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The Opening Presence Effect on the Flexural Response of Concrete Beams

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Abstract:
In this study, an investigation of the flexural behavior of concrete beams with mid-span openings was implemented using different combinations of four specimens. The first specimen has no opening, as a reference beam (M-R). The other three samples have square openings of dimensions 100 mm in the mid-span. Two beams have been propped up with square steel tubes having two thicknesses, that is 2mm called (M-HS2), and 3mm(M-H). The fourth sample was left without reinforcement and called (M-H). The specimens used all have dimensions of 250 mm height and 150 mm width with a span of 90 cm. Digital Image Correlation (DIC) technique was implemented to measure the strains, displacements, and cracking behavior. The results indicate that the steel tube reinforcements of the opening significantly enhance the bending response of the R.C. beams.

Keywords: Concrete reinforced with steel tube, Composite effect on opening, Flexural behavior of beams with openings.

Introduction

The practical benefit of having the openings or holes in beams is to allow the pipe services to pass through the beams below the buildings to save the area and the pipes will be organized more and be of economic benefit as well and give a form free of impurities to see. The presence of duct openings in the shear and flexural of R.C beams reduces the load capacity. The load under which bending crack initiated doesn't depend on the presence of the opening, but shear cracks around the openings will induce sooner than shear cracks around the similar area in solid beam.

MANSUR M.A. (2006)[6] investigated the design of reinforced concrete beams with web openings. totally four ' T beam ' specimens were tested, which as S,O,O-G,O-FRP .The same dimensions for all specimens. The beam 'S' design without opening and beam 'O' was intended to resist the effects of making opening. In the beam 'O-G', the opening was filled with non-shrink grout. In contrast , beam 'O-FRP', which was strengthened by FRP plate. J.V. Amiri (2004)[7] investigated the effect of small circular strength of reinforced concrete using normal and high strength concrete . Totally 14 specimens were made and tested . The test of all beam was carried out 28 days , after the casting concrete , and found that the capacity increase in concrete doesn't effect the over all capacity directly but it will increase the stiffness and will improve serviceability of the beam.

S. A. Al-Sheikh (2014)[8] investigated the behaviour of reinforced concrete specimens with openings. Totally of 27 R.C beam specimens have been investigated to its capacity under two-point loading. The investigate

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behaviour as ultimate load, maximum deflection, failure patterns and found the large openings in R.C beam decrease the over all ultimate flexural capacity and also the beam deflection decreased more than the control beam.

Dr. Latha M S.et.al (2017)[9] investigated the behaviour of R.C beam with circular openings with varying percentage openings .Totally 6 models were tested , all the models were loaded by two point loading, using finite element method .The numerical method providing useful information about the test and explain effect on load deflection , crack pattern and found strength of the R.C beam can be increased by adding composite sheets or by additional steel reinforcement around the opening region.

R.Vivek , and T. Ch. Madhavi (2016)[10] also investigated the behaviour of R.C beam with web openings . The presence of small and large opening in the beam. Opening assumed small if it's size is approximately less than 40% of beam over all depth. In this case when web openings are small the beam action will prevail and the beam may be act as solid beam. Large openings in beam case reduce in strength and stiffness and cause large cracking at the vicinity of hollow area due to large stress induced.

NAZAR.et.al (2013)[4] investigated the response of R.C beam with multiple web openings to static load. The tested 7 R.C T-beam as simply supported beam under one incremental concentrated load at mid-span until failure. The parameters were the no. of web openings 4 or 6 and the method used to strength beams at openings deformed steel bars or CFRP fabric. One of the beams was solid beam without openings. Two beams with 4 and 6 openings without strengthening. Two beam with 4 and 6 openings strength with steel bars and two beams with 4 and 6 openings strengthening with CFRP fabric. The circular openings have 110 mm dia. and it was sizable with the web depth. The beams have 2000 mm long. The openings reduce the strength capacity in beam by 20% and 41% respectively increase deflection and cracks around openings. The strengthening decrease deflection and cracks and increase ultimate capacity at the beam. The gain in shear capacity with steel bars was (89 and 36 to 27 and 45) and the gain in shear capacity with CFRP fabric was (92 and 114 to 32 and 92) so CFRP gives better result.

