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Flexural Behavior of Reinforced SCC Rectangular and Trapezoidal Beams Strengthened with CFRP

سلوك الانثناء للعتبات المسلحة الخرسانية ذاتية الرص ذات المقطع المستطيل وشبه المنحرف والمقواة بأشرطة البوليمير المدعم بألياف الكربون

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ABSTRACT

This study investigates experimentally the behavior of ten self-compacting reinforced concrete beams under flexural failure and comparing between rectangular and trapezoidal cross-sections of beams with and without strengthening. Carbon fiber reinforced polymer CFRP was used for strengthening. These beams divided into two groups according to their cross-sections. First group (R) has rectangular cross-section with dimensions of (length 1600 × height 260 × width 160 mm). Second group (T_{24}) has trapezoidal cross-section with dimensions of (length 1600 × height 260 × width in bottom 160 and in top 240 mm). The experimental results show that beams with trapezoidal cross-section have higher ultimate load capacity of (13 %- 19%) and lower defection compared to that with rectangular cross-section reinforced concrete beams. Also, strengthening beams by CFRP strips lead to increase in ultimate load capacity by (4.8 %-28.6 %) for rectangular cross-section beams and (4 %-24 %) for trapezoidal cross-section beams. The addition of CFRP strips as reinforcement elements to concrete beams also reduce their deflection measured in the middle of beams at working load by (13.4 %-17.57 %) for rectangular cross-section beams and (6.4 %-17 %) for trapezoidal cross-section beams and delay the appearance of first crack in concrete. Two methods of placing same amount of CFRP on beams have been used. The first method is by applying CFRP strips along the beams (R-1 , R-2 , T_{24}-1 , T_{24}-2). While the second method strengthen beams by CFRP strips on the maximum and high moment regions with the same total length of CFRP, as in beams (R-3 , R-4 , T_{24}-3 , T_{24}-4). The results indicate that the second method gives higher ultimate load capacity by (4.5 %-8 %) in rectangular cross-section beams, and (4 %-6.9 %) in trapezoidal cross-section beams, in addition to reduce their deflection.

Key words: Self-compacting reinforced concrete, flexural failure, carbon fiber reinforced polymer.

المستخلص

تبحث هذه الدراسة بشكل تجريبي في سلوك عشر عتبات خرسانية مسلحة ذاتية الرص تحت فشل الانثناء ومقارنة بين العتبات ذات المقطع العرضي المستطيل والشبه منحرف مع التقوية او بدونها. اشرطة البوليمر المدعم بالياف الكاربون (CFRP) تستخدم للتقوية. تقسم هذه العتبات الى مجموعتين حسب مقطعها العرضي. المجموعة الاولى رمزها (R) ذات المقطع العرضي المستطيل بأبعادها (الطول 1600, الارتفاع 260, العرض 160 ملم). المجموعة الثانية رمزها (T_{24}) ذات المقطع العرضي شبه المنحرف بأبعاد (الطول 1600, الارتفاع 260, العرض في الاسفل 160 وفي الاعلى 240 ملم). اظهرت النتائج التجريبية ان العتبات الخرسانية المسلحة ذات المقطع العرضي الشبه المنحرف تمتلك اعلى قابلية تحميل عظمى بنسبة (13% –- 19%) واقل هطول مقارنةً بالعتبات الخرسانية المسلحة ذات المقطع العرضي المستطيل. كما ان تقوية العتبات بأشرطة البوليمير المدعم بألياف الكاربون

(CFRP) تؤدي الى زيادة في قابلية التحميل العظمى بنسبة (4,8% –- 28,6%) في العتبات ذات المقطع العرضي المستطيل وبنسبة (4% –- 24%) في العتبات ذات المقطع العرضي شبه المنحرف. ان اضافة أشرطة البوليمير المدعم بألياف الكاربون (CFRP) كعناصر تقوية للعتبات الخرسانية تقلل ايضا من الهطول المقاس في منتصف العتبات عند حمل التشغيل بنسبة (13,4% –- 17,57%) للعتبات ذات المقطع العرضي المستطيل وبنسبة (6,4% - – 17%) في العتبات ذات المقطع العرضي شبه المنحرف وكذلك تؤخر ظهور التشقق الاول في الخرسانة. تم استخدام طريقتين لوضع نفس المقدار من أشرطة البوليمير المدعم بألياف الكاربون (CFRP) على العتبات. الطريقة الاولى بواسطة تطبيق أشرطة البوليمير المدعم بألياف الكاربون (CFRP) على طول العتبات ($R-1$, $R-2$, $T_{24}-1$, $T_{24}-4$) , بينما الطريقة الثانية بواسطة تقوية العتبات بأشرطة البوليمير المدعم بألياف الكاربون (CFRP) في مناطق العزم الاعظم والمناطق ذات العزم العالي بأستخدام نفس الطول الكلي لـ (CFRP) في العتبات $R-3$, $R-4$, ($T_{24}-1$, $T_{24}-4$) . تشير النتائج الى ان الطريقة الثانية تعطي اعلى قابلية التحميل العظمى بنسبة (4,5% –- 8%) في العتبات ذات المقطع العرضي المستطيل وبنسبة (4% –- 6,7%) في العتبات ذات المقطع العرضي شبه المنحرف, بالاضافة الى تقليل الهطول فيها.

1. INTRODUCTIN

Self-compacting concrete is an inventor material that provides concrete characteristics to fill formwork with full compacting under its own weight without any need to vibration. This kind of concrete has ability to flow in narrow places in formwork even in congested bars of steel reinforcement. Generally, SCC made from common materials which used with normal concrete with low water cement ratio by using super-plasticizer. [1]

Concrete reinforcement beams are important structural members which transfer loads from slabs to columns or walls. There are many shapes of concrete beams cross-sections used in frame building to perform different functions structural and architectural function. The common cross-sections are rectangular and T-section. On the other hand, other cross-sections can be used like trapezoidal and varying cross-section like tapered and haunches beams. The concept of resisting reinforced beams to loads is by resist compressive stress by concrete compression zone and steel bars carry tension stress in tension zone. [2]

The failure of beam in building can be classified into two types, first one load capacity failure; this occur when applied load exceed capacity strength resistance of beam, failure happened may be by shear or flexural or torsion loads. Second type is service failure which caused by cracks or deflection when exceed limits that lead to damages in other part of structure. From this point, successfully construction must be able to carry applied load within limits of deflection which has been taken in this study.

