports as practicable as possible. Also Olanitori and Tifase (2019), investigated the effect of small transverse service holes on shear strength of reinforced concrete slender beams. The study shows that the ultimate load of beams with service holes depends on the size of holes, position of holes, and of type loading. Ame, *et al*, (2020) study the effect of the size of service holes and their vertical positions on the ultimate load. The results show that the ultimate load is affected by the size of the holes and their vertical positions.

MATERIALS AND METHODS

The materials used are Portland cement of grade 42, fine aggregate, crushed granite, water and reinforcing bars. The concrete grade used is determined from the concrete trial mix tests carried out, while that of the reinforcing bar was determined from tensile test. The reinforcing bar was sourced locally. After 24 hours of casting, the beams were de-moulded and were cured by covering the with wet nylon materials to prevent evaporation of the water. The wetting of the beams were carried out in the morning and in the afternoon and the covering replaced immediately after the wetting. The covering of the beams were removed 24 hours before testing. The beams were subjected to bending test at the 28th day. The concrete cubes were cured by immersion in water in curing tank. The cubes were removed from the curing tank 24 hours before subjected to compressive tests at 7th, 14th, 21st and 28th days respectively. Plate 1 shows the curing of the beams.

Plate 1: Curing of Experimental Beams.

The total number of reinforced concrete slender beams cast was ten, two of which were control beams while the remaining eight were experimental beams. The cross-sectional dimensions of the beams were 100 mm x 150 mm and 1000 mm length, with effective span of 750 mm. All the beams were reinforced with Y12 main reinforcing bars and with 8 mm bars as links. The two control beams (TI) were without the service ducts, while the remaining eight experimental beams were with service openings. The first two experimental beams (TII) have 40 mm diameter opening at the supports of the beams, while the second pairs of the beams (TIII) were having 40 mm service opening at the centre. The third pairs of the beams (TIV) have 50 mm service openings at supports, while the forth pair of the beams (TV) were having 50 mm service openings at the centre. All the beams were loaded at the centre with a point load until failure occurred. The load at failure for each of the beams were noted and recorded. Table 1 and Figure 1 show the details of the beams. Plate 2 shows the UTM used for the work.

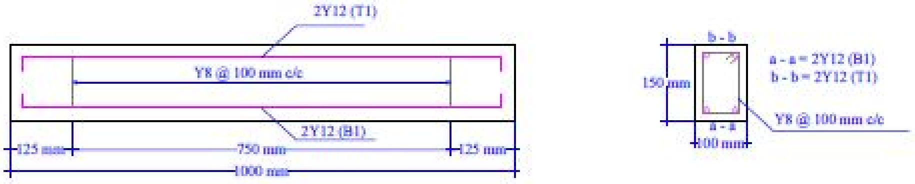

Figure 1a: Details of Control Beam

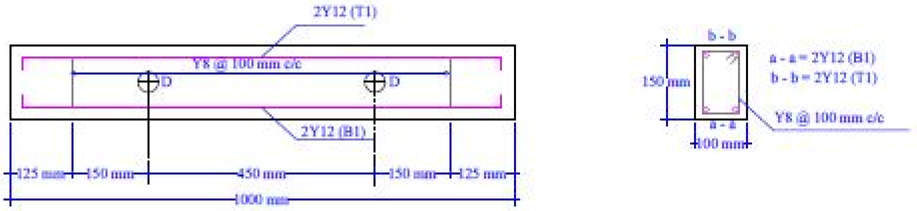

Figure 1b: Details of Experimental Beams (Types II & IV) with Openings at Supports

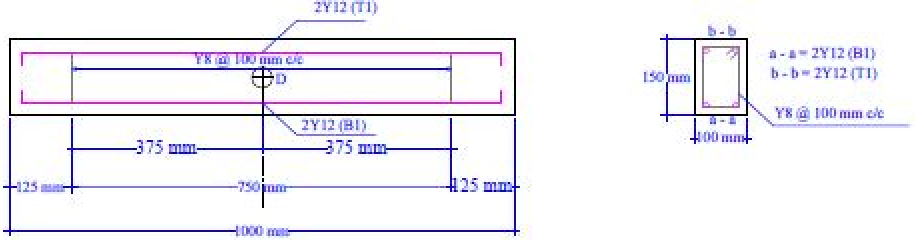

Figure 1b: Details of Experimental Beams (Types III & V) with Openings at the Mid-span

FIGURES 1a – c: Details of Experimental Beams

TABLE 1: Details of the Experimental Beams

Beam Type	Cross-section	Length (mm)	Opening	Position of

	(mm)		**Diameter (mm)**	**Opening (mm)**
I	100 x 150	1000	-	-
II	100 x 150	1000	40	Supports
III	100 x 150	1000	40	Centre
IV	100 x 150	1000	50	Supports
V	100 x 150	1000	50	Centre

Plate 2: The Universal Testing Machine Setup

RESULTS AND DISCUSSION

The results of the compressive tests carried out on the concrete cubes at 28th day are presented in Table 2, and normal distribution statistical method was used to determine the characteristic strength of the concrete mix.