J. SURESH.et.al(2014)[1] investigated the behaviour of steel fibre R.C beams with duct openings strengthened by steel plates. Totally 14 specimens were tested with cross section 150 x 300 mm and 2000 mm long. The test 2 R.C beams without openings and one of the beams is strengthened with fibre and the other is not. 4 R.C beams with openings in various size and 4 strengthened by fibre. The beam without openings as control beam. Ultimate load, deflection and cracking patterns are investigated. The openings in shear zone in beam reduce the carrying capacity by (55-70)%. The beam with strengthened with fibres openings increase the carrying capacity and ductility. R.C beams with different size openings and strengthened by fibre increase the carrying capacity but is a considerable increase in deflection to fore failure. Cracks are delayed when the beam is strengthened by steel plates. S.C.CHIN.et.al(2011)[2] investigated retrofitting of R.C beams having wide hollow area at bending zone with CFRP materials . A total of 5 R.C beams (cross section of 120 x 300 mm and 2000 mm long). One solid beam without openings. Two beams with large circular openings (230 in diameter) and square openings (210x210 mm) without strengthening. Other two beam with large circular openings (230 in diameter) and square openings (210 x 210 mm) strengthening with CFRP laminates. The beams have been examined to rupture under two- point load, testing to study the bending behaviour as crack modes, maximum capacity f mode and the load -deflection behaviour . the found that square openings tend to behave as a less ultimate load than the wide circular opening due to concentration of large stress at the four edges of the large square openings where the cracks were first started.

ROHIT VYAS.et.al (2017)[11] investigated the experimental study of R.C beam with openings for both bending and shear effect. A standard R.C beam of size (230 mm x 450 mm) and 2.5 m long and having two different openings size of(100 mm and 150 mm) is scaled down to a size of (65 x 126 mm) and 700 mm length similarly openings are scaled to a size of 28 mm and 42 mm . Three beams were tested without reinforcement in it having 1,2,3 openings respectively on each beam size 28 mm. To identify the cracking pattern due to which the beam fails. The beam is placed over the jaws of the UTM and fixed over it . The found that reinforcement is recommended to avoid the inclined cracks and decrease the deformation and the beam without openings have less deformation.

Research Significance

The main objective of this research project is to investigate the flexural behavior of Reinforced Concrete beams with openings in the middle. the effect of reinforcing the internal surface of the opening with different thickness of steel tube is also investigated.

Experimental Procedure

in this research, four specimens were selected to be tested under two-point load flexural test. All the beams have flexural span of 900mm. the cross sectional size of the beams were 150mm height and 100mm depth as explained in Fig. (1). One of the specimen was solid which labeled as M-R. the second specimens has an opening of 10mm * 10mm dimensions which labeled as M-H. while the other two specimens have an opening of 10mm * 10mm dimensions which reinforced with steel tube of 2mm thickness for M-HS2 and 3mm thickness for M-HS3 Table (1) below describes the details of the composite beams.

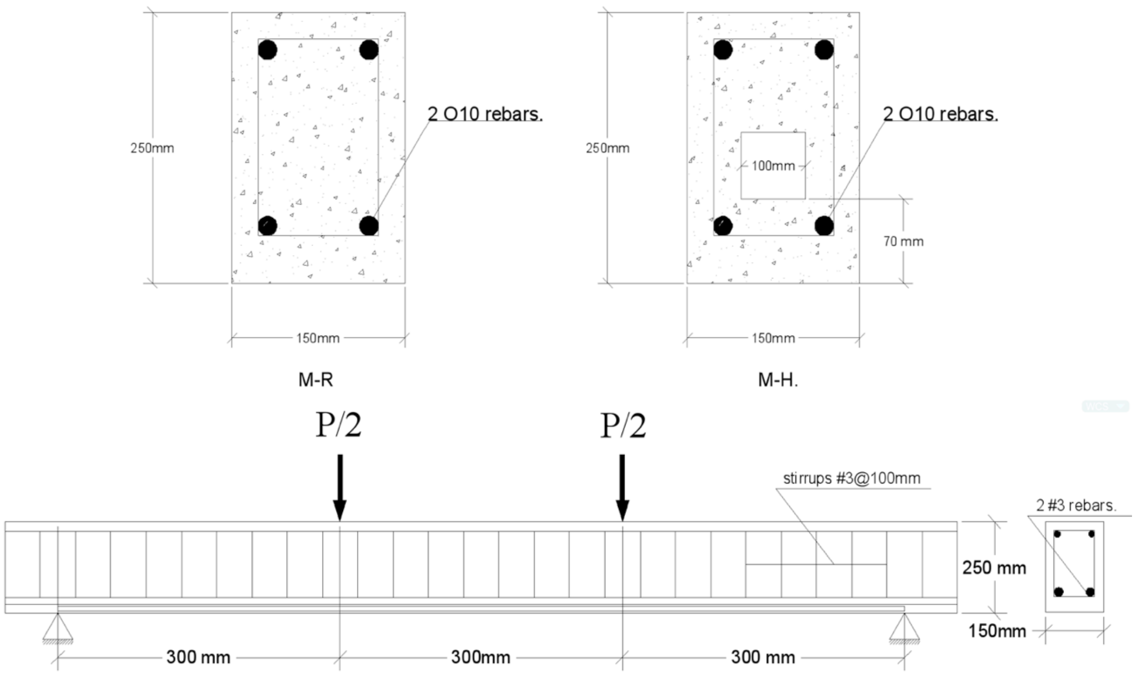

Figure 1 Properties of Beams.

