Enhancement behavior of reinforced concrete beam with transverse holes under combined twisting and bending using steel fiber

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Abstract
Openings in beams cause load path and stress discontinuities. Several research experiments have been conducted in recent years to improve the area surrounding the opening using various techniques. In this research investigate the effect of hybrid concrete (normal concrete and steel fiber reinforced concrete) on the beams with transfer opening subject to combined loading (torsion and bending). Six specimens of reinforced concrete beams with the same dimension and reinforcement were tested. The variable where distance of hybrid area around opening (150, 225, 450 and 1500) mm. The opening in reference concrete beams was decrease in the ultimate twisting moment (18.28%) with respect to solid one (without opening). The ultimate twisting moment increases by (32-68%) as steel fiber reinforced concrete is used around the opening. Simultaneously, the twist angle was increased by about (27.6-46.7%). In addition, relative to the control specimen, the first crack was delayed by about (41.6-75) %.

key word; opening, torsion, steel fiber, hybrid concrete

1. Introduction:
Structural features of reinforced concrete (RC) including interior beams on each floor of multi-story structures, edge beams of shell roofs, ring beams on the lower edge of circular-shaped tanks, beams supporting spiral staircases and archway slabs are subject to large torsional loading in addition to flexure and shear [1]. In the construction of reinforced concrete, depending on the load transfer process, torsion is defined by compatibility and equilibrium torsions. In beams that sustain overhanging projections sideways, the torsion balance exists and gives rise to the eccentricity of the load. Torsion of incompatibility, torsion is obtained through applying rotations (twists) at one or more points along the length of a structural member [2].

One of the most widely used is steel fiber. The fibers tiny, isolated steel fibers offer discontinuous three-dimension reinforcement that at the micro crack stage picks up load and transfer stresses. This reinforcement provides the concrete segment with tensile capacity and crack control before visible macro cracks are formed, thereby fostering ductility or durability [3]. In most modern buildings there is a need to install pipes and conduits such as water pipes and sewage supply as shown in Figure (1), electricity and telephone wires, gas lines, internet...
networks, and air conditioning. There are different shapes and size of transverse openings in beams as shown in Figure (2).

The microcrack stage picks up load and transfer stresses, and this reinforcement provides tensile capacity and crack control to the concrete section before observable macro cracks form, supporting ductility or toughness[3]. In most modern buildings there is a need to install pipes and conduits such as water pipes and sewage supply as shown in Figure (1), electricity and telephone wires, gas lines, internet networks, and air conditioning. There are different shapes and size of transverse openings in beams as shown in Figure (2). The shape of opening may be rectangular, circular, triangular, diamond, trapezoidal and even irregular shapes, but rectangular and circular openings are the most common shape. The service pipes, such as plumbing and electrical supply, are pushed through circular holes. While the rectangular openings are generally used to pass air-conditioning ducts [4].

![Figure 1. Water diversion pipelines passing through the beams [5]](image1)

![Figure 2. Shape of opening [6]](image2)

Steel fibers in concrete improve the mechanical properties of the matrix by slowing the growth of cracks and creating pinching forces at the crack tops. As a result, steel fiber reinforced concrete becomes a stronger energy absorbing medium, making it ideal for earthquake and blast resistance buildings. [7].

Hassan (2019) studied the torsional performance of reinforced concrete-beams-containing transverse horizontal-opening strengthened with fiber wire mesh All tested beams containing opening showed a decrease the ultimate torque with respect to the reference beam. While
strengthens beams increase in ultimate torque when compared with un strengthened beams in a range between (8.85% to 14.8%) [4]. Ban alla (2019) studied the effect of using different types of fibers under the combined effect of bending moment and torsional moment for reinforced concrete beams strengthened with different of fibers types. All types of fiber where increased capacity of beams and enhanced behavior of beams [2].

2. Objective of the Research

1- Studying the combined behavior (torsional and bending) of reinforced concrete beams have a transverse opening.

2- Experimentally investigating the effect of using of steel fiber and different area of hybrid concrete.

3. Experimental work.

The experimental program consisted of testing (6) beams specimens of dimensions (150 X 200 mm) in width and height respectively and 1500 mm in length as shown in Figure (3). The specimens are divided into two groups. The variable where distance of hybrid area around opening with the same volume friction (1%) of steel fiber. All the specimens have the same flexural and torsional steel reinforcement and tested under combined loading (torsion and bending). The first group consisted of two beams, which are cast as a normal strength concrete as control beam (with and without opening). The second group consisted of four beams with circular opening of (75 mm) diameter, which are cast as a hybrid concrete (normal concrete steel fiber reinforced concrete "SFRC" with 1% steel fiber with different distance (150, 225, 450, and 1500) mm around of opening in the center of beams. For the beams specimens, two types of concrete used normal strength concrete mixtures with compressive strengths of 35 MPa and the other type is steel fiber reinforced concrete with 1% steel fiber with compressive strengths getting from trail mix 52 MPa. Each case presented in Table (1) with a simple diagram explain the area casted with steel fiber concrete.

