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BEHAVIOR OF COMPOSITE I-SECTION MODIFIED REACTIVE POWDER CONCRETE BEAMS WITH ULTIMATE TORQUE

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Abstract: This paper presents experimental work includes investigation of seven composite modified reactive powder concrete (MRPC) I- beams, 1300mm length, 100mm web width and 320mm height, with and without opening tested under pure torsion. The first beam was the control beam without steel plate and the second beam was solid with steel plate and the five of these beams were cast as composite beams and opening in web. The main variable was the location, shape and size of opening in web .The experimental results show that the web opening decreases the ultimate torque of composite beams in the range of 17.6% to 30.8% for the tested specimens.as well as the results show that the used steel plates increase the ultimate torque of composite beams by 7.7%.

Keywords*: Modify Reactive Powder Concrete (MRPC), ultimate torque, Shear Connector, Composite, solid, opening,*

سلوك العتبات الخرسانيه المركبة مع الحديد ذات المقطع (I) والمحتوية على خرسانه المساحيق الفعالة المطورة مع عزم اللي الاقصى.

الخلاصة: هذا البحث يتضمن التحريات العملية لسبع عتبات خرسانيه مركبه من خرسانه المساحيق الفعالة المطورة ذات مقطع (I) بطول 1300mm وعرض الساق 100mm وارتفاع 320mm لمقاطع مختلفة (مع فتحات وصلده) فحصت تحت تأثير عزم اللي الصافي. العتبة الاولى كانت العتبة المرجعية بدون صفيحه حديديه والعتبة الثانية كانت صلده وتحتوي على صفيحه حديديه اما العتبات الخمسة الاخرى فقد كانت عتبات مركبه تحتوي على فتحات في الساق .المتغيرات الرئيسية في هذه الدراسة هي موقع وشكل وحجم الفتحات في الساق .اظهرت نتائج الفحص ان الفتحات في الساق تقلل من عزم الدوران الاقصى للمقاطع المركبة بحدود17.6% الى30.8% وكذلك اظهرت النتائج ان وجود الصفائح الحديدية تزيد من عزم الدوران الاقصى للمقاطع المركبة بنسبه 7.7%.

1. Introduction

The interest in gaining better understanding of the torsional behavior of reinforced concrete (RC) members has grown in recent decades. This may be due to the increasing use of structural members in which torsion is a central feature of the behavior such as curved bridge girders and helical slabs. The achievements,

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however, have not been as much as those made in the areas of shear and bending.

Dealing with torsion in today's codes of practice is also very primitive and does not contain the more elaborate techniques. Predictions of current standards for the ultimate torsional capacity of RC beams are found to be either too conservative or slightly risky for certain geometry, dimensions and steel bar sizes and arrangements [1].

Steel-concrete composite structures are becoming increasingly popular around the world due to the favorable performance regarding stiffness, strength and ductility of composite systems under seismic loading, and also due to the speed and ease of erection. The use of steel–concrete composite structures in seismic areas potentially represents a fairly effective design solution. In fact, the adoption of such a solution is in general more efficient from both a structural and a constructional viewpoint when compared to bare steel structures [2]. .

In modern building construction, transverse openings in reinforced concrete beams are often provided for the passage of utility ducts and pipes. These ducts are necessary in order to accommodate essential services such as water supply, electricity, telephone, and computer network. These ducts and pipes are usually placed underneath the soffit of the beam and for aesthetic reasons, are covered by a suspended ceiling, thus creating a dead space [3].

Kamal A.(2005)[4] studied the behavior of Ferro cement beams under torsion to observe the effect of number of wire mesh layers, the type and the form of layer distribution and compressive strength of mortar. An increase of 10.42 % in ultimate torque was achieved by using closed-form wire mesh layers near the surface and the increase of the mortar compressive strength by 43.8% increases ultimate torque by39 %.

Alzargany (2010) [5] investigated the structural behavior of simply supported composite beams, in which a concrete slab is connected together with steel I-beam by means of headed stud shear connectors. The experimental results show that the web openings decrease the strength of composite beams in the range of 19% to 24% for the tested specimens.

Ridha T. A (2012) [6] studied the behavior of composite beam with web opening under repeated loading. The test results show that the web openings decrease the strength of composite beams in the range of 3% to 19% for the tested specimens.

