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STRENGTHENING OF REINFORCED SELF-COMPACTING CONCRETE T- DEEP BEAM WITH LARGE OPENING BY CARBON FIBER SHEETS

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ABSTRACT

This research based on experimental work included testing of thirteen specimens categorized into two groups. The first group included five beams: one is solid while the others are hollow beams with two openings of different sizes and locations. The second group included eight specimens strengthened with CFRP sheets in three systems to determine the best configuration of strengthening. The experimental results showed that the presence of openings (150*150) mm and (150*250) mm, which located flushed to the flange, led to a decrease in the load capacity by (43% and 64%) for the square and rectangular openings respectively. On the other hand, when the openings located in bottom location the reduction in capacity was found to be (48% and 70%) for the square and rectangular opening respectively. Also, the results of the test showed that the strengthening of the carbon strips led to improving in the structural capacity, where in the case of openings located flushed to the flange, there was an increased by (19% and 64%) for square and rectangular openings respectively. In contrary, in the case of opening located in the bottom location, the improvement in capacity was found to be (37% and 87%) for square and rectangular opening, respectively.

KEYWORDS: Self compacting concrete; Strengthening; Opening; Shear; Deflection; Flange deep beam

1. INTRODUCTION

Deep beam is one of the important structural elements in concrete structures and it is used in number of applications such as in a multi-story buildings, structural parking, large water tanks, and long foundations on pillars (Zhang, 2004). In some of the above applications and others, the beams constructed monolithically with the slab. So, it can be considered as the portion of the concrete slab, which connected efficiently together with the beam, as a flange has been project of the beam in each side. This may improve its performance as evidenced by some previous studies than the section was considered to be rectangular and neglecting the slab above. Also, it found that the introducing of openings in the beam is a better choice than passing ducts below the beam where most of the facilities need to achieve its function by introducing for ducts for services such as sewage and air conditioning, power, network and Tv services that may intersect in paths with the supporting beam, must be open in place of these ducts to avoid some problems related to cost and height floor's lateral stability and increase leads (Mansur, 1999). Sometimes, having to make these openings in zones of high shear, with no sufficient reinforcement around it or the strip had been exposed to cut when introducing openings this may weaken the beam and the structure in general.

FRP has been used as a reinforcement in many application for retrofitting and rehabilitation of structures (Lee, 2008). The use of FRP composite has been increased dramatically with increased attractor in the last few years in strengthening rather than be as a reinforcing material due to their several advantages such as corrosion resistance, high strength to weight ratio (Yuan, 2004).

Many deteriorated civil infrastructures need to be retrofitted or strengthened primarily due to substantial increment in service and live loads, severe environmental conditions, inappropriate construction, and insufficient maintenance (Lee, 2004). While a number of traditional methods are available for the shear strengthening of RC beams and deep beams (Sharif, 1994). Many literatures studied shear and flexural strengthening with CFRP contain opening in deep beam (Yang et al., 2007), (Maaddawy and Sherif, 2009), (Wissam. et. al, 2009), (Chin et al, 2015). In the other side a few researches have been studied T-deep beams without opening (Lee et al, 2004). In the present study, series of experimental tests were carried out to investigate the strengthening of reinforced self-compacting concrete T-deep beam with large openings by CFRP sheets and to evaluate the configuration of strengthening and an anchorage using full-wrapped sheets on the shear performance of strengthened deep beams. A total of 13T- deep beams were designed to be deficient in shear with a shear span-to-effective depth ratio (a/d) of (1) Crack patterns and behavior of the tested deep beams were observed during two-point loading tests. Test variables included in this study are: size of openings, position of openings, strengthening of CFRP.

2-Experimental Program

2-1 Details of the test specimens:

In this study, 13 T-shaped, reinforced concrete (RC) deep beam specimens were designed and manufactured. Dimensions of a typical specimen were web of 160 mm width, flange width of 440 mm, a flange thickness of 100 mm, overall depth of 450 mm, and clear span 1400 mm with a total length of 1600 mm. The specimens were designed to fail in shear adopting Strut and Tie model (ACI 318-14, 2014).