It may be not possible to replace existing beam that does not satisfy structural requirements with new one, or may be replacing new element as alternate to old one is not economically feasible solution as well as substitutions of all structure. This problem considered as one of the more important problems facing structural engineers and needs to find new methods to strengthen the structural elements to become able to resist the increment service load and not exceed limits of deflection. [3]

There are many different methods to strengthen reinforcement concrete elements. One of most important of these methods is by using fiber reinforced polymer FRP materials as technique to upgrade those elements. [4]

In this study the beams were strengthened with carbon fiber reinforced polymer CFRP strips to resist flexural failure as simulation to old elements structure that need to upgrade and strengthen taking ultimate load capacity and deflection as priority.

2. EXPERMEMTAL PROGRAM

An experimental program consists of constructing and testing ten simply supported beams with symmetrically two point loading by using SCC designed with f_c' of (35 MPa).

Depending on the cross-section shape, the beams were divided into two groups, first one group (R) with rectangular cross-section and second group (T_{24}) with trapezoidal cross-section. All beams has dimensions of length (l) 1600 × height (h) 260 × width (b) (in group (R) 160 mm, while in group (T_{24}) in the bottom 160 and in the top 240 mm). The beams designed for flexure failure mode with details of reinforcement consist of longitudinal tensile reinforcement with two deformed steel bars having 10 mm diameter placed in bottom, longitudinal compressive reinforcement with two deformed steel bars having 6 mm diameter placed in top and vertical shear reinforcement deformed bar having 6 mm diameter placed at 100 mm distance center to center, as shown in Figures (1) and (2).

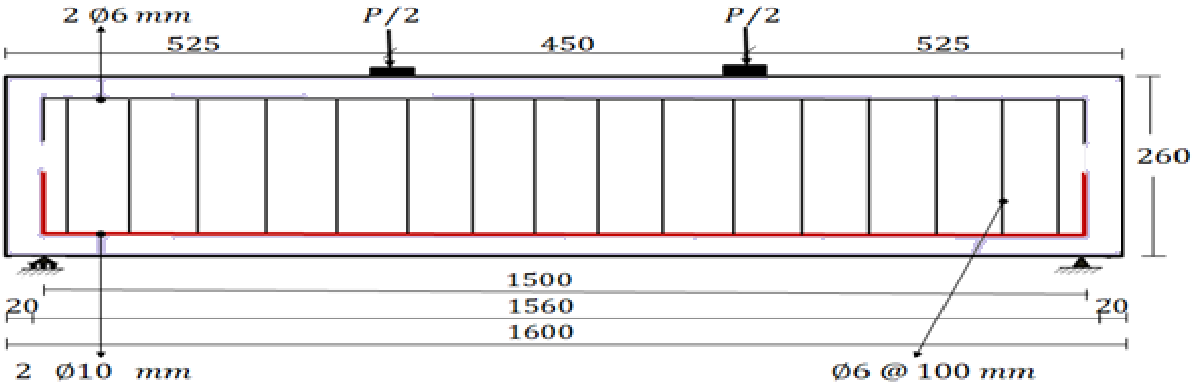
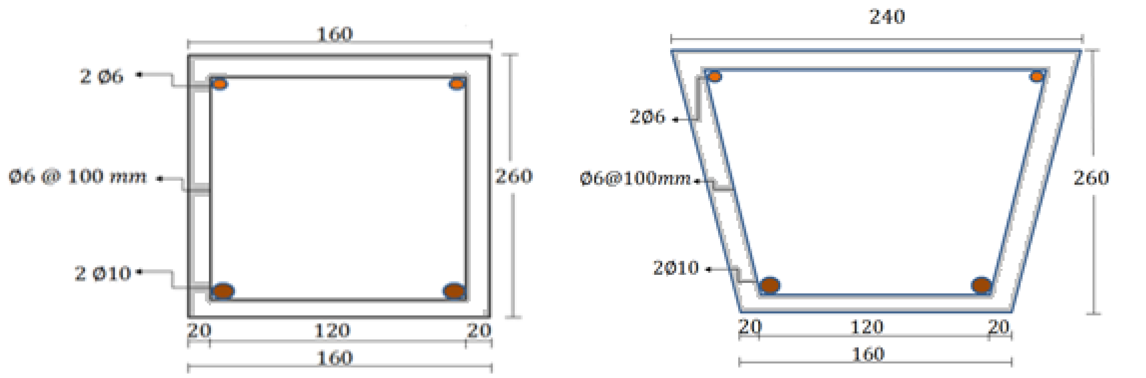


Figure (1): Longitudinal section of specimens (all dimensions in mm).



a) Rectangular b) Trapezoidal

Figure (2): Cross-sections of specimens (all dimensions in mm).

3. STRENGHENING SCHEME AND DETAILS

Samples divided into two groups, group (R) and group(T_{24}), each group includes five beams. For each group one of beams was control and has no strengthening. On the other hand four beams have different strengthening by CFRP strips with (40 mm) width placed on base of beams. The CFRP bonded with concrete by sikadur-330 [5], which is a "two part solvent free thixotropic epoxy based impregnating resin/adhesive". Moreover U-shape of CFRP strips with (40 mm) width was used at each end of strengthening CFRP longitudinal strips to prevent de-bonding between the longitudinal CFRP strips and concrete. The number of strips and spacing between them was designed according to ACI 440.2R-08 [6].

Generally, two types have been used to strengthen all beams in this study as following:
First: The beams were strengthened by CFRP strips placed along the beam.
Second: The beams were strengthened by CFRP strips placed on maximum and high moment regions of beam. All details of strengthening for all beams are shown in Table (1) and Figure (3).

Table (1): Details of beams strengthening

Beam Symbol	No. of strips	Width of strips (mm)	Length of strips (mm)	Thickness of strips (mm)	Clear spacing between strips (mm)	Width of U-shape strips (mm)
R-0 , T_{24}-0	-	-	-	-	-	-
R-1 , T_{24}-1	1	40	1400	0.166	-	40
R-2 , T_{24}-2	2	40	1400	0.166	30	40
R-3 , T_{24}-3	3	40	933	0.166	10	40
R-4 , T_{24}-4	2	40	700	0.166	30	40

4. CONCRETE MIX DESGIN

According to the recommendation of EFNARC [7] many trail mixes were performed to get properties of SCC (fresh and hardened). The mixes designed to achieve cylinder compression strength of (35 MPa) at (28) days. The mix proportion of SCC mixture shown in Table (2)

Table (2): Mix proportions of SCC

Cement (kg/m^3)	Limestone powder (kg/m^3)	Water (kg/m^3)	W/P^b ratio By weight	Corse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Super plasticizer (L/m^3)
350	175	180	0.34	767	797	4.9 [a]

