

Repairing of RC T-Section Beams with Opening by CFRP for Cracks and Ultimate Torque

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Abstract: The repair of reinforced concrete (RC) beams with carbon fiber reinforced polymers (CFRP) is experimentally investigated in this study. The four T-section reinforced reactive powder concrete beams with many locations of circular opening were repaired by CFRP and investigated under pure torsion. The repairing beams were tested to obtain the effect of the amount of CFRP laminate on beams cracking and ultimate torque behavior, angle of twist and failure modes. The results obtained from the adopted repairing technique showed a significant effect of external high strength CFRP laminates on effectively restore of section solid of 85% of crack torsional strength effectively restored. In addition, the results show that effectively restoring of section opening by 82%-80% of crack torsional strength, and the adopted repairing technique gives a good strength to the beams.

Key words: Torque, first and ultimate cracks, RPC, opening, T-section, repairing, carbon fiber reinforced polymer (CFRP).

1. Introduction

Carbon fiber-reinforced polymers (CFRP) are currently used worldwide to retrofit and repair structurally deficient infrastructures such as bridges and buildings. Using CFRP reinforcing bars in new concrete can eliminate potential corrosion problems and substantially increase member's structural strength. When reinforced concrete (RC) members are strengthened with externally bonded CFRP, the bond between the CFRP and RC substrate significantly affects the member's load-carrying capacity. This article presents the effects of adverse environmental conditions on the deflections and ultimate load-carrying capacities of beams strengthened with externally bonded CFRP [1, 2]. Long-term exposure to humidity was the most detrimental to the bond between the CFRP and the RC. Delamination was the primary failure mode for the tested beams. The CFRP strengthening provides additional flexural or shear

reinforcement; the reliability for this material application depends on how well they are bonded and can transfer stress from the concrete component to CFRP laminate [3]. Although CFRP composites are known to perform better under environmental action than glass fiber reinforced polymer laminates. No significant differences were detected, seemingly because using of carbon fiber reinforced polymer laminated for strengthening reinforced concrete beams in failure was not due to rupture of the fibers [4].

While concrete is one of the most widely used construction materials in the world, the durability of concrete is critical as it would have great effect on the service life of civil infrastructure and building. However, they are vulnerable to corrosion when concrete structures are exposed to severe environmental conditions. Corrosion causes section loss in the reinforcing steel; therefore, it affects the load carrying capacity of the concrete structure. Corrosion resembles a major threat to hinder the durability and safety of concrete structures. CFRP is used in strengthening and restoration of concrete

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structures, thus it can be used to restore the capacity of concrete structures with the corrosion problem. CFRP composites are commonly used when there are deficiencies in the quality of concrete and lack of adequate confinement reinforcement [5, 6].

The tests showed that it is beneficial to use the CFRP sheet to cracks so that they are useful to use for many types of concrete failing [7-9]. Beams, columns and any other types or sections for reinforced concrete structures of different types of cracks use the CFRP for repairing purposes.

2. Experimental Program

Experimental program consists of testing of four specimens damaged. The specimens were casted and tested by Refs. [10, 11]. In this work, these specimens were repaired using CFRP, then they were tested under pure torsion. The dimensions of T-beam are as follows:

b_w (width) = 100 mm

h (total thickness) = 280 mm

b_f (bottom and top width) = 320 mm

t_f (thickness of flange) = 80 mm

length = 1,300 mm

The reinforcements for beams were with stirrups as distributed with bottom reinforcement 2 Φ 10, top

reinforcement 2 Φ 6, shear reinforcement Φ 6@200 mm. The total tested beams were 10 having the same geometry and steel reinforcement.

The main variables adopted in the experimental work were web opening: the opening in this study contains variables in location and number.

3. Opening Layout

The openings layout and configurations in the web of the T-section beams, are shown in Table 1. Three beams with many locations of opening and one beam without opening are shown in this table.

3.1 FRP Material Properties

The Sika Wrap Hex-230C is an externally applied strengthening or repairing the system for structural members made of reinforced concrete [12]. This system was supplied by Sika near East s. a, I. Beirut—Lebanon. Epoxy based impregnating resin Sikadur—330 were used with fabric [12]. The following information related to this system is listed in Tables 2 and 3.