![Figure 3. Dimension and cross section of beams](image)

| Symbol | Area cast with mortar infiltrated fiber concrete | Case details | percentage of fiber (%) by volume |
|--------|-----------------------------------------------|--------------|---------------------------------|
| NC     | normal strength concrete(control beam without opening) | [Diagram] | ---- |

Table 1. Summary of all specimens
4. Material properties

The material use in the normal strength concrete with steel fiber were described below and mixing proportions show in Table (2).

Table 2: The mixing weight for normal concrete

| Materials         | Mix proportion |
|-------------------|----------------|
| Cement            | 368 kg/m³      |
| Coarse aggregate  | 900 kg/m³      |
| Fine aggregate    | 850 kg/m³      |
| Water             | 184 kg/m³      |
| \( w/c \)         | 0.5            |
| Hooked fiber      | 78 Kg/m³       |
4.1 Cement
Limestone Portland cement was the type of cement used in this research, respect with the (IQS No. 5/1984) limitations [10].

4.2 Fine Aggregate
Natural local sand conforms to the limits of Iraq specification (IQS No.45/1984) [9], Zone (2).

4.3 Coarse Aggregate
The coarse aggregate in this research is natural rounded gravel with a maximum size of 14 mm. Mechanical and chemical properties according to the requirements of (ASTM C33 /86) [9].

4.4 Steel Fibers
In this research used the fiber is hooked steel end fibers with a length of (35 mm) and a diameter of (0.55 mm), the hooked fiber was supplied by KOSTEEL's BUNDREX company in India and subsequently by KOSTEEL BUNDREX in India (EN 14889-1 and ASTM A820 M04).[11]

Table (3) indicates the technical properties of steel fibers used as provided by the manufacturer company Figure(4) show the hooked fibers used in this work

| Property                | Results of hooked end steel fiber |
|-------------------------|----------------------------------|
| Appearance              | Bright and clean wire            |
| Length (l), mm          | 35                               |
| Diameter (d), mm        | 0.55                             |
| Aspect ratio(l/d)       | 60                               |
| Density (kg/m3)         | 7800                             |
| Tensile strength (MPa)  | 1100                             |

Figure 4. The fibers used
4.5 Reinforcing Steel

In this research, deformed steel bars of three different diameters were used. The yielding and ultimate strength of the nominal diameter (6, 8 & 10 mm) bars were determined by tests. The recorded data are presented in Table (4). According to ASTM A615 [12]. Reinforcement details shown in Figure (5) and (6) all dimension in mm.

![Figure 5. Reinforcement details for beam without opening](image1)

![Figure 6. Reinforcement details for beam with opening](image2)

| Diameter (mm) | Nominal | Measured* | Yield stress* (MPa) | Ultimate strength* (MPa) |
|---------------|---------|-----------|---------------------|--------------------------|
| 6             | 5.88    | 459.78    | 510.23              |
| 8             | 7.9     | 550.83    | 678                 |
| 10            | 10      | 580.98    | 724                 |

5. Casting, Compaction, and Curing Process of the Specimens

The first step was the selection materials, prepared and weighed according to the required volume of the mix show in Table (2). All specimens in this research were cast in molds plywood with a clear dimension of (150*200*1500 mm) as shown, slices of Aluminum used to separate and isolate the area that will be cast with steel fiber reinforced concrete "SFRC" as shown Figure(7). The two types of concrete casting at the same time after filling the mold to the required level the slices of Aluminum removed by a steady upward pull. Then use vibration to achieve the full bonding between the two types of concrete. Addition of steel fiber in dry concrete in the electrical mixer. After (24) hours remove the plywood mold and curing the specimen.