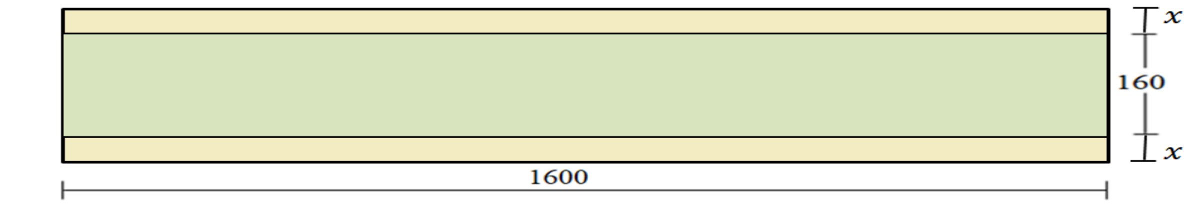
a (1.4 Liter)/(100 kg cement)
b p = Cement + Limestone

5. HARDENED PROPERTIES OF SCC

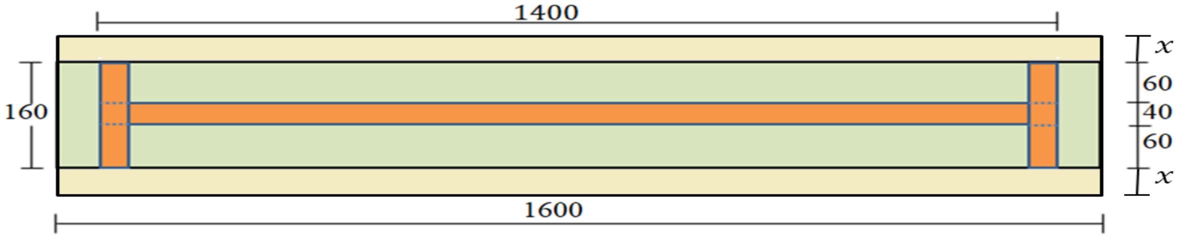
Table (3) show the results of hardened properties of the chosen SCC mix used in this research, according to ASTM C39 [8], C496 [9], C469 [10] and C78 [11] for compressive strength, splitting tensile strength, static modulus of elasticity, and flexural strength respectively.

Table (3): Hardened properties of SCC

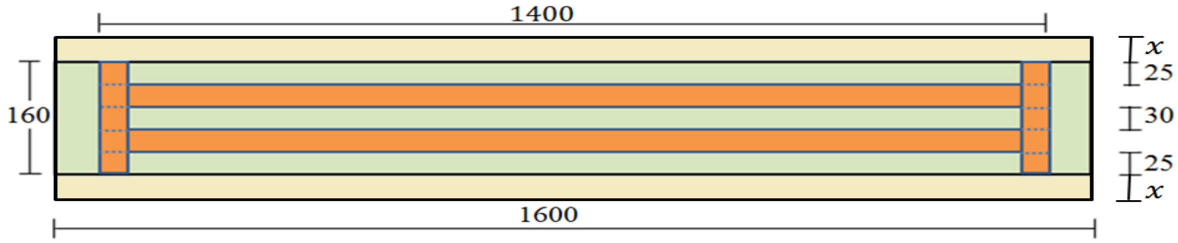
Age	Compressive strength fc' (MPa)	Splitting tensile strength fct (MPa)	Static modulus of elasticity Ec (GPa)	Flexural strength fr (MPa)
7 days	24.62	2.75	-	3.78
28 days	34.23	3.54	26.73	4.35
56 days	38.74	-	28.14	-



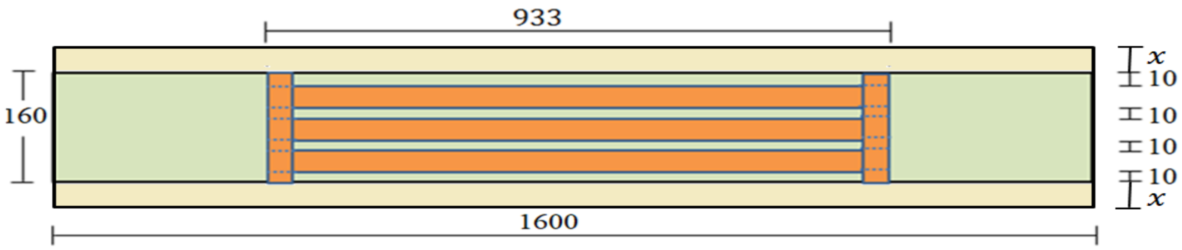
a) Control beams (R-0, T_{24}-0)



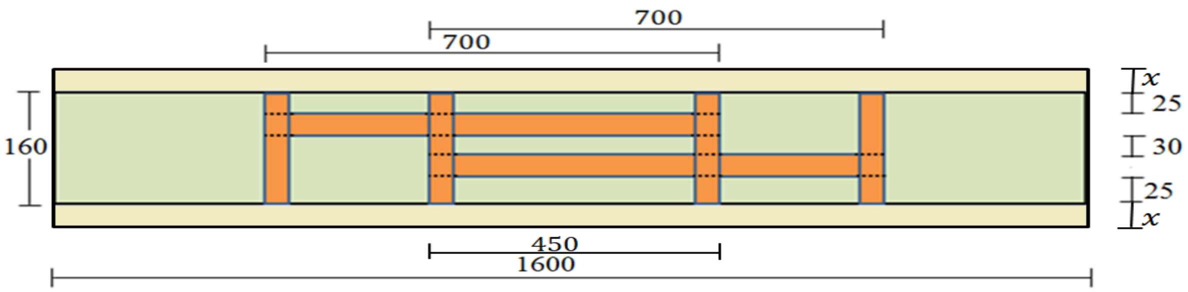
b) Beams strengthened by one strip (R-1, T_{24}-1)



c) Beams strengthened by two strips (R-2, T_{24}-2)



d) Beams strengthened by three strips (R-3, T_{24}-3)



e) Beams strengthened by two opposite strips (R-4, T_{24}-4)

Figure (3): Bottom view of beams with strengthening details [x=0 for group (R), while x=40 for group (T_{24}), all dimensions in mm].

6. TESTING PROCEDURE

During testing each beam, first crack was observed and marked by a pen and follow its propagation, then sketch other cracks patterns and write the load for major cracks in tons. Most cracks that appeared during the test were flexural cracks because all tested beams designed to fail by flexure.