3.2 Effects of Repairing by CFRP

Beam Number 1 represents solid web without opening (control beam), the maximum first cracks torque

Table 1 Details of beams and web openings.

| Details of opening | Specimen mark |
|---|---------------|
| No opening | T rep 1 B1 |
| Circle Φ 100mm @ center of beam span | T rep 2 B2 |
| Circle Φ 100mm @ 1/3 of beam span | T rep 3 B3 |
| Circle Φ 100mm @ center of beam span and Φ 100mm @ 1/3 of beam span | T rep 4 B4 |

Table 2 Sika Wrap Hex-230C (carbon fiber fabric).

| High strength carbon fibers | Fiber type |
|--|-----------------------------|
| 0° (unidirectional). The fabric is equipped with special weft fibers which prevent loosening of the roving (heatset process) | Fiber orientation |
| 225 g/m ² | Areal weight |
| 0.13 mm (based on total area of carbon fibers) | Fabric design thickness |
| 3500 MPa | Tensile strength of fibers |
| 230 GPa | Tensile E—modulus of fibers |
| 1.5 % | Elongation at break |
| ≥ 45.7 m | Fabric length/roll |
| 305/610 mm | Fabric width |

Table 3 Sikadur-330 (impregnating resin).

| | |
|--|-------------------------|
| Comp. a: white | Appearance |
| Comp. b: grey | |
| 1.31 kg/L (mixed) | Density |
| A : B = 4 : 1 by weight | Mixing ratio |
| 30 min (at + 35 °C) | Open time |
| Pasty, not flowable | Viscosity |
| + 15° C to + 35 °C (ambient and substrate) | Application temperature |
| 30 MPa (cured 7 days at +23 °C) | Tensile strength |
| 3800 MPa (cured 7 days at +23 °C) | Flexural E-modulus |

is 27.5 kN·m, but B1 before repairing needed (32.5 kN·m) for the first crack. That means the beam restored 85% of torque capacity in the solid beam, but the beam with opening like B2 where the maximum first cracks torque is 20 kN·m, but B2 before repairing need 25 kN·m for first crack. That means beam with opening reducing the crack torque and angle of twist.

3.3 Cracked Stage

The results of cracking stage before repairing taken from Ref. [10] (Figs. 1 and 2) show the comparisons between all tested beams specimen up to the first crack. In general for all tested beams that were compared with repairing beams, the interesting points for discussion are the torque for first crack for B2-4 was less than B1, angle of twist at first crack was less; the linearity behavior of control beam was more. All tested beams that were directed to the horizontal axis indicated that the RC T-beams become weaker when the applied torque increased in loading.

The relationship between angles of twists and distance was compared for all tested beams. The control beam behaved as linear and the angle of twist increased as the distance increased because of increasing in applied torque. The main point in case of presence web opening in RC T-section is that when all tested beams were compared with that control B1, the behavior of all beams that appear from the curves below concluded with T-section behaved as solid web. It should be mentioned, however, that the effects of opening refer to the reducing of the values of cracking and ultimate torque and corresponding twisted angles. The repairing beams (rep 1 to rep 4), while the

original beams before repairing are (Beam No. 1 to Beam No. 4), respectively (Figs. 1 and 2).

3.4 Ultimate Stage

Figs. 3 and 4 show the comparisons between all tested beams specimen up to ultimate loading capacity (failure). In general, for all tested beams, it indicated that there was a reduction in cracked failure ultimate torque with corresponding angle of twist. All behaviors of tested beams from Figs. 3 and 4 are lying and oriented parallel to the x-axis that indicated after the inflection point that translate the beams behavior from linear and formulating plastic hinge so that the beam became weak due to increasing in applied loading.

Angles of twists and distance were compared for all specimens. The control beam behaved as linear and the angle of twist increased because the twisted angle is a function of applied torque. The cracked twisted angle for B1 was greater than other beams because of the presence of web perforation that caused a reduction in torque strength capacity. The experimental results to cracking torque are listed in Table 4. The repaired beams are rep1 to rep 4, while the original beams before repairing are Beam No. 1 to Beam No. 4, respectively.