The characteristic compressive strength of concrete cubes can be determined using Equation (1)

Table 2: Result of Concrete Compressive test (mix ratio 1:1½:3) at 28 Days

S/N	Weight (kg)	Load (kN)	Strength (N/mm^2)	Average Strength - $\bar{x}$ (N/mm^2)	$\sum(\boldsymbol{x}-\boldsymbol{x_i})^{\boldsymbol{2}}$
1	8.40	494.9	22.0		0.25
2	8.20	528.3	23.1		0.36
3	8.30	492.4	22.0		0.25
4	8.20	513.8	22.6		0.01
5	8.40	532.1	23.6		1.21
7	8.40	488.3	21.7		0.64
8	8.00	522.1	23.2		0.49
9	8.30	528.9	23.4		0.81
10	7.90	508.2	22.6		0.01
11	7.80	438.6	19.5		9.0
12	8.30	501.3	22.1	22.5	0.16
13	8.10	523.8	23.0		0.25
14	8.50	508.5	22.6		0.01
15	8.20	535.5	23.8		1.69
16	8.70	477.0	21.2		1.69
17	8.60	530.4	22.9		0.16
18	8.35	486.4	22.0		0.25
19	8.35	535.2	23.9		1.96
20	8.60	506.3	22.5		0
			$\sum = 450$		$\sum = 19.24$

$$f_k = \bar{x} - 1.64\sigma \qquad Eq.(1)$$

Where f_k is the characteristic strength and σ is defined by Equation (2)

$$\sigma = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \qquad Eq.(2)$$

Where x – the strength of a sample; $\bar{x}$ - The arithmetic mean (or average) of the sample strengths, and n – The number of samples; σ – The standard deviation

Applying Eq. (2), we have:

$$\sigma = \sqrt{\frac{19.24}{20-1}} = 1.01$$

Substituting for $\bar{x}$ and σ in Eq. (1), we have:

$$f_k = 22.5 - 1.01x1.64 = 20.8\ N/mm^2$$

From the above, the characteristic strength of the concrete mix used for the production of the beams was 20.8 N/mm^2.

Table 3 shows the result of tensile tests carried out on high yield bars of diameters 8 mm and 12 mm respectively. The average yield stress of the reinforcing bars was determined to be 370 N/mm^2.

Table 3: Results of tensile tests of high yield reinforcements

Reinforcement diameter ϴ (mm)	Yield Load (KN)	Yield Stress f_y (N/mm^2)	Average Yield Stress f_{yA} (N/mm^2)
8	18.60	370.00	370
12	41.92	370.65	

Table 4 shows the results of the flexural tests on the control beams, while Tables 5 and 6 show results of the flexural tests on the experimental beams with 40 mm and 50 mm diameter openings respectively.

From Table 4, the average load at failure for the control beam TI is 63.88 kN, while from Table 5, the average loads at failure for beams (TII & TIII) with 40 mm diameter of openings at supports and centre are 49.48 kN and 63.28 kN respectively. Also from Table 6, average loads at failure for beams (TIV &TV) with 50 mm diameter of holes at supports and centre are 42.85 kN and 62.26 kN respectively.

Using equation of equilibrium of reinforced concrete rectangular section, the estimated load at failure for both the control and experimental beams was 70.13 kN.

Table 4**:** Results of Flexural Test on Control Beam (TI)

Beam No	Weight (kg)	Position of Hole	Position of Load	Load at Failure (kN)	Average load at Failure F_{AUL}
TI_1	43.40	-	At beam centre	63.85	63.88
TI_2	43.50	-	At beam centre	63.74	

Table 5: Results of Flexural Test on Experimental Beam with 40mm Ducts (TII & TIII)

Beam No	Weight (kg)	Position of Hole	Position of Load	Load at Failure (kN)	Average load at Failure F_{AUL} (kN)
TII_1	44.2	Supports	At beam centre	49.28	49.48
TII_2	44.0	Supports	At beam centre	49.67	
$TIII_1$	43.6	Center	At beam centre	63.0	63.28
$TIII_2$	44.1	Centre	At beam centre	63.55	

Table 6: Results of Flexural Test on Experimental Beam with 50mm service holes (TIV & TV)

Beam No	Weight (kg)	Position of Hole	Position of Load	Load at Failure (kN)	Average load at Failure F_{AUL} (kN)
TIV_1	44.0	Supports	At beam centre	43.52	42.85
TIV_2	43.8	Supports	At beam centre	42.17	
TV_1	43.5	Center	At beam centre	61.52	62.26
TV_2	44.1	Centre	At beam centre	62.99	

From Table 7, the Estimated Ultimate Load (F_{EUL}) is 70.13 kN, while F_{AUL} of the control beams (TI) is 63.88 kN, and this represents a decrease of 8.91% in the ultimate load when compared with the estimated one.