7. EXPERIMANTAL RESULTS

The first crack started in mid span where in this region maximum moment was exist. This happened in control beams (R-0, T_{24}-0) and when strengthens strips placing along beams (R-1, R-2, T_{24}-1, T_{24}-2). On the other hand, first crack started from the end of strengthen strips if the strengthening was not laying along the beam because the strip of CFRP make its region stronger from other region of beam this happened in beams (R-3, R-4, T_{24}-3, T_{24}-4).

7.1. Behavior and strength of beams in group (R)

This group contains five beams of rectangular cross-section. One of them was control without any strengthening strip of CFRP, on the other hand four beams were strengthened with CFRP, where number of strips and their locations differs from beam to another and all these details are illustrated in Table (1) and Figure (3).Testing results of this group are listed in Table (4) and failure modes of beams are shown in Figure (4). In beams (R-0), (R-1) and (R-2) the first crack occurs in the middle of beam in tension area at the bottom of beam and the cracks propagate up to the compression area at the top of beam until the strengthening strips was break up,where in beam (R-1) the CFRP strip cut off at the middle of beam where maximum moment was present and the failure occurred after that. While in beam (R-2) one of CFRP strips cut off from mid and the other CFRP strip is detached from concrete at the edge of strip because of the U-shape of CFRP strip was cut off and it was supposed to resist de-bonding between CFRP strips and concrete. Finally, the failure occurred by flexure, where the CFRP strips are ruptured after steel bars yielded. In beams (R-3) and (R-4) the first crack occurs in the edge of CFRP strips in tension area at the bottom of beam, this may happened due to the CFRP strips make the middle region of beam stronger to resist maximum moment. While the adjacent region to the CFRP strips become weaker and therefore the cracks propagate in it up to the compression area at the top of beam, where the strips remain without cutting off and the failure occurs in concrete at adjacent region to the CFRP strips.

Table (4): Testing results of group (R).

Beam	Pcr (kN)	Δcr⁄ center (mm)	Δcr⁄ (under load) (mm)	working load (kN)	Δ ⁄ (working load at center) (mm)	Pu (kN)	Δu⁄ center (mm)	Δu⁄ (under load) (mm)
R-0	45	2.31	1.92	75	5.52	105	10.73	8.62
R-1	55	2.77	2.52	75	4.78	110	10.5	9.08
R-2	60	2.57	2.15	85	4.64	125	10.79	9.5
R-3	65	2.29	2.14	95	4.55	135	9.62	9.35
R-4	60	2.86	2.69	80	4.55	115	10.45	9.87

Pcr: Visible first crack load (kN).

Pu: Ultimate Load (kN).

Δcr⁄ center, Δcr⁄ (under load): deflection measured in conjunction with visible first crack at mid span and under load respectively.

Δu⁄ center, Δu⁄ (under load): deflection measured in conjunction with ultimate load at mid span and under load respectively.
Working load (kN): represent 70 % from ultimate load.
Δ⁄ (working load at center): deflection measured in conjunction with working load at mid span.

Table (5): Increasing of loads and decreasing of deflections by percentage for group ®

Beam	$\Delta_{cr/45/center}$ (mm)	$\Delta_{u/105/center}$ (mm)	(-)% Deflection at center			(+) % p	
			Δcr	Δ⁄ (working load)	Δu	% Pcr	% Pu
R-0	2.31	10.73	0	0	0	0	0
R-1	1.92	9.4	16.88	13.4	12.4	22.22	4.76
R-2	1.5	6.81	35.06	15.94	36.53	33.33	19.05
R-3	1.13	5.58	51.08	17.57	48	44.44	28.57
R-4	1.67	8.47	27.71	17.57	21.06	33.33	9.52

$\Delta_{cr/45/center}$: Deflection measured in conjunction with cracking load of control beam (45 kN) at mid span
$\Delta_{u/105/center}$: Deflection measured in conjunction with ultimate load of control beam (105 kN) at mid span

7.2. Behavior and strength of beams in group (T_{24})

This group includes five beams of trapezoidal cross-section. One of them is control without any strengthening strip of CFRP, and the other four beams strengthened with CFRP strips, where number of strips and their locations differs from beam to another. Testing results of this group are listed in Table (5) and modes failures of beams are shown in Figure (5). In beams (T_{24}-0), (T_{24}-1) and (T_{24}-2) the first crack occurs in the middle of beam in tension area at the bottom of beam and the cracks propagate up to the compression area at the top of beam until the strengthening strips was cut off at the middle of beams T_{24}-1 and T_{24}-2 where maximum moment was present and the failure occurred after that by flexure, where the CFRP strips are ruptured after steel bars yielded. In beams T_{24}-3 and T_{24}-4, the first crack occurs in the edge of CFRP strips in tension area at the bottom of beam, this may happened due to the CFRP strips make the middle region of beam stronger to resist maximum moment. While the adjacent region to the CFRP strips become weaker and therefore the cracks propagate in it up to the compression area at the top of beam, where the strips remain without cutting off and the failure occurs in concrete at adjacent region to the CFRP strips.

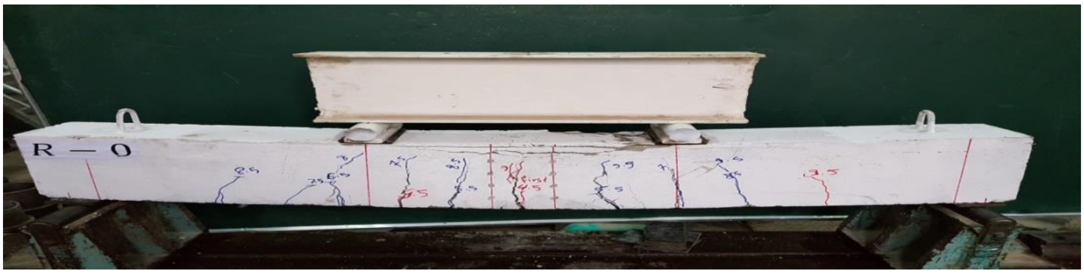
Table (6): Testing results of group (T_{24}).