Djaaz, M.M (2012) [7] studied the flexural behavior of I-shape composite SCC beams. The beams were composed by adding steel plates. The increase of ultimate strength for plated beam compared with unplated beam (8%-153%).The addition of steel plates increase the cracking load that induces first crack by about (25% - 36%)**.**

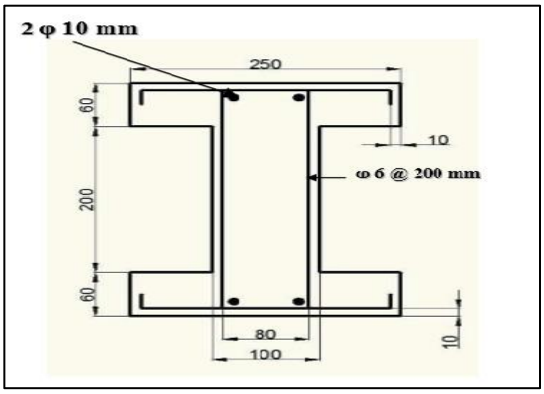
Abdulridha, A.A (2014) [8] studied the behavior of composite concrete-steel rectangular beams under pure torsion. The experimental results show that the maximum increase in the cracking torque and ultimate torque of the composite beam (B1) was (250%) and (278%), respectively comparable to the reference beam.

2. Research Objective

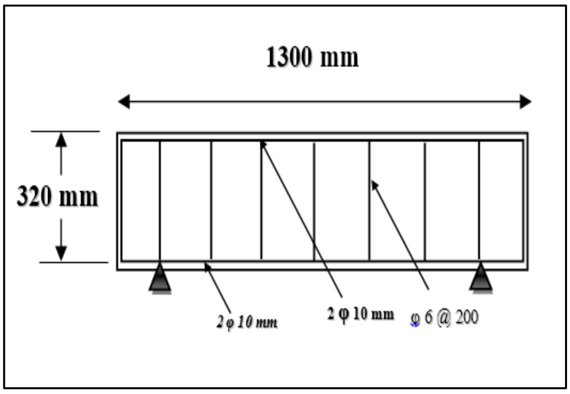
The aim of the present study is to investigate the structural behaviour of composite I-section beams, with and without opening tested under pure torsion. The composite beams are made of a modify reactive powder concrete beams connected with steel plates at the bottom of beam by means of headed stud shear connectors.

3. Experimental Investigation

The experimental program consists of testing of 7 specimens to explore the ultimate resistance of MRPC composite beams under pure torsion. The main variables considered in the test were the shape, size and location of opening. The cast beams dimensions were (1300 × 320 ×100 mm). Specimen details and main study parameters were summarized in Table (1) and Figures (1) and (2). Applied torque- twisting angle curves crack pattern and failure mode were observed throughout the study.



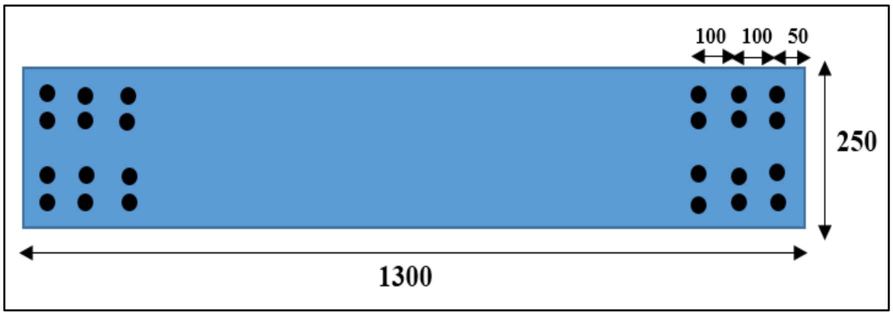
(a)



(b)

(c)

Figure (1): Defiles of Beams Reinforcement
(a) Cros Section of Steel Reinforcement, (b) Reinforcement Profile along the Beam
(c) Reinforcement Cage of the Concrete Beam.
(all the dimension in(mm)



Bottom view of all beam composite

Figure (2) details of plate with shear connector. (**All the dimension in (mm)**)