Also from Table 7, for the beams with 40 mm diameter openings at the supports (beam TII), there was 29.45% decrease in the ultimate load when compared with the estimated one, while there was 9.77% decrease in the ultimate load for beam (beam TIII) with 40 mm diameter openings at the centre when compared with the estimated one. For beams with 50 mm diameter openings at the supports (TIV), there was 38.9% decrease in the ultimate load when compared with the estimated one, while there was 11.22% decrease in the ultimate load for beam (TV) with 50 mm diameter opening at the centre when compared with the estimated one.

Table 7: The comparison of estimated ultimate load and actual load of the experimental beams

Beam No	**Estimated Ultimate Load (F_{EUL}) kN**	**Actual Ultimate Load (F_{AUL}) kN**	**$\left(\frac{F_{EUL} - F_{AUL}}{F_{EUL}}\right) \times 100$**
TI	70.13	63.88	8.91
TII	70.13	49.48	29.45
TIII	70.13	63.28	9.77
TIV	70.13	42.85	38.90
TV	70.13	62.26	11.22

Table 8 shows the effects of big service openings on the ultimate load of the beams when compared with that of the of the control beam. From Table 8, there was 22.54% decrease in the ultimate load for beam with 40 mm diameter openings at the supports (beam TII) when compared with the control beam, while there was 0.94% decrease in the ultimate load for beam (beam TIII) with 40 mm diameter openings at the centre when compared with the control beam. For beams with 50 mm diameter openings at the supports (TIV), there was 32.92% decrease in the ultimate load when compared with the control beam, while there was 2.54% decrease in the ultimate load for beam (TV) with 50 mm diameter openings at the centre when compared with the control beam.

Table 8: Effect of holes on the strength characteristics of slender beams

Control Beam	**Experimental Beam**							
	40 mm Opening				**50 mm Opening**			
TI	**TII**		**TIII**		**TIV**		**TV**	
F_{AUL} (kN)	**F_{AUL} (kN)**	**% Difference**	**F_{AUL} (kN)**	**% Difference**	**F_{AUL} (kN)**	**% Difference**	**F_{AUL} (kN)**	**% Difference**
63.88	49.48	22.54	63.28	0.94	42.85	32.92	62.26	2.54

SUMMARY OF DISCUSSION OF RESULTS

The discussion of results above are summarised below:

1. The actual ultimate load of the beams without openings is less the estimated one.

2. For beam (TII) with 40mm openings at the supports, there were decreases of 29.45% and 22.54% of actual ultimate load when compared with the estimated ultimate load and the actual ultimate load of the control beam respectively, while for beam (TIV) with 50 mm openings at the supports, there were decreases of 38.9% and 32.92% of actual ultimate load when compared with the estimated load and the actual ultimate load of the control beam respectively.

3. For beam (TIII) with 40 mm openings near the centre, there were decreases of 9.77% and 0.94% of actual ultimate load when compared with the estimated ultimate load and the actual ultimate load of the control beam respectively, while for beam (TV) with 50 mm openings at the centre, there were decreases of 11.22% and 2.54% of actual ultimate load when compared with the estimated load and the actual ultimate load of the control beam respectively.

4. Increasing the size of openings at the supports from 40 mm to 50 mm, the ultimate load reduces from 49.48 kN to 42.85 kN, which represents a 13.4% reduction, while increasing the size of opening at the centre from 40 mm to 50 mm, the ultimate load reduces from 63.28 kN to 62.26 kN, which represents a 1.61% reduction.

5. The ultimate load of beam (TIII) with 40mm openings at the centre was 63.28 kN, while the ultimate load of beam (TII) with 40 mm ducts at supports was 49.48 kN, hence there was decrease of 21.81% of the actual ultimate load, when the opening was moved from centre to the supports.

6. The ultimate load of beam (TV) with 50mm ducts at the centre was 62.26 kN, while the ultimate load of beam (TIV) with 50 mm ducts at supports was 42.85 kN, hence there was decrease of 31.18% of the actual ultimate load, when the duct was moved from centre to the supports.

CONCLUSION

From the discussion of results above, the following conclusions can be made:

1. Estimated ultimate load is higher than the actual ultimate load.

2. Introduction of service openings resulted in the decrease of the ultimate load of beams, and increasing the diameter of the service openings increases the decreasing effect of openings on the ultimate load.

3. Openings placed at the supports have more decreasing effect on the ultimate load of beams when compared with that at the centre.

RECOMMENDATIONS

Based on the above conclusions, the following recommendations can be made.

1. Since there is decrease in the ultimate load of beams with service holes, loaded at the centre with a concentrated load, when compared with the estimated one, there is need to modify the existing design equations of beam for flexure when designing beams with service ducts to take care of the decreasing effect of service ducts on the ultimate load.
2. For beams loaded at the centre with a concentrated load, service ducts must be located near the centre of beams, since the effect of openings located at the centre on strength characteristics of beam is reduced when compared with openings located at the supports.

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