Beam	Pcr (kN)	Δcr⁄ center (mm)	Δcr⁄ (under load) (mm)	working load (kN)	Δ⁄ (working load at center) (mm)	Pu (kN)	Δu⁄ center (mm)	Δu⁄ (under load) (mm)
T_{24}-0	*50*	2.06	1.62	90	5.47	125	11.44	8.68
T_{24}-1	50	1.86	1.53	90	5.12	130	10.11	8.65
T_{24}-2	60	2.06	1.82	100	4.88	145	10.46	9.45
T_{24}-3	65	1.89	1.74	110	4.82	155	9.56	9.07
T_{24}-4	65	2.61	2.36	90	4.54	130	9.62	8.85

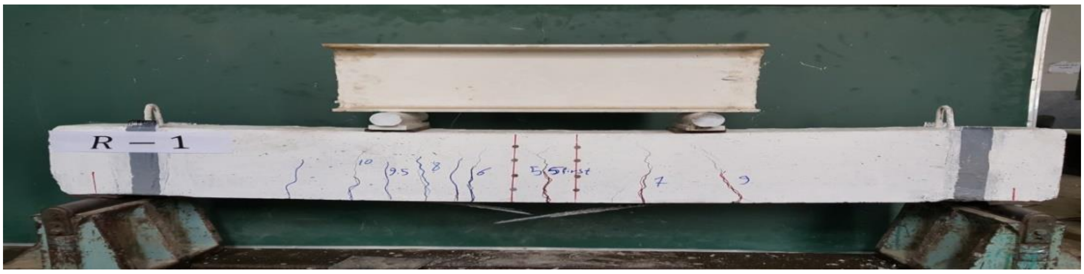
Table (7): Increasing of loads and decreasing of deflections by percentage for group (T_{24})

Beam	$\Delta_{cr/50/center}$ (mm)	$\Delta_{u/125/center}$ (mm)	(-)% Deflection at center			(+)	
			Δcr	Δ/(working load)	Δu	% Pcr	% Pu
T_{24}-0	2.06	11.44	0	0	0	0	0
T_{24}-1	1.86	9.25	9.71	6.4	19.14	0	4
T_{24}-2	1.53	7.56	25.73	10.77	33.92	20	16
T_{24}-3	1.25	5.91	39.32	11.88	48.34	30	24
T_{24}-4	1.69	8.88	17.96	17	22.34	30	4

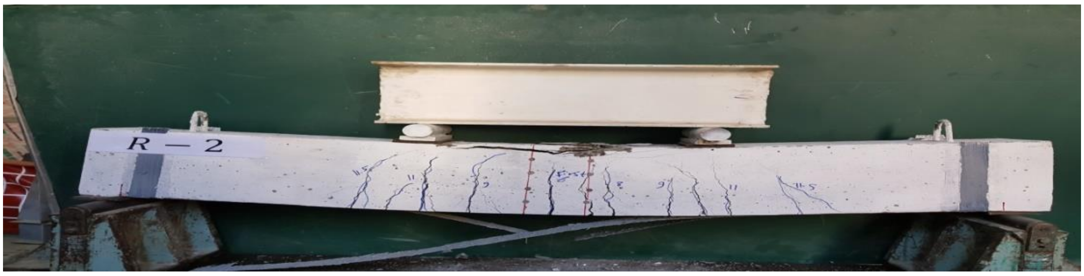
$\Delta_{cr/50/center}$: Deflection measured in conjunction with cracking load of control beam (50 kN) at mid span.
$\Delta_{u/125/center}$: Deflection measured in conjunction with ultimate load of control beam (125 kN) at mid span. Kdk



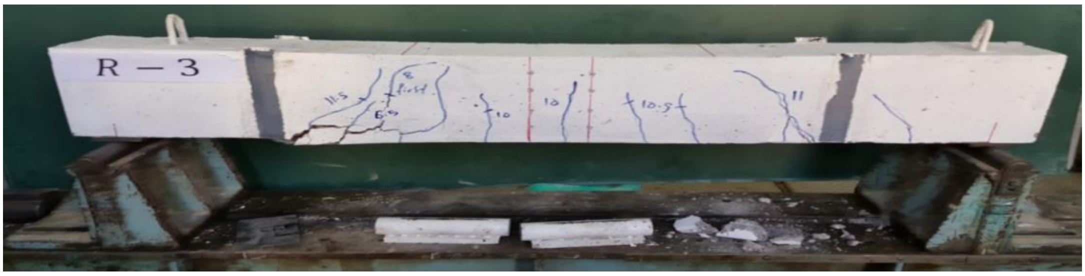
a) Control beam



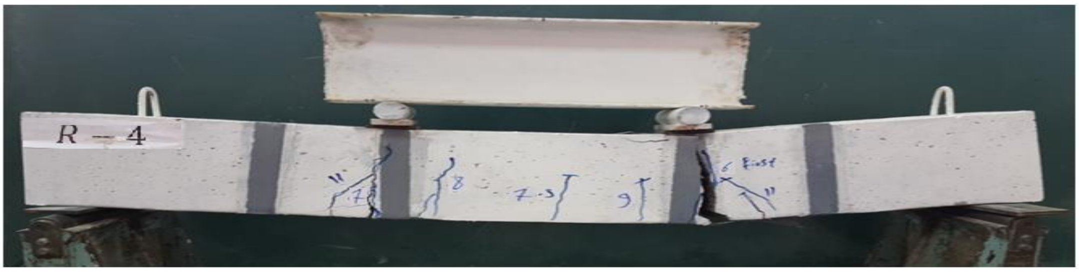
b) Beam strengthened by one strip



c) Beam strengthened by two strips



d) Beam strengthened by three strips



e) Beam strengthened by two opposite strips

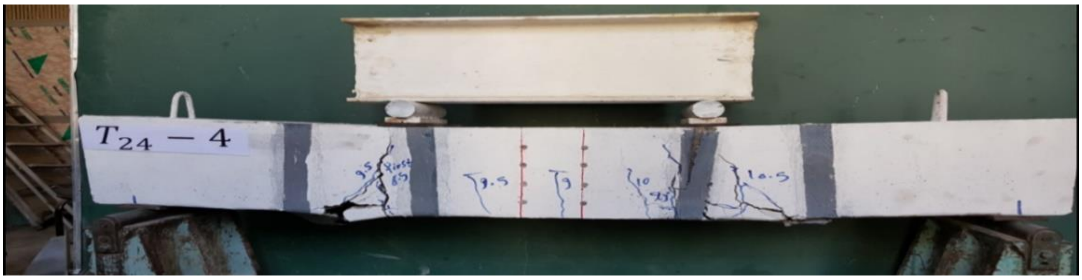
Figure (4): Cracks pattern of group (R).

a) Control beam

b) Beam strengthened by one strip

c) Beam strengthened by two strips

c) Beam strengthened by three strips



e) Beam strengthened by two opposite strips

Figure (5): Cracks pattern of group (T_{24}).