The specimens were categorized into two groups, the control specimens (group one) consisted of five unstrengthen specimens. The first specimen was solid and the others having two web openings that were symmetrically positioned about the center of the beam, two sizes and two different locations were investigated. The second group consists of eight strengthened specimens with several strengthening configurations, Table 1 and Fig.1, shows the dimensions and the location openings details of the T-deep beam.

Table 1. Details of control beams opening

Beam designation	Beam type	X1	X2	Y1	Y2
C solid	Control	-	-	-	-
CSBO	Control	225	150	75	150
CSTO	Control	225	150	0	150
CRBO	Control	175	250	75	150
CRTO	Control	175	250	0	150

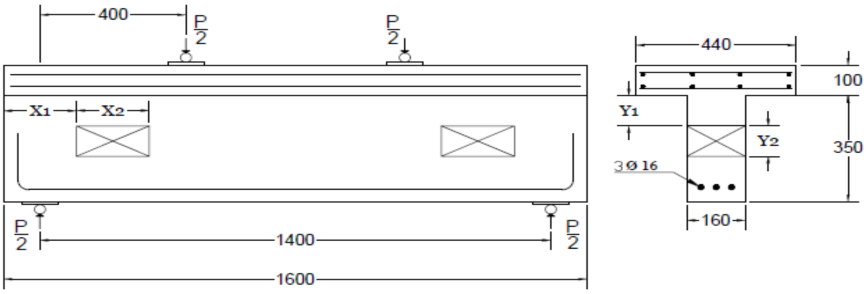

Fig. 1. Detail of control beams

2.2 Materials

Concrete mix was made to produce a self compacting concrete with a 28 day cylinder compressive strength of about 48.5 MPa. The materials used in SCC mix were conformed to Iraqi Specification which were:

- Ordinary (KAR) cement (type1).
- Locally available crushed gravel was used as a course aggregate, and local natural sand was used as a fine aggregate.
- Limestone powder-locally named as "Al-Gubra", was used as a filler material.
- Superplasticizer (GLENIUM 54) was used as a water reducing admixture.
- Tap water used in concrete mixes.

The mix has designed according to the (ACI R237-07). To verify the passing ability, the ability of the criteria filling and the resistance of segregation. It should be made trials mixes and then the composition of the mix must be adjusted until meeting all of the requirements and achieving the ability of self-compact that was obtained by evaluating tests (Slump flow, T500, J-Ring and Stability (column segregation)) of the fresh concrete. Table 2 lists the proportion of the final SCC mix, Table 3 show result of the tests and Fig. 2 showed the tests which were made on the mix.

Table 2. SCC mix proportion

Material	**Cement**	**Coarse aggregate (kg/m^3)**	**Fine aggregate (kg/m^3)**	**Water (L/m^3)**	**Limestone (kg/m^3)**	**Glenum 54 (L/m^3)**	**W/c**
Amount	400	780	962	128	75	4.8	0.3218

Table 3. Test result of SCC

Test	**Result**	**Limits of (ACI 237-R07 code)**
Slump flow	600	(450-760) mm
T500	2.4	2-5 sec
J-Ring	561	Difference between J-ring flow and slump flow must be not exceed 50 mm
Stability (Column segregation)	9.2%	Less than 10%.