3.5 Cracks Development

Fig. 5 shows the propagation of the cracks for all tested RC T-beams. The locations of their opening are shown in Table 1. All cracks started from the bottom of the web with spiral form toward the flange. The shape of cracks is similar. They are rounded and

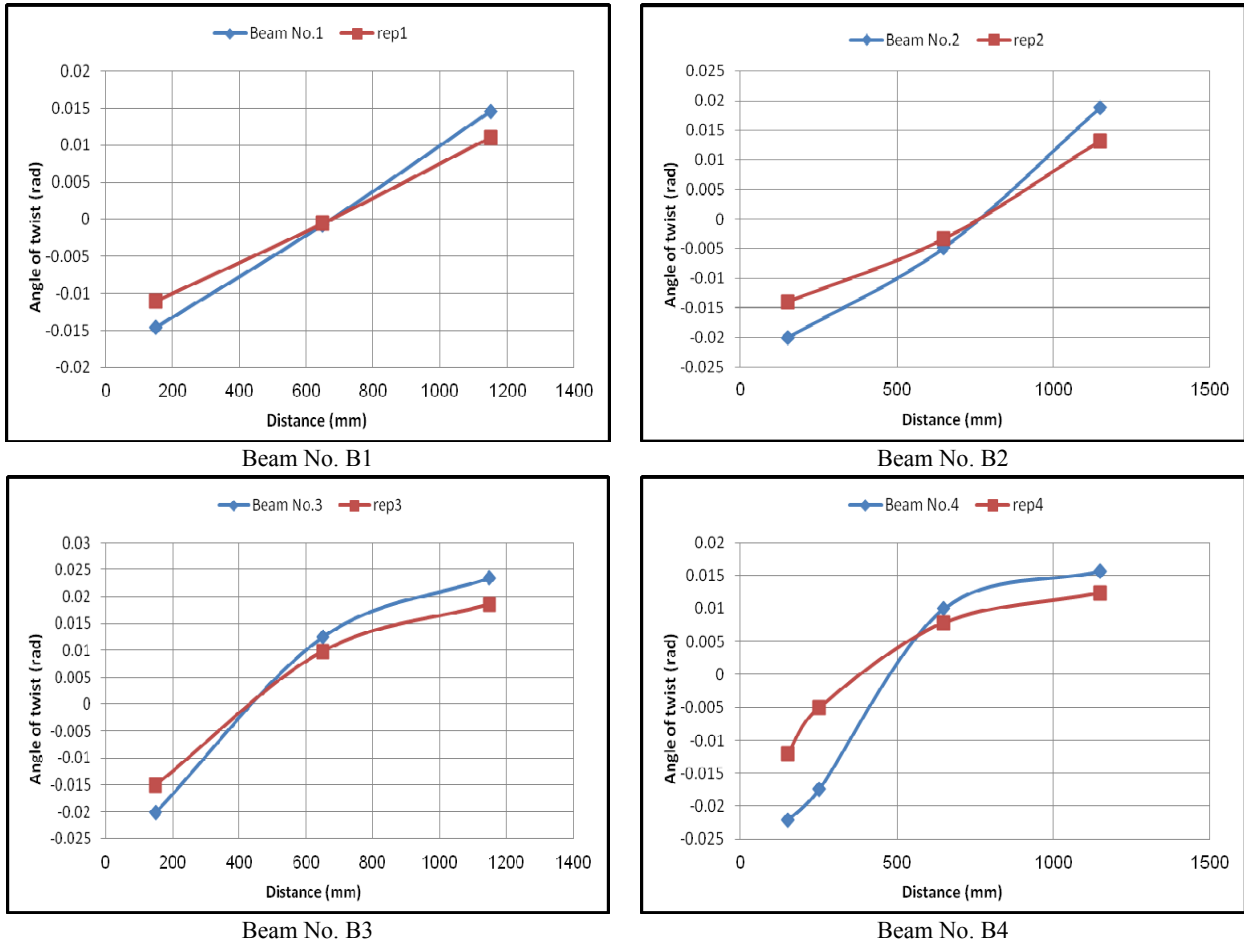
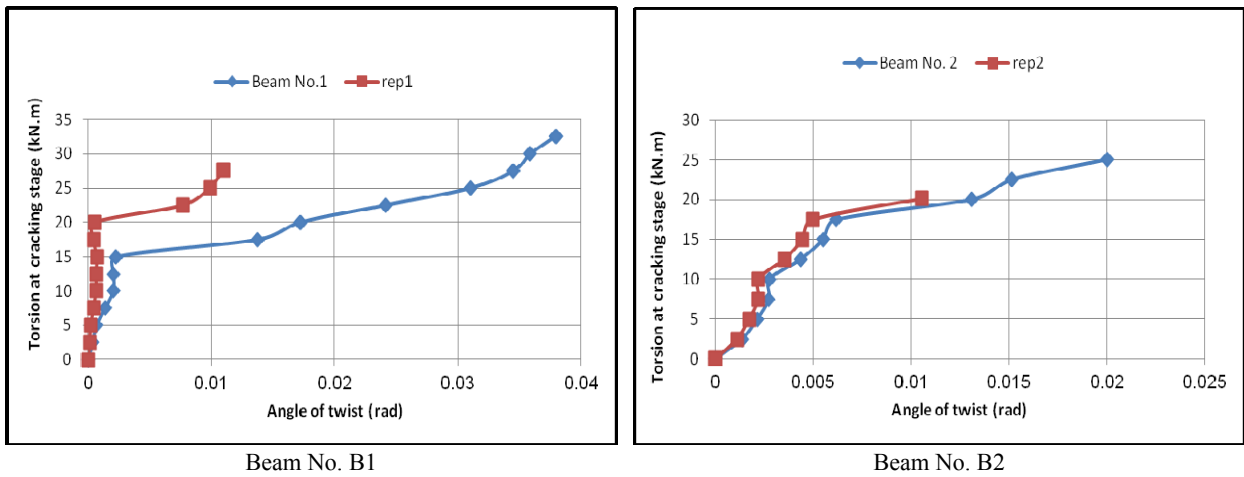