EFFECT of CFRP STRIPS NUMBER on BEAMS BEHAVIOR:

By observing testing results, and comparing between beams strengthened with one and two strips with unstrengthen beams for all cases, it was clear that the CFRP strengthening affect ultimate load capacity, cracking load, and deflection. Adding one strip of CFRP to beams R-1 and T_{24}-1caused increasing in ultimate load capacity of reference beam by (4.8 % and 4%) respectively, also increasing in cracking load of (22.2%) in beam R-1 while beam T_{24}-1 has no increment, and decreasing the deflection value at middle of beams R-1 and T_{24}-1 measured at cracking, working and ultimate loads by (16.88% ,9.71%), (13.4% ,6.4%) and (12.4% ,19.14%) respectively. This happened because the strip of CFRP resist tension in additional to steel bars. Adding two strips of CFRP to beams (R-2 and T_{24}-2) caused increasing in ultimate load capacity of reference beam by (19% and 16 %) respectively, also increasing in cracking load in beams R-2 and T_{24}-2 of (33.3% and 20 %) respectively and decreasing the deflection value at middle of beams R-1 and T_{24}-1 measured at cracking, working and ultimate loads by (35.06% ,25.73%), (15.94% ,10.77%) and (36.53% ,33.92%) respectively. This may be due to increment in cross-section area of CFRP for two strips which resist tension comparing with one strip. Generally, adding more CFRP strips gives a certain increment of ultimate load and cracking load also gives a certain decrement of deflection value for the same level load. Figures (6) and (7) show effect of strengthening strips number on ultimate load capacity and deflection of beams at mid span.

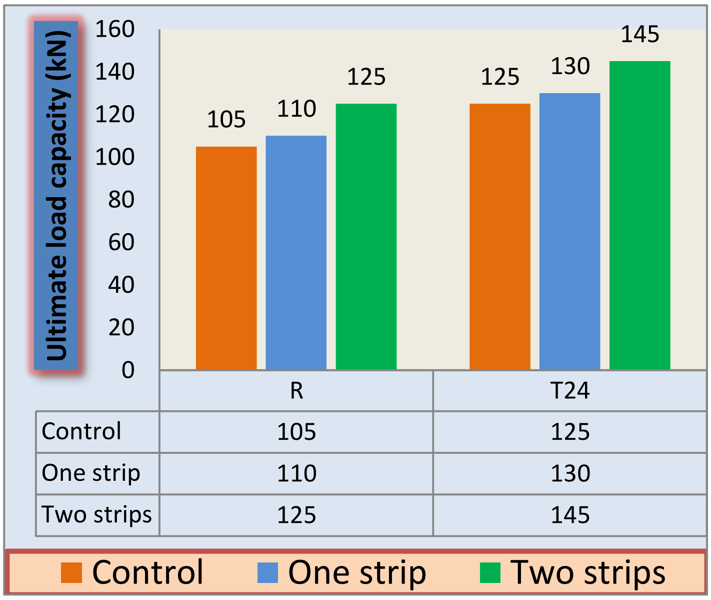


Figure (6): Effect of strengthen strips number on ultimate load capacity.

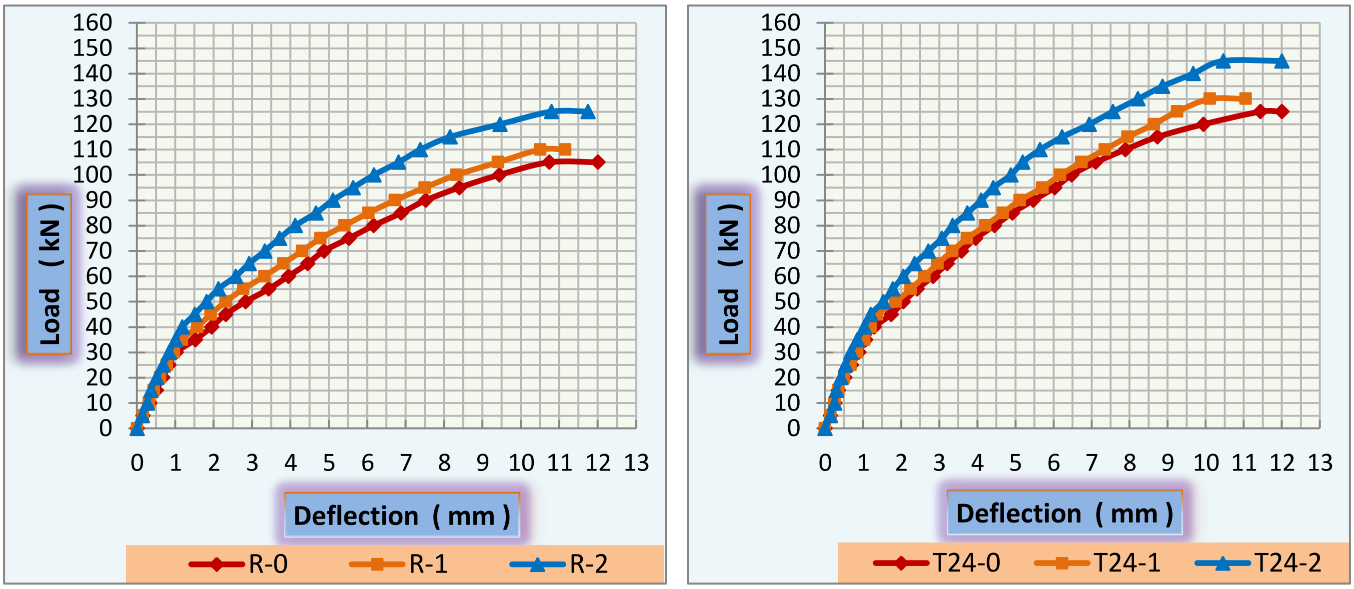
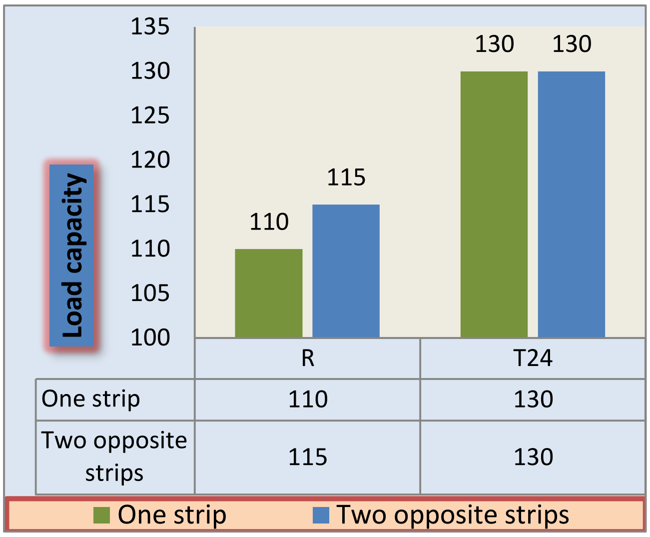