Table (1) General Details of the Tests Beams

Beam No.	Name of beam	Dimension of opening (mm)	Location of opening
B1	I-beam solid without steel plate(reference)	———	———
B2	I-beam solid with plate	———	———
B3	I-beam with steel plate and square opening in web	*A= (100*100)	Mid span
B4	I-beam with steel plate and square opening in web	*A= (100*100)	Third span
B5	I-beam with steel plate and circular opening in web	(*d=150)	Mid span
B6	I-beam with steel plate and circular opening in web	(*d=100)	Third span
B7	I-beam with steel plate and circular opening in web	(*d=100)	Mid span

* A=area of opening, * d= diameter of opening

3.1. Materials and Mixing Proportions

MRPC matrix consisted of ordinary Portland cement locally available [9] and natural sand with fineness of 2.36[10] and 8 % by weight of cement was replaced by silka fume[11]. The crush coarse aggregate with maximum size of 10 mm was used as a gravel [10]. The water to binder ratios by weight were chosen to be 0.27. Supperplastcizer type (Glenium 51) [12], was used as high range water reducer. The dose of superplasticizer used was 0.41% by total binder weight. tap water was used in the experimental work for both mixing and curing.

The steel fiber with hook ended was used in this study and having unit weight of 7850 kg/m³ with tensile strength 1150 MPa. A steel fiber of 0.5 mm diameter and 60 mm length was manufactured in Bekaert factory in UAE. The cylinder compressive strength of (90.3MPa) at (28) days.

The steel reinforcement of the tested beams consisted of two 10 mm diameter bars at the bottom and two10 mm diameter bars at the top of the beam. Stirrups were made of 6 mm diameter bars. The center-to-center spacing of the stirrups was 200 mm. The steel plate of 2mm thickness and 1300 mm length was used in strengthened composite I beams. The head stud connectors are used in this study with diameter of 8 mm and length 50 mm. The average shear force is (20) kN. The yield stress, ultimate strength and longitudinal elongation of steel reinforcing bars and steel plate used in this study are summarized in Table (2).

Table (2): Specification and test results of steel reinforcing bar values

Diameter of Bar (mm)	Yield Stress (MPa)	Ultimate Strength (MPa)	Elongation %
6	383	545	16
10	521	615.7	19
2 mm steel plate	386.3	426.6	15.2

4. Testing Procedure

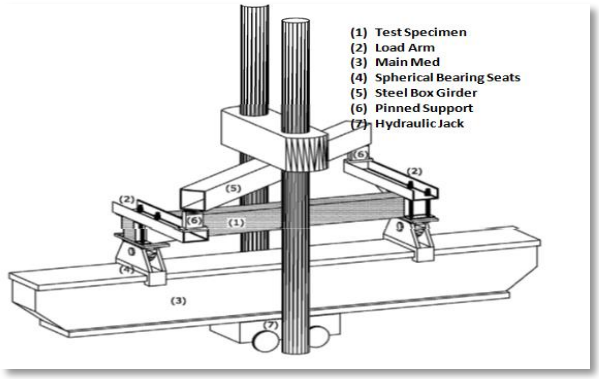
The hydraulic universal testing machine (MFL system) was used to test the beam specimens. The testing machine has a capacity of (3000 kN). This machine was calibrated by the "Iraqi central organization for standardization and quality control.

The normal load can just be applied by this machine on the specimen at several points and the supports should be remaining fixed without rotating around the longitudinal axis. In this research the applied loads outside the bed of the universal machine are needed in order to get torsional movement.

The experimental requirements need to move the supports circularly (ball bearing) and transmitting the load from the center of the universal machine to the two external points that represent the moment arm the idea of this loading arrangement was mentioned by (Zararis and Penelis)[13] as shown in Figure (3). The special clamping loading frame on each end of the beam used in this research is shown in Figure (4).

This frame consists of two large steel clamps which work as arms for applied torque with separated faces to connect them over the sample by large bolts; four bolts are used for each arm. This frame is made of thick steel plate (12 mm) with two steel shafts attached by welding. This final shape is similar to a bracket. These arms were capable of providing a maximum eccentricity of (500 mm) with respect to the longitudinal axis of the beam. In order to get pure torsion the center of support should coincide with the center of the moment arm. The steel girder of (300 mm) depth and (3 m) length is used to transmit the loads from the center of the universal machine to the two arms (pure torsion), in addition, two lines load are used to transmit the load of bending (combined stresses) as shown in Figure (4).