6. Test Setup and Procedure

The major structural behavior of the beam samples was discovered during the test at each loading level. The load was applied on the beam at third of beams to get bending moment and torsion moment, the arm of torsion moment (45 cm) from the center of beam. A 0.01 mm dial gauge was utilized at the arm of torque of the beam to record the twist angle and 0.01 mm dial gauges were utilized in the center of the beam to record deflection as shown in Figure (8A, B, and C). The beams were tested under torque and bending and then the beams were loaded at a constant loading rate [1]. At each loading interval, the twist angle and deflection readings were noted, as well as the load of the first crack, allowing for the recording of different types of cracking and load failure, as shown in Figure (9).
Figure 8. Schematic of test combined "torsion and bending"
7. Result and discussion

7.1 First group

This group consist of two beams with and without transverse opening normal concrete tested under combined (torsion and bending) the loading increased gradually until failure. Then cracks formed on all other faces around the beam within testing length as shown in Figure (10) and Figure (11). The values of twisting moments, angles of twist, first cracking load and the maximum load are demonstrated in Table (5). The ultimate twisting moment of (O1F0L0) specimen was decreased by (18.28%) with respect to the reference beam (NC), The founding of openings, however, produces discontinuities or disturbances in the normal flow of stresses cusses the decreased in ultimate torque The cracks were developed in a spiral pattern all over the main beam which later leads to the failure of the beam in torsional shear. These findings are in agreement with other researchers (Mansur, 1999) and (Hassan 2019). The decrease in torque shown in Figure (12).

| Specimen | Ultimate Load (KN) | Ultimate Twisting moment (kN.m) | The Ultimate twisting angle (radians) | Deflection (mm) | Comments |
|----------|-------------------|--------------------------------|-------------------------------------|----------------|----------|
| NC       | 33.65             | 7.57                           | 0.0448                              | 3.66           | First crack at 13.5 kN |
| O1F0L0   | 27.5              | 6.18                           | 0.0441                              | 4.12           | First crack at 12 kN  |

Figure 9. Method of testing specimens using the universal testing machine
**Figure 10.** Cracks patterns of NC specimens

**Figure 11.** Cracks patterns of O1F0L0 specimens
Figure 12. The curve of torque moment vs twisting angle for (NC and O1F0L0)

7.2 Second group:
This group consist of four beams, which are casted as a hybrid concrete (normal concrete and steel fiber reinforced concrete with volume fraction of fiber a 1% with different distance (150, 225, 450 and 1500) mm at center of beams, all beam with circular opening of (75 mm) diameter. When increasing area of hybridization of concrete around of opening found enhance twisting moment capacity, angle of twist, deflection and daily appearing of first crack), because of resistance mechanism due to fibers, in addition in concrete making bridging the micro cracks growth, and consequently lead to the higher strength and making specimen have more stiffness. The values of twisting moments, angles of twist, first cracking load and the maximum load are demonstrated in Table (6). Cracks patterns of second groups specimens as shown in Figure (13). Figure (14) show the behaver of second groups.

Table 6. The values of twisting moments, angles of twist

| Specimens   | Ultimate Load (kN) | Ultimate Twisting moment (kN.m) | Increasing in ultimate twisting with respect to O1F0L0 (%) | Ultimate twisting angle (radians) | Increasing in twisting angle with respect to ultimate twisting of O1F0L0 (%) | Ultimate deflection (mm) |
|-------------|--------------------|---------------------------------|----------------------------------------------------------|----------------------------------|--------------------------------------------------------------------------|-------------------------|
| O1F0L0      | 27.5               | 6.18                            | -----                                                    | 0.0441                           | -----                                                                    | 4.12                    |
| O1F1L150    | 40.94              | 9.215                           | 32.9                                                    | 0.0647                           | 46.7                                                                    | 5.48                    |
| O1F1L225    | 41.4               | 9.234                           | 49.4                                                    | 0.0519                           | 17.6                                                                    | 5.53                    |
| O1F1L450    | 44                 | 9.9                             | 60.1                                                    | 0.0546                           | 23.8                                                                    | 5.69                    |
| O1F1L1500   | 45.73              | 10.29                           | 68                                                      | 0.0563                           | 27.6                                                                    | 6.81                    |
Figure 13. Cracks patterns of second groups specimens

Figure 14. The curve of torque moment vs twisting angle for (second groups)
8. Conclusion

From the experimental program enhance of behavior of beams when cast hybrid concrete around the opening, and the result where

1. When the size of opening (0.375) form all depth of beam caused decrees in ultimate twisting about (18.28)% from control without opening.
2. Using steel fiber in hybrid concrete enhance the ultimate twisting moment, angle of twist and deflection.
3. When using hybrid concrete (normal concrete and SFRC) with volume friction of steel fiber 1%, the increase in ultimate twisting moment (32.9, 49.4, 60.1 and 68)% and the increase in twisting angle with respect to the beams (46.7, 17.6, 23.8 and 27.6)% when the distance of SFRC (150, 225, 450 and 1500) mm respectively.
4. When using hybrid concrete (normal concrete and SFRC) with volume friction of steel fiber 1%, causes daily in first cracking load about (41.6, 60.8, 65.8 and 75)% when the distance of SFRC (150, 225, 450 and 1500) mm respectively.

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