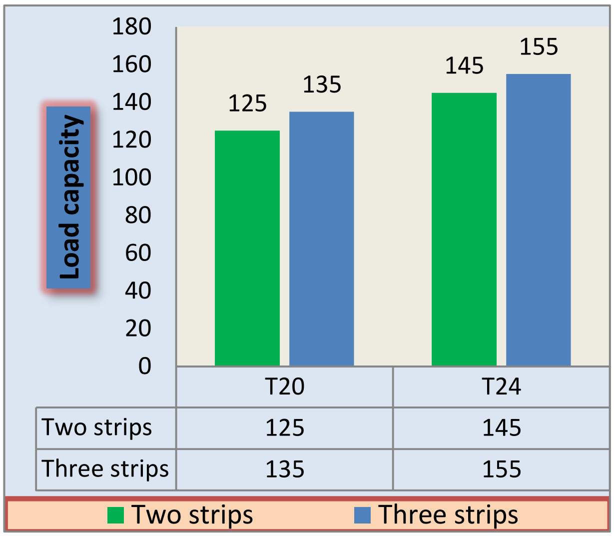
Figure (7): Effective of strips number of CFRP on deflection at mid span.

EFFECT of STRENGTHENING STRIPS LOCATION on BEAMS BEHAVIOR:

There are different methods to place the same amount of CFRP on beams. This study compare between beams (R-1 and T_{24}-1) using one strip along beam with length (1400 mm) and (R-4 and T_{24}-4) respectively using the same strip but cutting it into two strips with length (700 mm) putting on the maximum moment region about (450 mm) and drag remaining length for each strip to near side high moment region, also comparing between beams (R-2 and T_{24}-2) using two strips along beams with length (1400 mm) and beams (R-3 and T_{24}-3) using the same amount of CFRP but with three strips with length (933 mm) putting on the middle distance between supports of beams to resist the maximum moment in mid span and high moment in the adjacent region. According to the detailed results and comparing between two above methods, it is evident that the second method which focusing strengthening strips on maximum moment region used in beams (R-4 and T_{24}-4) and (R-3 and T_{24}-3) gives better result, where increment in ultimate load capacity in beams(R-4 and T_{24}-4) of (9.5 % and 4 %) respectively, while in beams (R-1 and T_{24}-1) of (4.8 % and 4 %) respectively, also increment in cracking load for beams (R-4 and T_{24}-4) of (33.3 % and 30 %) respectively, while in beams (R-1 and T_{24}-1) of (22.2 % and 0 %) respectively and the deflection value for the same level load in beams (R-4 and T_{24}-4) less than in beams (R-1 and T_{24}-1) respectively. On the other hand increment in ultimate load capacity in beams(R-3 and T_{24}-3) of (28.6 % and 24 %) respectively, while in beams (R-2 and T_{24}-2) of (19 % and 16 %) respectively, also increment in cracking load for beams (R-3 and T_{24}-3) of (44.4 % and 30 %) respectively, while in beams (R-2 and T_{24}-2) of (33.3 % and 20 %) respectively and the deflection value for the same level load in beams (R-3 and T_{24}-3) less than in beams (R-2 and T_{24}-2) respectively. Figures (8) and (9) illustrated effect of strengthen strips location on ultimate load capacity and deflection of beams at mid span.

Generally, the methods of placing CFRP strips on beams give different results, and the more effective method is to focus on placing CFRP strips in maximum moment region and high moment regions by consume the same amount of CFRP which used in (R-4, T_{24}-4, R-3, and T_{24}-3).

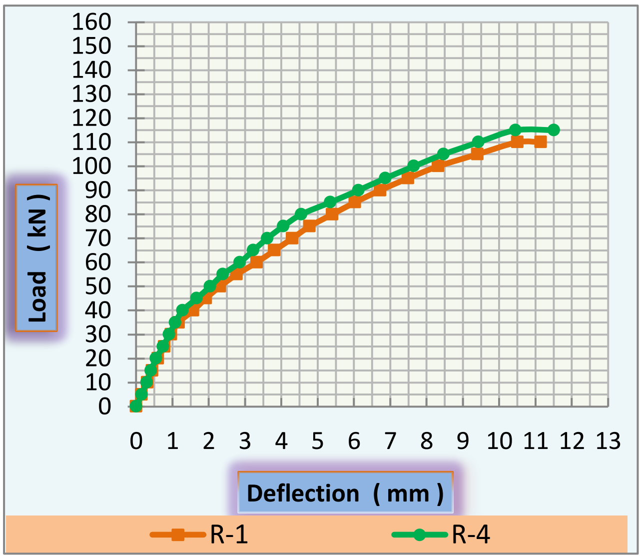




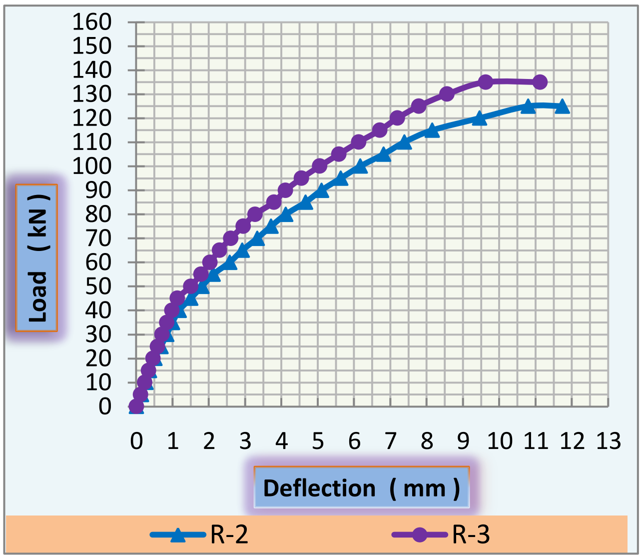
a) Comparing between one strip and two opposite strips

b) Comparing between two and three strips

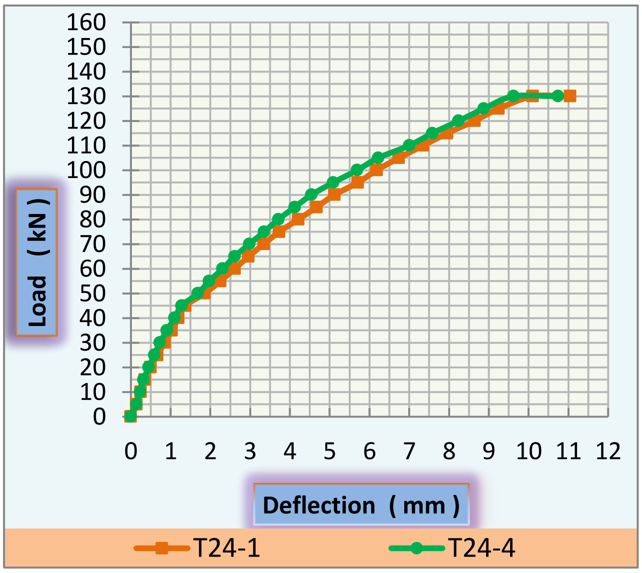
Figure (8): Effect of strengthen strips location on ultimate load capacity.