All beams were tested under monotonically increasing torque up to failure, the load was applied gradually. For each (5 kN) load increment, readings were acquired manually. The torque was increased gradually up to failure of the beam.



Figure(3): Suggestions of load Arrangement Showing the Test Rig [13]

Figure (4): Arrangement of Beam Testing

5. Measuring Instruments

5.1. Angle of Twist Measurements

The dial gage used to measure the vertical strain caused by the applied torsion, the angle of twist can be found by dividing the amount of displacement - that occurred as a result of torsion- on the vertical distance at the displacement direction by using trigonometric functions laws which have the displacement on one side and the distance (chord) between dial gage and the center of section on other side. As shown in Figure (5).

Figure (5): Angle of Twist

6. Results and Discussion

6.1. Effect of Opening on Load Carrying Capacity (Ultimate Torque)

The load carrying capacity reflects the maximum torsional moment and represents the ultimate applied load on the tested beam, after that drop in machine reading appears with rapidly deformation on beam, which termed as failure. Figure (6) shows this value for the tested beams.as will as Figures from (7) to (13) show the relationships between ultimate torque and ultimate angle of twist For each specimen, the general relationship between torque and angle of twist is such that, initially linear elastic behavior at a low loading stage was observed.

The general Test results show that the reinforced concrete beams strengthened with steel plate gain an increase in ultimate torque over that of the un strengthened beam (B1). As well as the results showed that the reinforced concrete composite beams that contain the opening in the web gives a decrease in ultimate torque more than beams without opening in the web. The openings are considered as the zones of weakness on the beams. The largest increment at ultimate torques were recorded for the composite beams (B2) without opening in web where it has shown an increase of (7.7%) compared with reference beam (B1) and decrease of beam(B1) (7.7%) compared with beam(B2).

The present of opening in a web of beams lead to decrease of ultimate torques. It can be seen from this figure, all other parameters are the same, the beams contain square opening appeared a more reduction of ultimate torque than the specimens have circular opening. This may be due to more stress concentration at corners of the square opening. Also, from this figure can be shown, the opening at the third point of the beam span apparent a more reduction of ultimate torque than those at the span center.

As compared to the control beam the percentage reduction in ultimate torque of beams contain opening at the third span are (28.6) % and (24.2) % for square and circular opening, respectively. While, these lowering in ultimate torque of the beams having the opening at the center become (19.8) % and (17.6) % for square and circular opening, respectively. The increasing the opening from (100) mm to (150 mm) lead to decrease the ultimate torque from (17.6) to (30.8) compared with the solid beam.