Fig. 1 Comparison Angle of twist vs. distance relationship for beams.



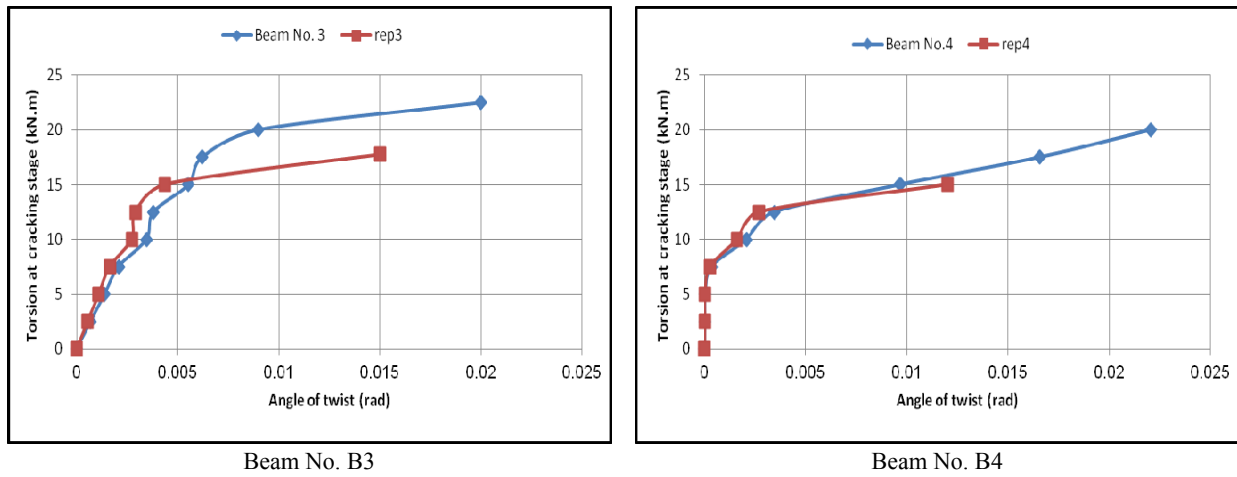


Fig. 2 Comparison Cracks torque vs. angle of twist relationship for beams.