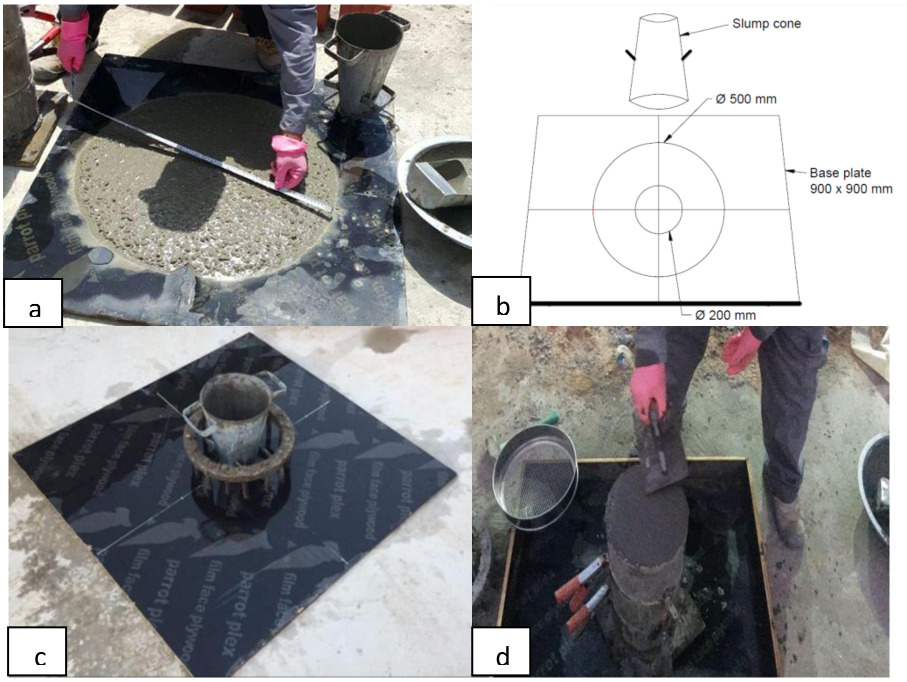

Fig. 2. (a) and (b) Slump test (c) J-ring test (d) column segregation.

Steel bars used in the test were 8 mm diameter which were used for the mesh in flange and 16mm used in the long reinforcement the properties of steel bars are listed in Table 4.

Table 4. Material properties for steel reinforcement

Properties	D-16	D-8
Yield stress, MPa	550	509
Ultimate strength, MPa	600	677

2.3 Strengthening process methods

In this study CFRP SikaWrap®-301C is used in strengthening process. The properties of CFRP sheets and the used epoxy resin had been listed in Table 5 and Table 6.

Table 5. Properties of CFRP sheets

CFRP sheets thickness	Tensile strength (MPa)	Modulus elasticity (MPa)	Elongation at break (%)
0.167	4900	230000	1.7

Table 6. Properties of epoxy resin

Appearance	Mixing Ratio By (weight)	Tensile Strength (Mpa)	Density (kg/L) mixed	Modulus of elasticity (Mpa)	Elongation at break %
Com A: white Com B: Gray	A:B 4:1	30	1.31	4500	0.9

The surface of the specimens was ground by using an electrical hand grinder to get a smooth surface and assuring most efficient adhesion between carbon sheets and concrete surface. The surface of specimens was cleaned with water jet and air blasted to remove the powdered concrete and all the possible loose materials. The corners of specimens was ground to be rounded. Six of holes of diameter (12) mm were made in the flange on each side to fit the vertical CFRP sheets as shown in Fig. 3.

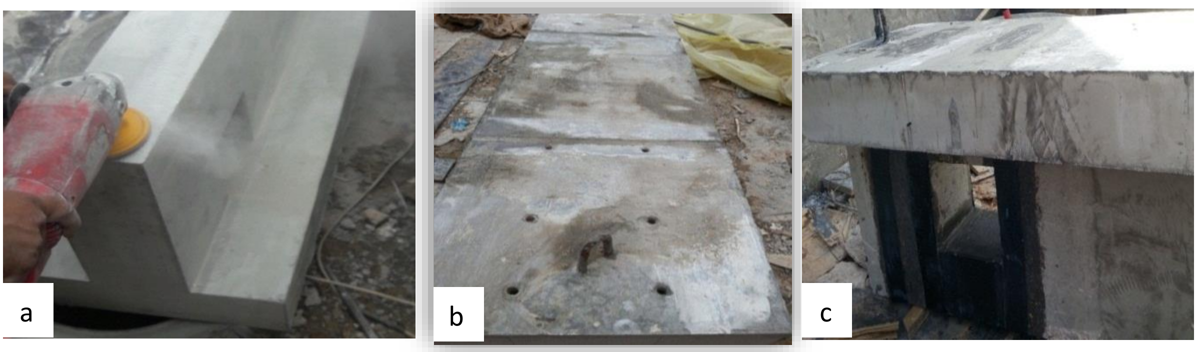

Fig. 3. (a) Concrete surface preparation (b) introducing holes the flange (c) install carbon sheets