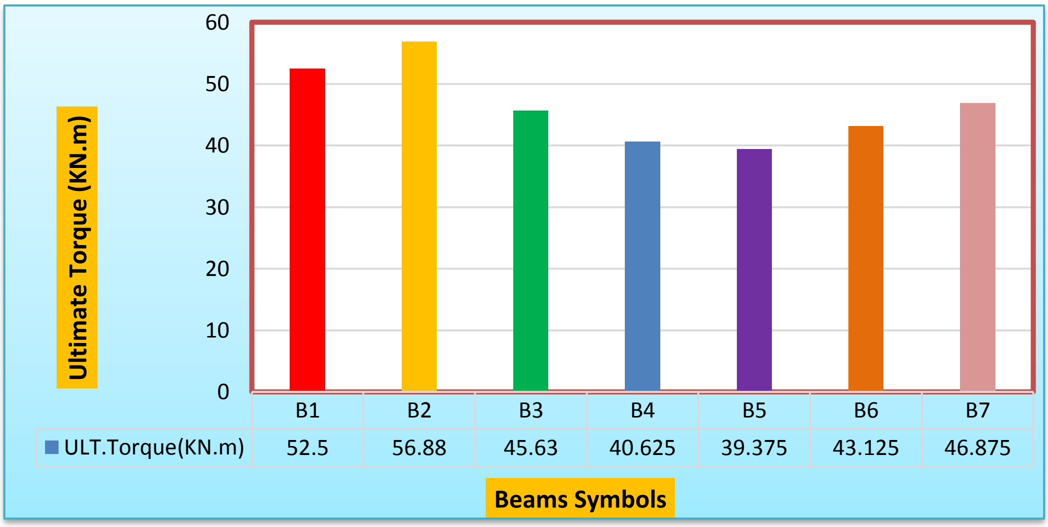


Figure (5): Load carrying capacity of the tested beams

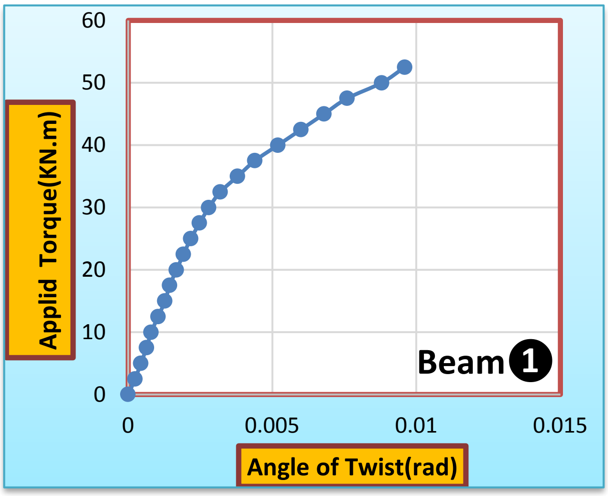


Figure (7): Torque–angle of Twist

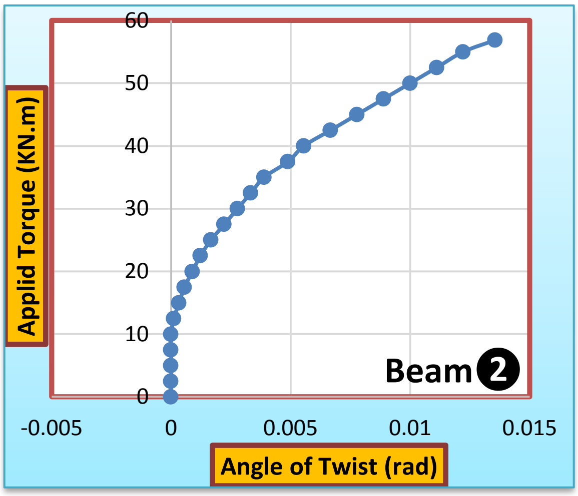


Figure (8): Torque–angle of Twist

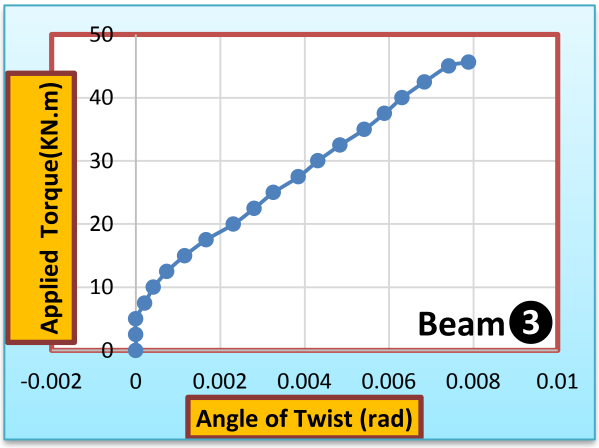


Figure (9): Torque–angle of Twist

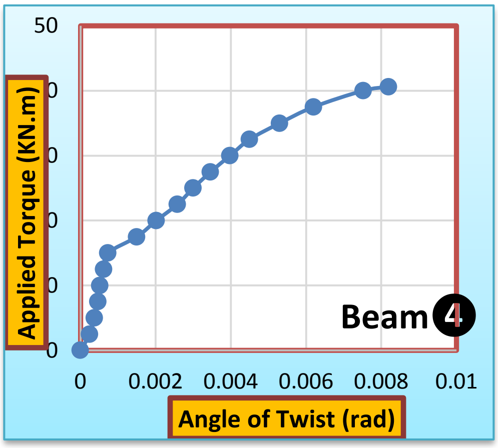


Figure (10): Torque–angle of Twist

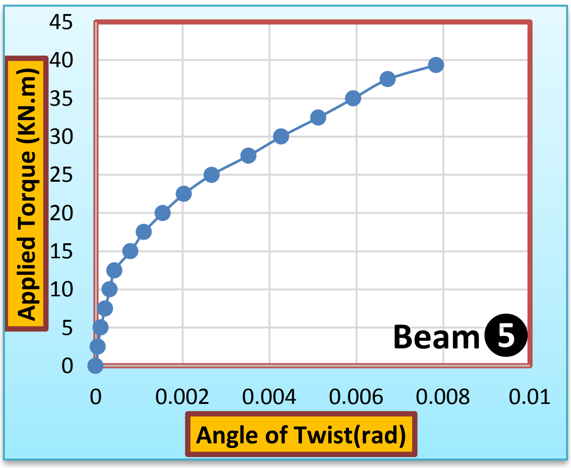


Figure (11): Torque–angle of Twist

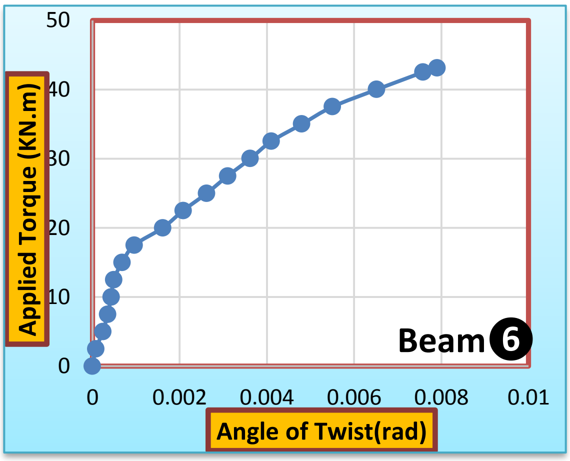


Figure (12): Torque–angle of Twist

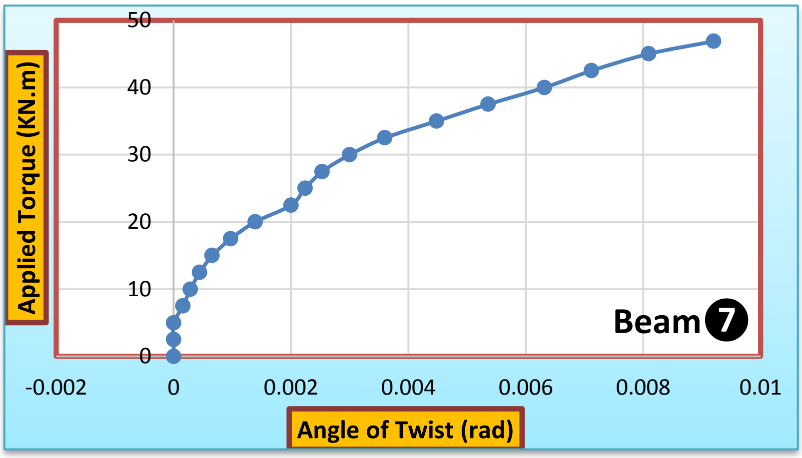


Figure (13): Torque–angle of Twist

6.2. Angle of twist-Distance along beam Curves

Figures (14) to (20), demonstrate the relationship between the ultimate angles of twist with the distance along the beams. The solid beams and beams with central opening have a symmetrical behavior along the beam.

The maximum angle of twist occurs at the begin of the beam (when support) and the gradually decreased till to zero approximately at the mid span, then the angle of twist began to increase gradually but in opposite direction (reverse clockwise) until reaching to maximum value at the begin of the beam from the other end.

While the beams with opening at a third span, it can be observed that the behavior along the beam seems unsymmetrical. The maximum angle of twist occurs at the begin of the beam and the gradually decreased till to zero approximately at the third span, Where opening location, then the angle of twist began to increase gradually but in opposite direction until reaching to maximum value at the begin of the beam from the other end. We conclude from the above that the critical angle of twist gradually decrease, the closer to the mid distance and gradually increases the closer supported in both directions.