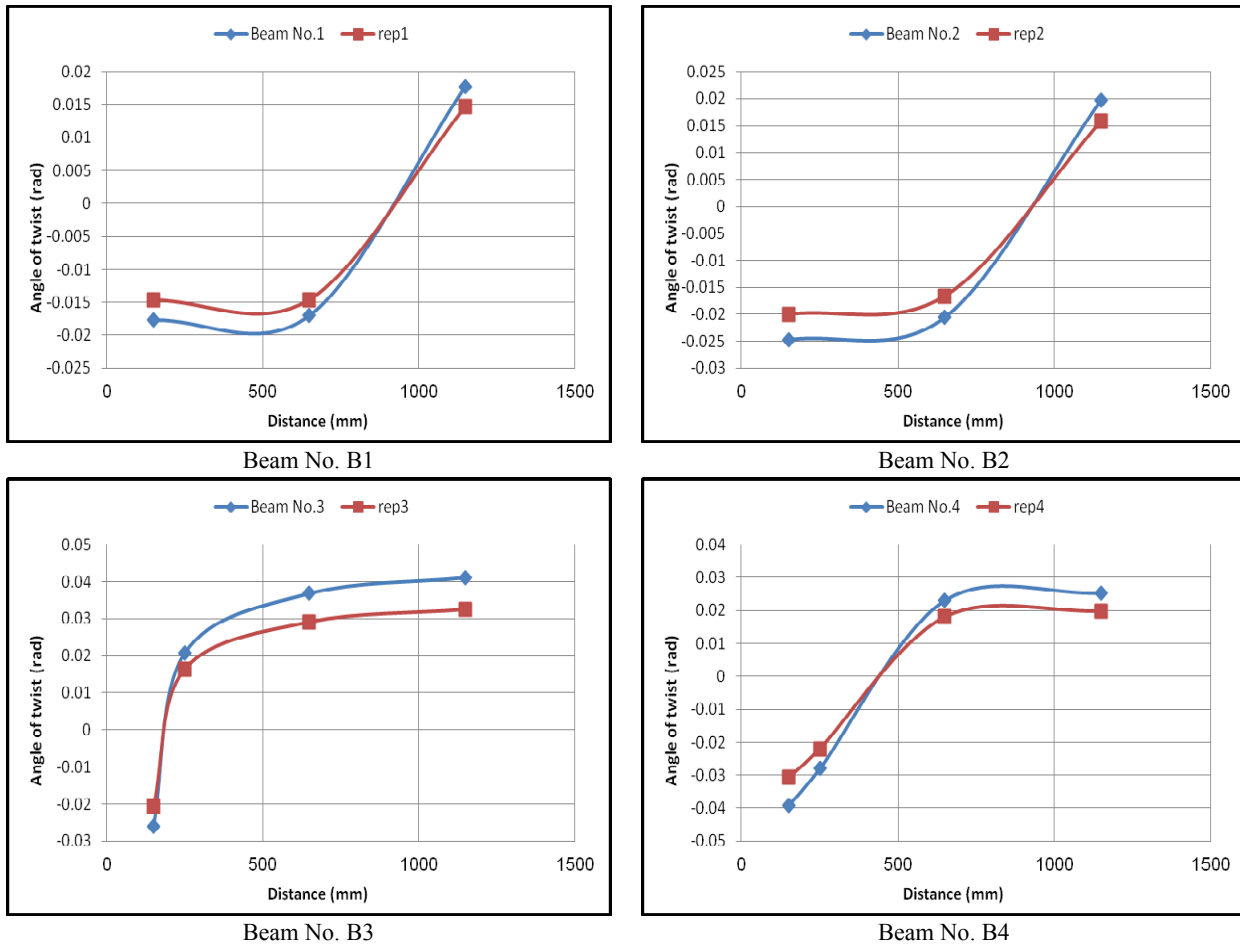


Fig. 3 Comparison Angle of twist vs. distance for beams in ultimate stage.