Table 1 Details of Specimens

Specimen No.	Filled Concrete	The Opening Details	Fc' (MPa)
MR	Solid	-----------	37
M-H	Hollow	Hollow 100mm sq.	37
M-HS2	Hollow	Reinforced with steel tube of 2mm	35
M-HS3	Hollow	Reinforced with steel tube of 2mm	35

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Materials

The materials used in this project were concrete and steel. Portland cement, fine and course aggregates of ratio 1:2:4 as well as water /cement ratio of 0.4 have been used to produce the compressive strength of 35 MPa. The steel rebar was pullout under tensile force and the yielding stress was about 500 MPa. The steel tube however has a yielding stress of 300 MPa as provided by the manufacture. As shown in Fig (2) the steel cage was designed according to fig (2) and put inside the mold. After that the concrete was mixed by mechanical mixer and poured inside the molds and leveled. Concrete cubes were also prepared to be tested after 28 -day age of curing.

Figure 2 Beams and cubic casting.

Instruments and procedure

Specimens were tested by two-point load distributed evenly on simply supported span of 900 mm. the loading frame was run by using a 500 kN hydraulic cylinder that connected to a electrical pump. The displacement of the specimens was captured by using LVDT that was placed under the beam at the mid span. The beams were tested under a monotonically increasing load until failure. the mid span displacements and the applied load were recorded at specific load stages. Fig.3 explain the loading frame and the setup of the test.

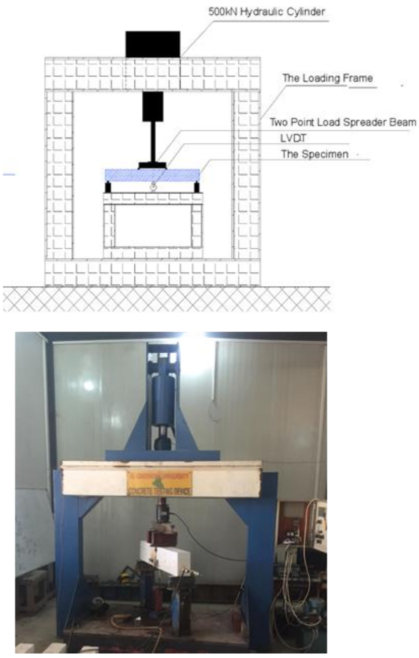

FIGURE 3 Loading Frame And Test Setup**.**

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Experimental Results

From the experimental results of load-deflection curves obtained from tested beams which are shown in Fig.4. It is obvious that hollow reinforced beams exhibit higher capacity than hollow beam. the capacity of the hollow reinforced beams was about 30% higher than the hollow beam. the ductility, stiffness, and the area under the load - deflection curve was also increased for hollow reinforced beams. Therefore, the energy absorption for hollow reinforced beams improved significantly and the ultimate loads were maintained. On the other hand, the efficiency of M-HS3 specimen were higher than the the efficiency of M-HS2 specimen in term of ultimate capacity and ductility. As observed from Fig.4 below, the capacity and the over all behavior of specimen M-HS3 was almost similar to that of M-R which contains no opening [,8].