2.4 CFRP Strengthening System

Based on the results control beams, the strengthening systems were suggested and chosen carefully according crack pattern, case of practical applied actual and the economic aspect. Such systems are described in Table 7 and shown in Fig.4 to Fig.6. Finally to investigate the effectiveness of using CFRP sheets in the strengthening of the beam specimens with rectangular openings and different positions in the vertical direction, the specimens R2crto and R2crbo were strengthened by the second system of strengthening.

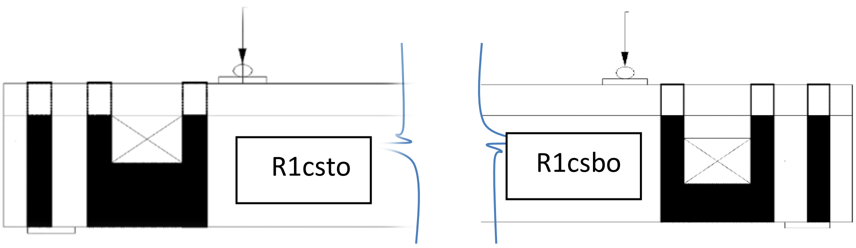

Fig. 4. The first strengthening specimens

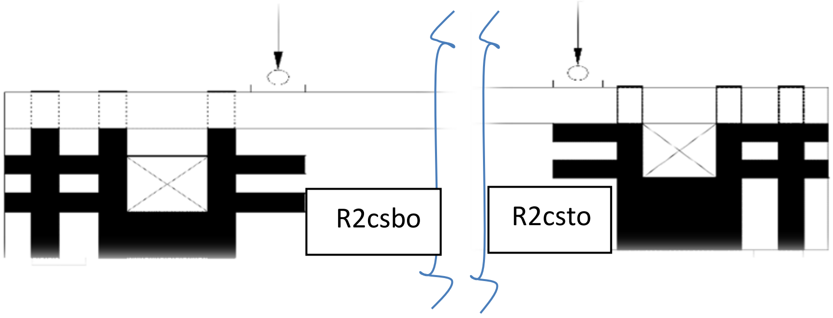

Fig. 5. The second strengthening specimens

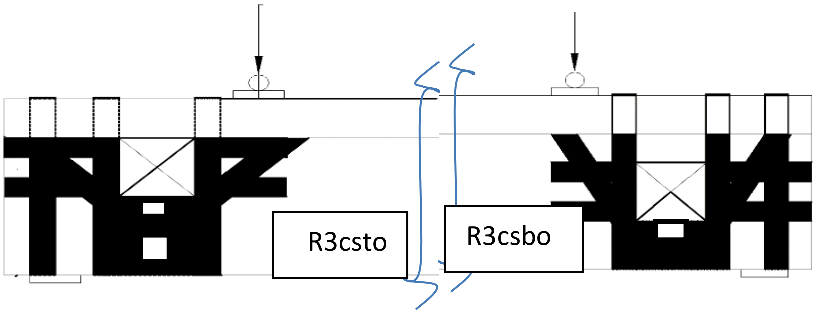

Fig. 6. The third strengthening specimens

Table 7. Describing methods of strengthening

Type strengthening	Details
R1	Three CFRP strips of 50 mm width with a Jacket for the bottom cord of the opening.
R2	R1+ strengthening of the internal face of the opening .
R3	R1+2 inclined sheet strips and replace the jacket bottom cord of opening with two strip 50 mm width

2.5 Test description

A universal testing machine at the structural laboratory in University of Al-Kufa with a maximum capacity of 2000 KN is used to achieve tests. The test specimens were loaded with two-point static loads that distributed across the width of the flange. The load was applied in a successive increments up to failure. The crack development in the concrete beams was traced. Also the cracking load was monitored and crack width was measured.