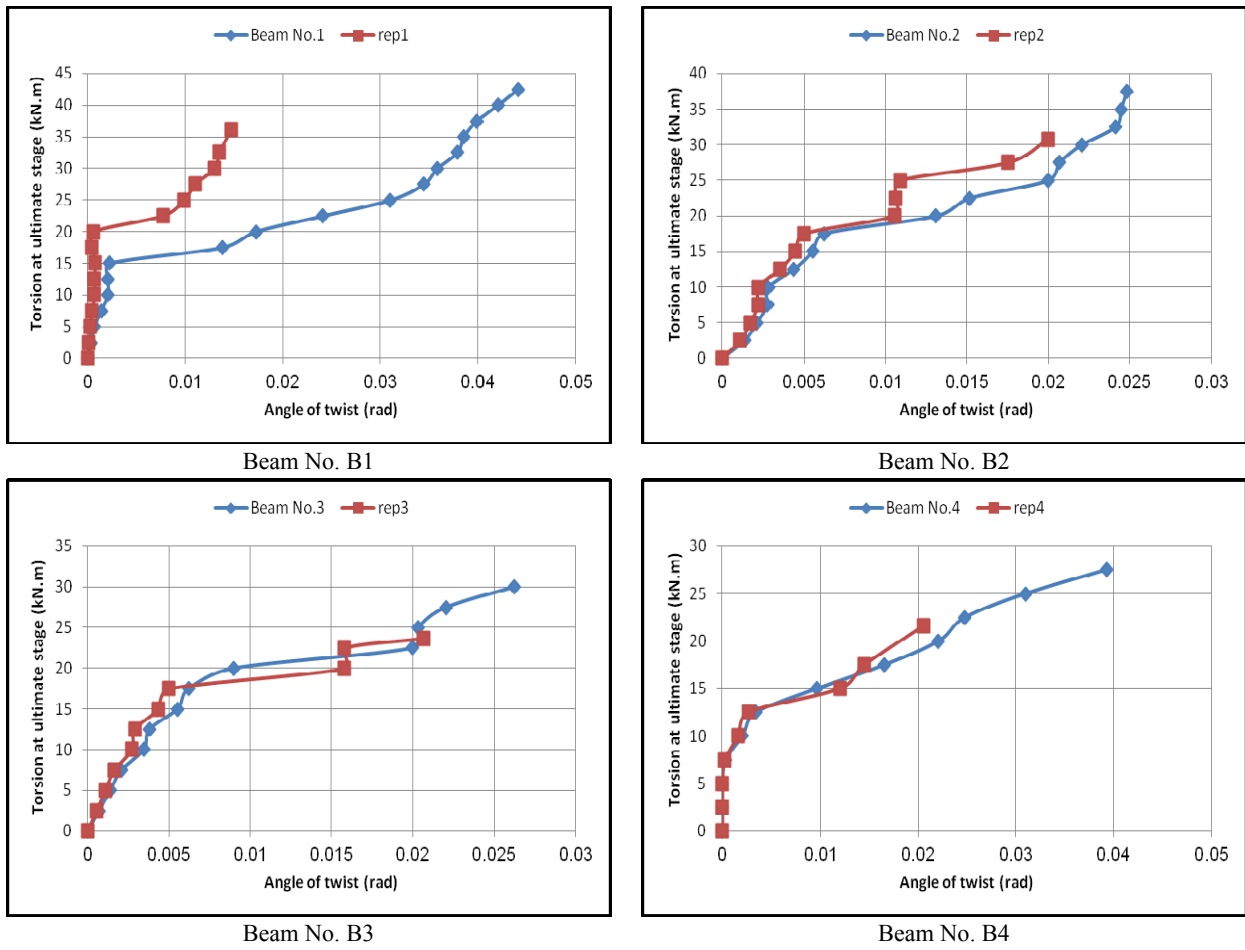


Fig. 4 Comparison Torsion vs. angle of twist for beams in ultimate stage.

Table 4 Experimental results for cracking torque.

| Beam mark | Maximum torque (kN.m) before repairing | Maximum angle of twist (rad.) before repairing | Maximum torque (kN.m) after repairing | Maximum angle of twist (rad.) after repairing | % torque after repairing/torque before repairing | % twist angle after repairing/twist angle before repairing |
|-----------|--|--|---------------------------------------|---|--|--|
| B1 | 42.5 | 0.0177 | 36.125 | 0.01469 | 85 | 83 |
| B2 | 37.5 | 0.02481 | 30.75 | 0.01997 | 82 | 80.5 |
| B3 | 30.0 | 0.02619 | 23.7 | 0.02069 | 81.5 | 79 |
| B4 | 27.5 | 0.0392 | 21.58 | 0.03077 | 80 | 78.5 |