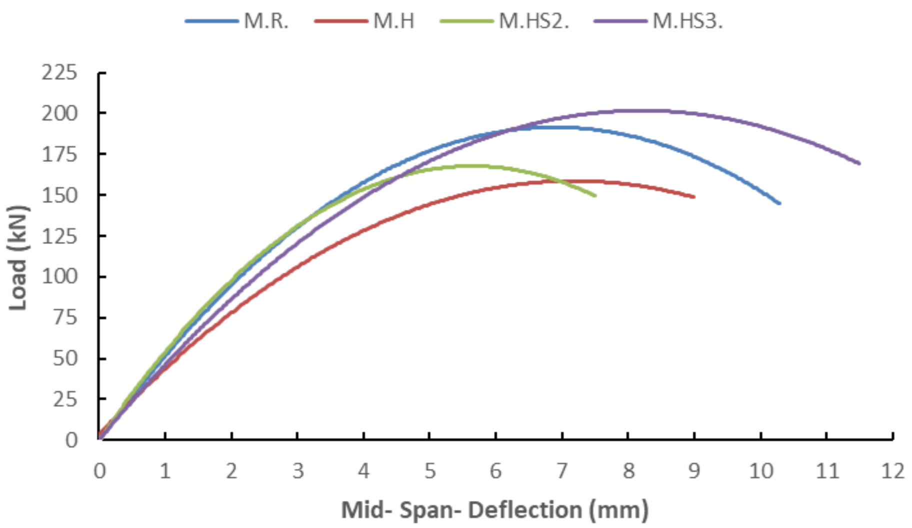

Figure 4 Load -mid-span-Deflection Curves for the Specimens.

The failure of hollow beam was pure flexural failure as shown in Fig 6. Where the bending cracks initiated at the soffit of the middle beam and extends towards the neutral axis. The cracks then widened as the load increase until the beam reach its capacity and failure occurred which is normally by crushing the concrete at the top of the specimens. As can be noticed from the figure below, the cracks of specimens M-H were less and wider than the cracks of the reinforced ones. This phenomenon gives an indication that the reinforcing method has redistributed the cracks and changed the behavior of the hollow beams.it is also obvious from the figure that the cracks in the hollow beam went through the opening. however, for the reinforced specimens the cracks pass around the steel tubes and continued their paths.

Digital Image Correlation (DIC) Technique.

Using new method called the Digital Image Correlation method (DIC), strain contour profile was carried out for hollow beams as shown in figure 5 and Table 2. By using this method first cracks and strain at any stages can be deducted. For instance, the first crack was reported as 10, 20, and 20 KN, for M-H, M-HS2, and M-HS3 respectively, this indicates that the steel tube reinforcement delays the first crams propagation more even the steel tube of 3mm thickness was more efficient than steel tube of 2mm thickness. The same observation was reported by J. SURESH.et.al(2014)1 .The profile also illustrates that the strain concentration was around the opening for the hollow specimens. However, for the specimens with steel tube reinforcement, the strain concentration shifted at a specific distance from the openings.

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Table 2 Cracks Patterns for the Specimens

Load (KN)	M-HS3	M-H	M-HS2
10	-	First crack (under the opening)	
20	First crack (under the opening)	Second crack (to the corner of the opening)	First crack to the bottom left of the opening
30	Second crack	Crack expansion	Second crack under the opening
45	-	Third crack	Third crack +second crack expansion
50	Third crack	Cracks expansion	Cracks expansion
60	Fourth crack	Cracks expansion	Cracks expansion
70	-	Cracks expansion	Cracks expansion + forth crack
80	Fifth crack +shear cracking (both sides)	Cracks expansion	Cracks expansion
95	-	Cracks expansion	Cracks expansion
105	Cracks expansion	Cracks expansion +shear crack reaching upward for both supports	Cracks expansion
130	Crack expansion + extending	Crack expansion	Cracks expansion
140	Crack expansion	Crack expansion Crack expansion +another crack to the corner of the opening	Cracks expansion
150	-	Cracks expansion Concrete crushing	Cracks expansion
160	Opening disintegration		Cracks expansion fifth crack to the corner of the opening+ concrete crushing
175	-	-	-
180	Cracks expansion	-	-

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	First crack disintegrate from the opening		
190	-	-	-
193	Cracks expansion	-	-
195	Crack expansion Concrete crushing	-	-

Conclusions

In this study, the flexural behavior of reinforced concrete Beams with Openings in the middle have been investigated. Four specimens have been studied also the Digital Image Correlation method (DIC) was carried out for all specimens to monitor the strain and the crack behavior

From the obtained results of the study, the following findings could be reported.

1- The steel tube reinforcement improved the flexural behavior of hollow beam significantly.
2- Stiffness, ductility, capacity, as well as the energy absorption of the reinforced hollow steel tube beams were increased.
3- The hollow steel tube of 3mm thickness was more efficient than the hollow steel tube of 2mm thickness in term of capacity and over all flexural behavior.
4- The steel tube reinforcement of hollow beam gains the same capacity as a solid beam
5- No bond slip happened in the surface between the steel plate and concrete surface of the opening.
6- Capacity of hollow steel tube increased when steel tube thickness increased from 2mm to 3mm.
7- Strain concentration was shifted from the corner of hollow section when steel tube reinforcement was used.

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