3. TEST RESULTS AND DISCUSSION

3.1 Load-Deflection curves of specimens

The load mid-span deflection curves for the first group (control beams) are shown in Fig.7 and the results of strengthening samples are shown in Fig.8 and Fig.9. It can be seen that the experimental results for solid specimens were higher than those of specimens containing openings. The maximum deflection of the beam (C soild) was (5.5)mm while the other specimens (crto), (crbo), (csto) and (csbo), were (3.24),(3.93),(3.84) and (3.51) respectively.

The maximum deflection for (C solid) at ultimate Load (700kN) and other control beams were (252), (210), (394) and (360) kN respectively.

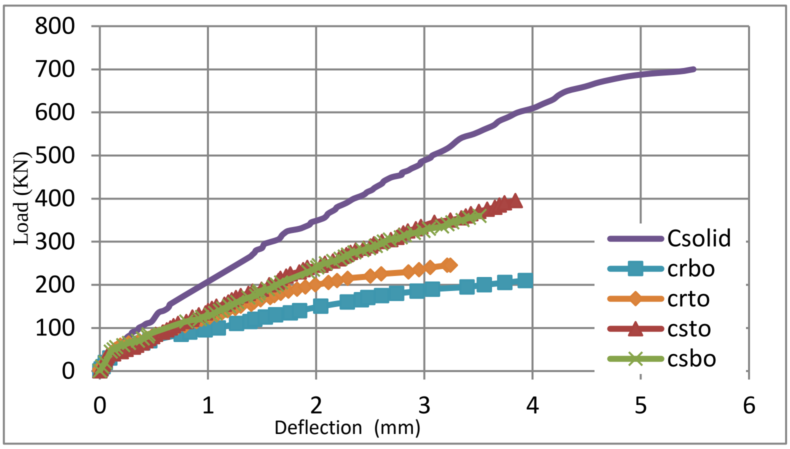

Fig.7. Load deflection curve for the control specimens.

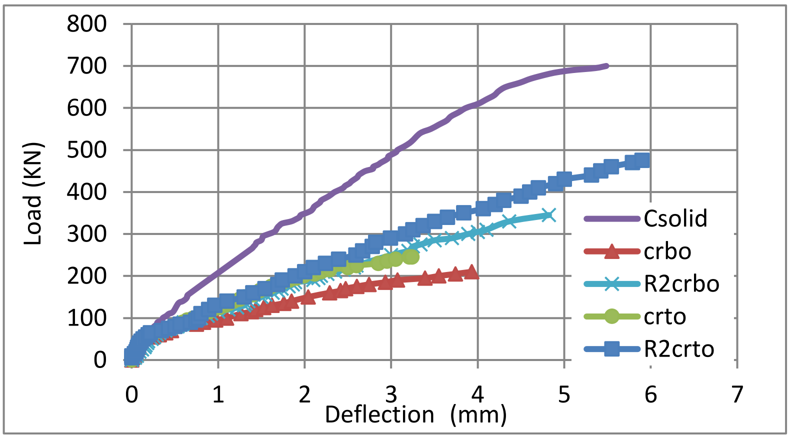

Fig.8. Load deflection curves for the strengthening beam with rectangular opening.