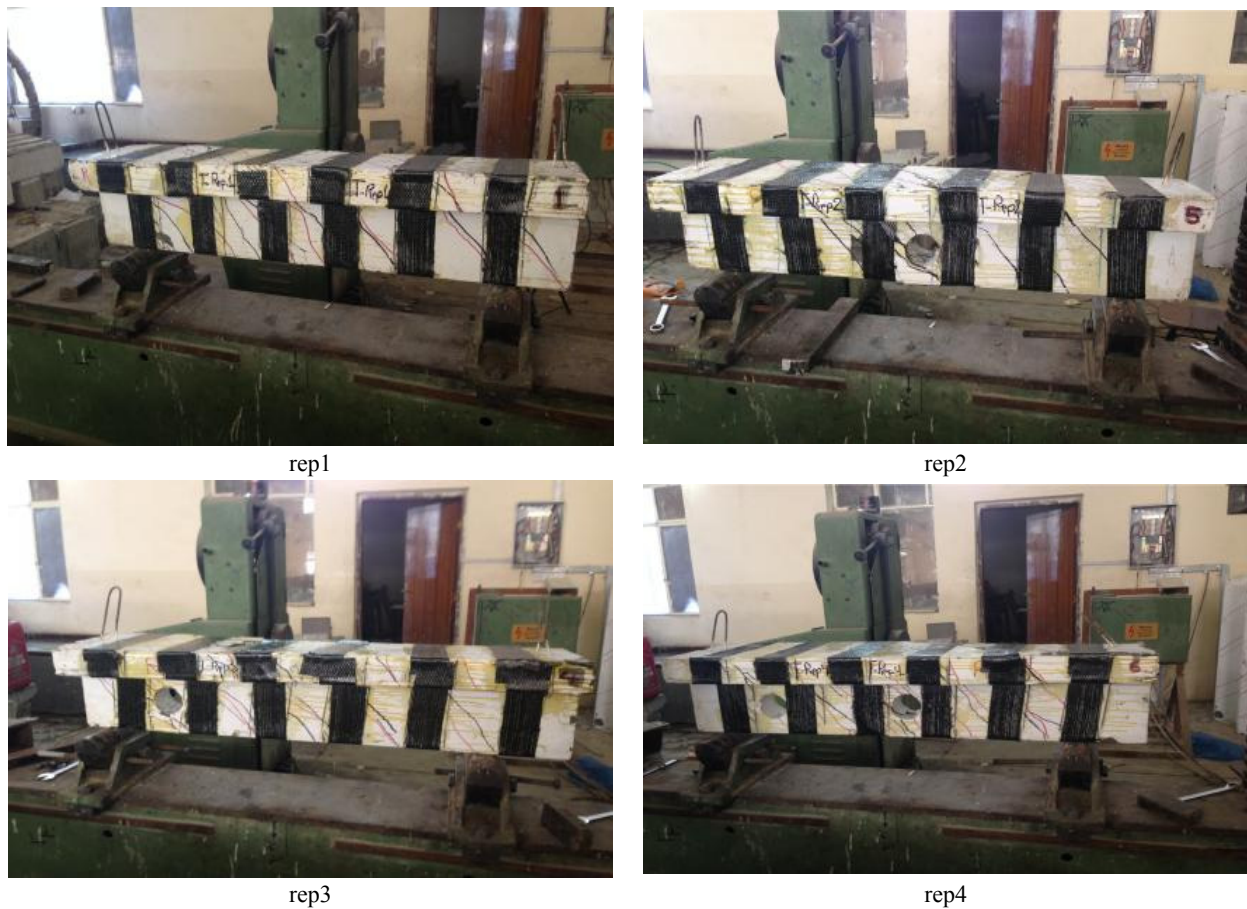


Fig. 5 The locations of openings for tested repairing beams.

connected together to form spiral cracks in the direction of opposite applied torque. The cracks intensity was around the web perforation because the weak region is around the opening.

4. Concluions

According to the results from experimental tests, the following conclusions were drawn:

(1) The repairing restores 80% to 85% torsional strength. This indicates that the adopted technique gives good torsional strength.

(2) The provision of the opening in the beams leads to decrease in the cracking and ultimate torsional strength of the beam, when using the same longitudinal and transverse reinforcements.

(3) The cracks start from the support and then take a spiral shape around the beams up to flange so the amount of cracks increased according to the presence

of openings.

(4) There is a small rise in the angle of twist in the repaired beams compared to the original beams.

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