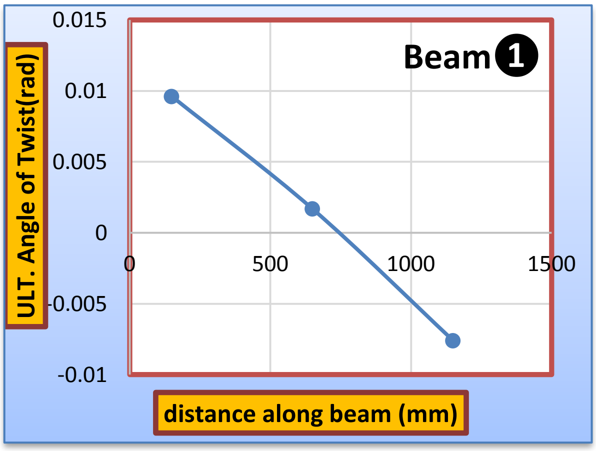


Figure (14): Ultimate angle of Twist with distance (mm)

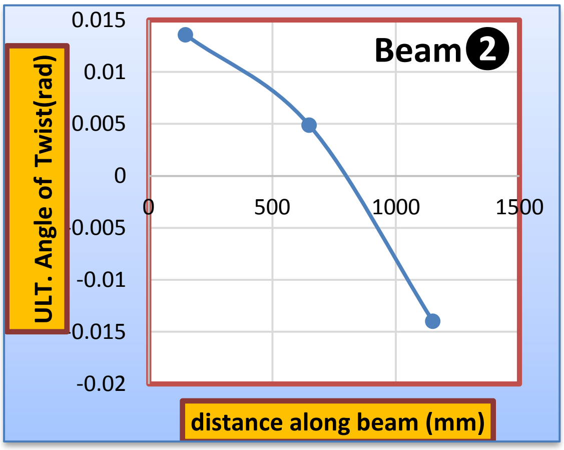


Figure (15): Ultimate angle of Twist with distance (mm)

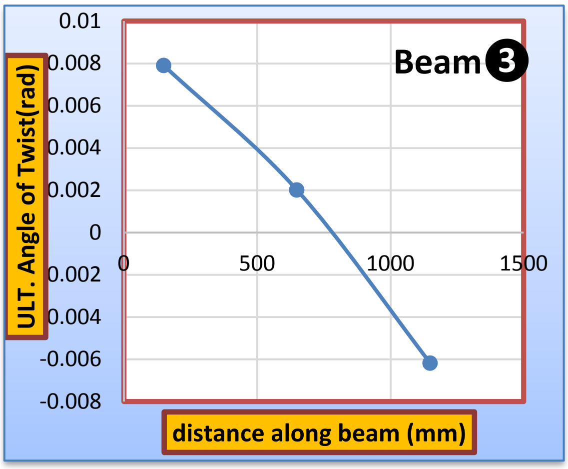


Figure (16): Ultimate angle of Twist with distance (mm)

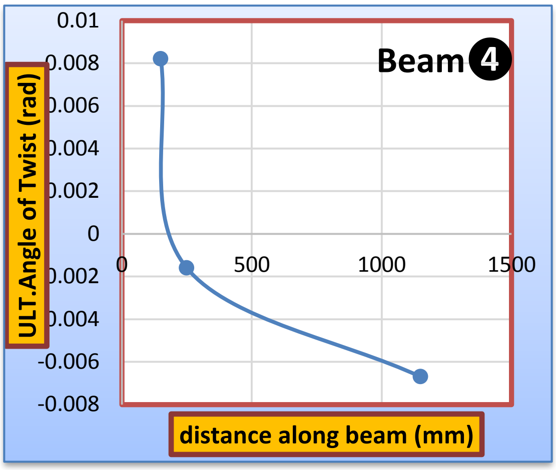


Figure (17): Ultimate angle of Twist with distance (mm)