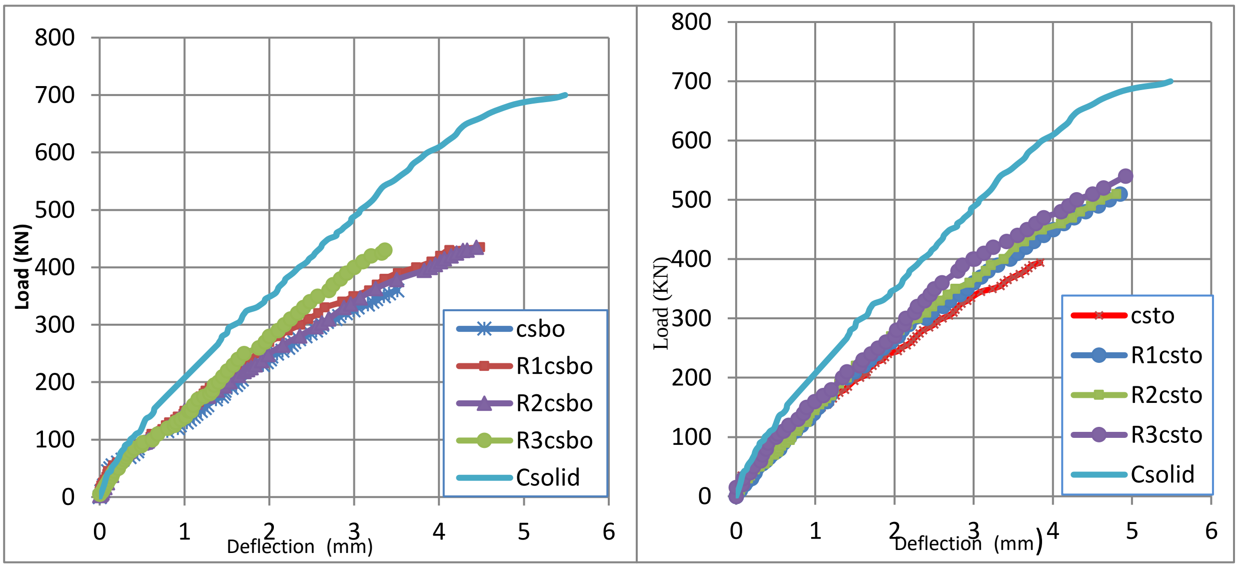

Fig. 9. Load deflection curves for the strengthening beam with square openings.

3.2 Ultimate Loads and Failure Modes

The failure modes of the tested deep beams are observed from the two-point loading tests. The failure mode of the solid control beams was observed to be a diagonal shear failure. It was shear at opening region failure for the specimens contains openings below the flange, the deformation occurs mainly in the shear span by relative rotation of three distinct blocks of the beam: one above the opening, another below the opening and the third between the opening and the end of the beam. While the flush opening with flange the shear failure is diagonal shear (failure shear at opening region). While the samples of strengthened T-section deep beams with CFRP sheets, two different types of failure modes had been observed, in the samples which contains the openings down flange the failure mode was observed to be shear at opening region and separation concrete cover. While for the samples which contains opening flush with flange it was shared at opening region failure. The beams were tested prior to failure, the first cracking loads and developing, ultimate loads and failure modes that recorded for the tested beams are listed in Table 8 and Fig.10 showed crack patterns of the tested specimens.

Table 8. Details the all specimens.

Specimens	**Flexural Crack load(KN)**	**Shear Crack Load (KN)**	**Ultimate Load Pu (KN)**	**Failure Mode**
c solid	150	260	700	Diagonal shear failure
Csto	150	55	394	Shear at opening region
Csbo	190	50	360	Shear at opening region
Crto	75	42	252	Shear at opening region
Crbo	80	35	210	Shear at opening region
R1csto	130	115	510	shear at opening region
R1csbo	160	110	435	shear at opening region with separation concrete cover
R2csto	170	120	500	Diagonal shear failure shear at opening region
R2csbo	140	115	435	diagonal shear and shear at opening region with separation concrete cover
R2crto	200	100	470	Diagonal shear failure (shear at opening region)
R2crbo	175	80	345	shear at opening region with separation concrete cover
R3csto	160	120	540	Diagonal shear failure shear at opening region
R3csbo	165	115	430	shear at opening region with separation concrete cover