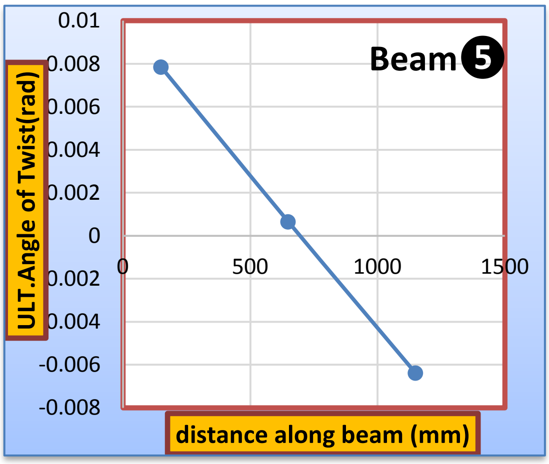


Figure (18): Ultimate angle of Twist with distance (mm)

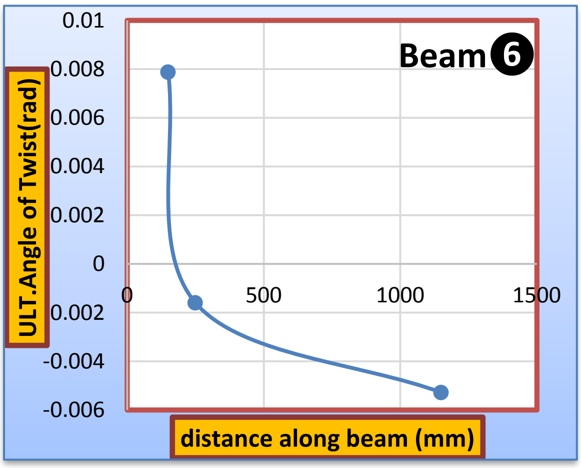


Figure (19): Ultimate angle of Twist with distance (mm)

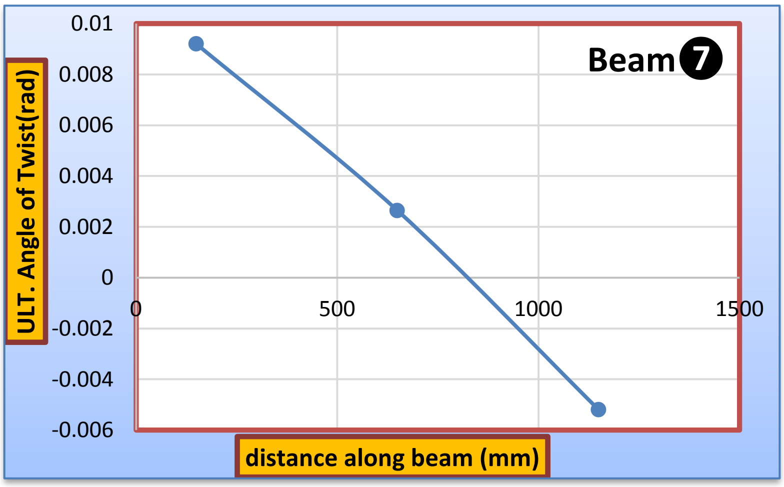


Figure (20): Ultimate angle of Twist with distance (mm)

7. Cracks Patterns of Test Specimens

All the reinforced concrete beams were tested under pure torsion loading failed in torsion. Figures (21) to (27) show the crack pattern and modes of failure for the tested beams. Where the angle of the first crack were close to 45 degree in each tested beams.

Figure (21): Failure of Reference (B1)

Figure (22): Crack pattern and modes of Failure(B2)

Figure (23): Crack pattern and modes of Failure (B3)

Figure (24): Crack pattern and modes of Failure (B4)

Figure (25): Crack pattern and modes of Failure (B5)

Figure (26): Crack pattern and modes of Failure (B6)

Figure (27): Crack pattern and modes of Failure (B7)

8. Conclusions

The following conclusions can be drawn from the test results of this study:

1. The presence of external steel plates connected to tension face of beam reduces the angle of twist of concrete sample and thus increased the ultimate torsional resistance.
2. Presence of openings in web decreases the ultimate strength of composite beams.
3. The reduction is more for square opening. This may be due to more stress concentration at corners of the rectangular opening.
4. The ultimate torque increases as the size of the opening decreases.
5. According to ultimate torque, the best location for the opening is within the center of the span and the best shape for the opening, in the composite beam is the circular opening.
6. The angle of twist gradually decrease, the closer to the mid distance and gradually increase the closer supported in both directions (positive and negative).
7. The global stiffness of the composite beams increase significantly as the size of the opening decrease.

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