3.3 Crack width

In the present study, the diagonal shear cracks were measured by using the crack-meter . The shear cracking load is defined as the load at which the first major inclined diagonal tension crack appears in the shear span. In this part, the crack patterns for the tested beams are shown and discussed. Crack initiation and propagation across the beam have been monitored. Cracks distribution and their propagation have been measured during loading. The formation of first crack was monitored throughout the test to record the width of this crack with increasing load until near failure of the beam models. The relation between load and first crack width for the three groups are shown in Fig. 11 and Fig. 12. The development of crack width for control beam specimen (Csolid) was more than the other strengthened beams because there is no CFRP reinforcement to resist its cracks propagation. The development of crack width for strengthening beams was approximately similar but it was observed that the development of

Fig. 10. Crack patterns of the tested specimens.

crack for configuration (R3) bettert than the other specimens. The different strengthening configuration does not give significant differences in load capacity, but there are clear differences in the width of cracks between one configuration and another. The strengthening configuration (R3) is the best among them.

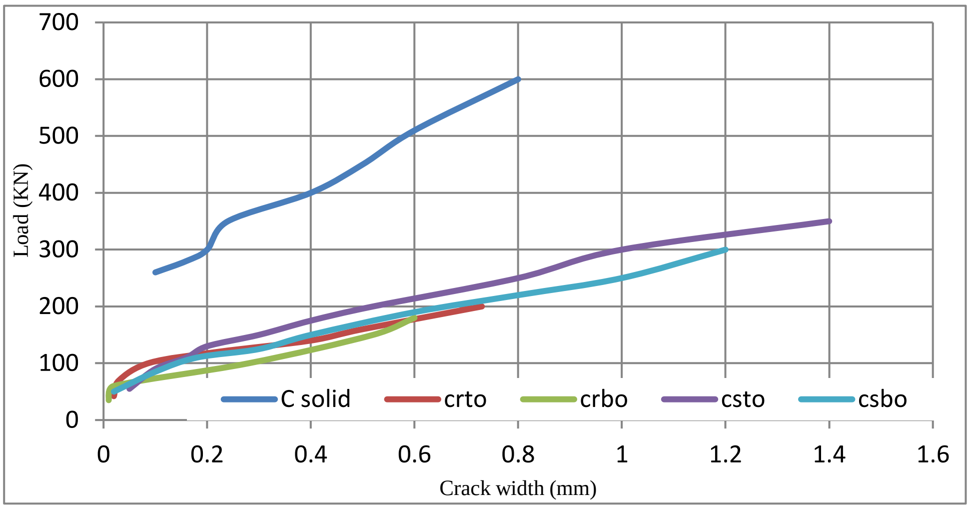

Fig. 11. Cracks width the control beams.

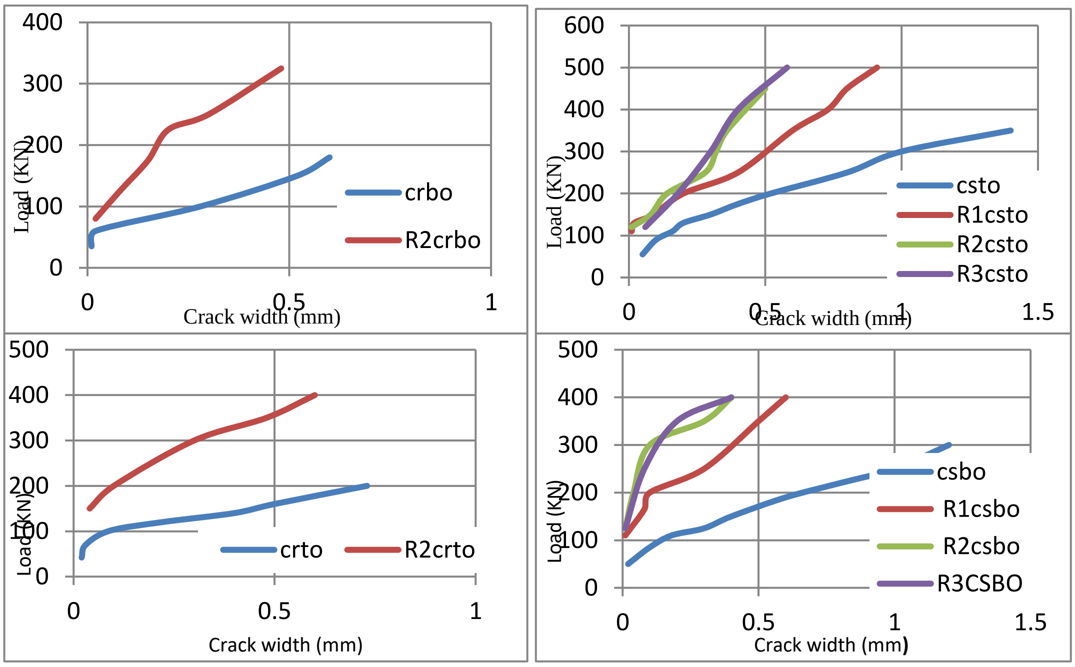

Fig. 12. Cracks width the strengthening beams.

The results of the test shown that the inclusion of such events lead to a decrease in the capacity by (43% and 64%) for the square and rectangular openings respectively when located flushed to the flange. While bottom location the reduction in capacity was found to (48% and 70%) for the square and rectangular openings respectively compared with control samples. It was also found that the strengthening of the carbon strips led to an improvement in structural capacity by (19% and 64%) for square and rectangular openings respectively, when located flushed to the flange while bottom location, the improvement in capacity was found to be (37% and 87%) for square and rectangular openings respectively. It was also found that the location of the opening flushed to the flange gives greater resistance from which interrupts the load path from the test results. Also, it can be concluded that the second strengthening system gave resistance to specimens R2crto and R2crbo higher than R2csto and R2csbo which confirms the validity of using CFRP sheets as an external strengthening to repair damaged installations. A serious reduction of load capacity can be seen when the beam continued openings compared with the solid one and the effect more obvious with rectangular opening rather than square opening. It can be seen in general that the top location of opening yielded more capacity than the bottom location with a ration of capacity for rectangular and square.

4. CONCLUSIONS

This paper summarized a result of an experimental study on the strengthening of self-Compacting Reinforced Concrete T-deep beam with large opening by (CFRP) carbon fiber reinforced polymer sheets. Within the scope of this study the following conclusions can be drawn:

1. Increasing in the size of the openings results in a substantial decrease in cracking load, ultimate carrying capacity. It can be obviously seen that the introducing openings with size of (150*150) mm and (150*250) mm led to a reduction in the load capacity by (43% and 64%) for the square and rectangular opening respectively when it located flushed to the flange. While with bottom location the reduction in capacity was found to be (48% and 70%) for the same openings respectively.
2. The behavior and the ultimate load of the strengthened deep beam with web openings depend on the interruption of the load path. Therefore, when the opening located away from the supports and the load path, the ultimate load increased with respect to that located on the load path.
3. It was noticed that the anchorage by CFRP sheets with full-wrapped has a significant effect in increasing the carrying capacity of load, the ductility, and the initial stiffness, as a result of the effect of the anchorage.
4. The crack width decreases due to the application of CFRP sheets as a strengthening material for flanged deep beams containing web openings, while there is no significant effect on the formation of the diagonal cracks that characteristics deep beams.
5. The full warp below opening (bandage) is necessary to provide the resistance, especially when the opening is located close to the bottom of the web.
6. The strengthening with the CFRP sheets led to an improvement in structural capacity by (19% and 64%) for square and rectangular openings respectively, when located

flushed to the flange while bottom location, was found the improvement in capacity by (37% and 87%) for square and rectangular openings respectively.

7. Strengthening the interior faces of the opening corners with CFRP sheets did not contribute a significant improvement in the general behavior due to the comparison of CFRP sheets in the opposite side that desiring the resistance. Thus it is recommended to adopt such of configuration when using material strong in comparison as steel plates and angle.

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