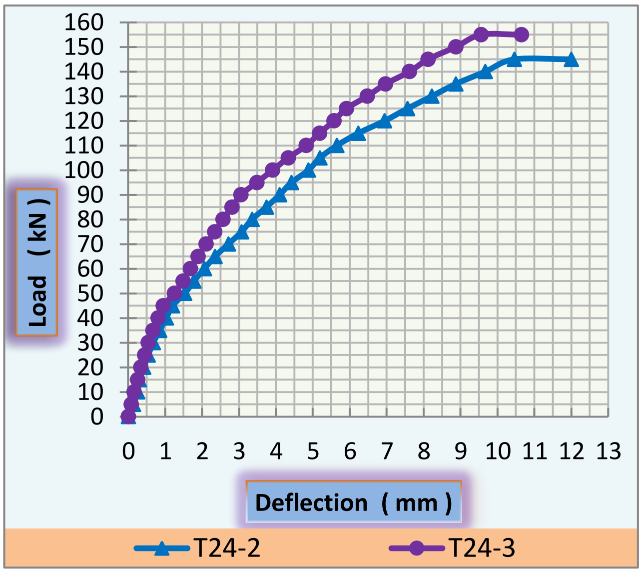
a)



b)



c)



d)

Figure (9): Effect of strengthen strips location on deflection at mid span.

THE EFFECT OF CROSS-SECTION SHAPE ON BEAMS BEHAVIOR:

Figures (10) and (11) show the effect of cross-section shape of beams in their strength and deflection. Results indicate that is using trapezoidal cross-section lead to increase in ultimate load capacity of (13 % - 19%) in comparing with beams of rectangular cross-section. This may due to compression area in trapezoidal cross-section is bigger than rectangular cross-section, therefore the depth of equivalent rectangular compression zone (a) become smaller, this lead to increasing in moment arm $\left(d-\frac{a}{2}\right)$. Moreover, the moment of inertia in trapezoidal more than rectangular, for all this reasons load capacity and cracking load in trapezoidal cross-section increases and become bigger than rectangular for all cases unstrengthen and strengthen beams by CFRP strips.

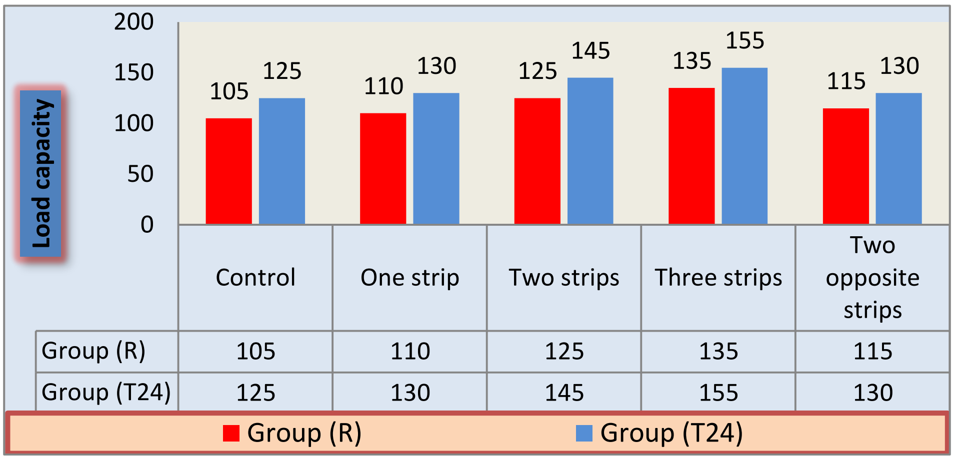


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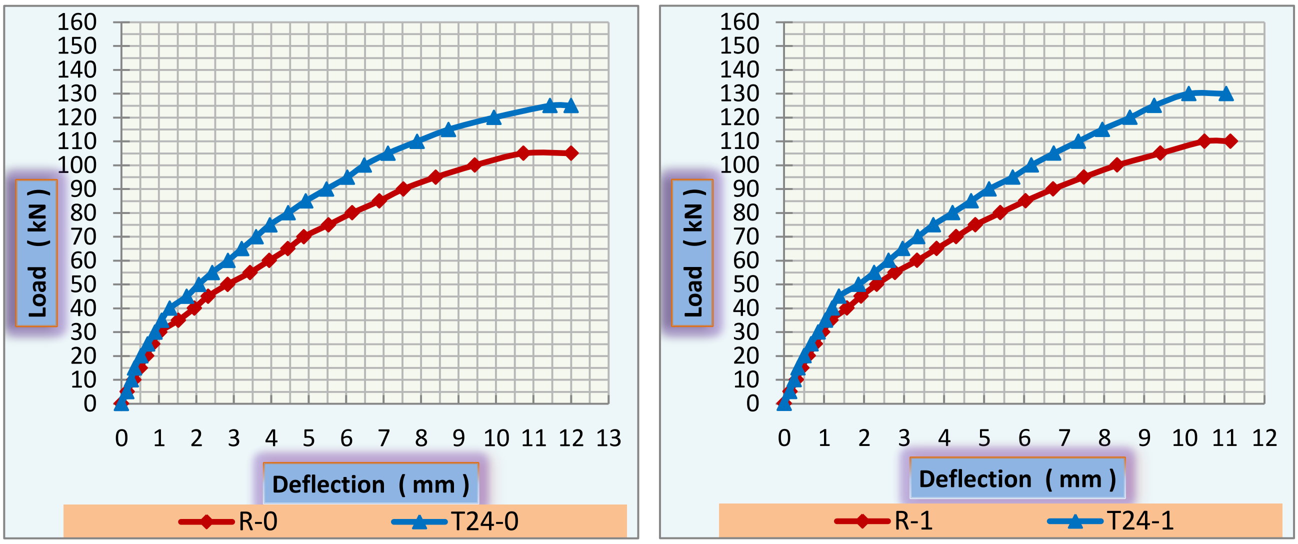
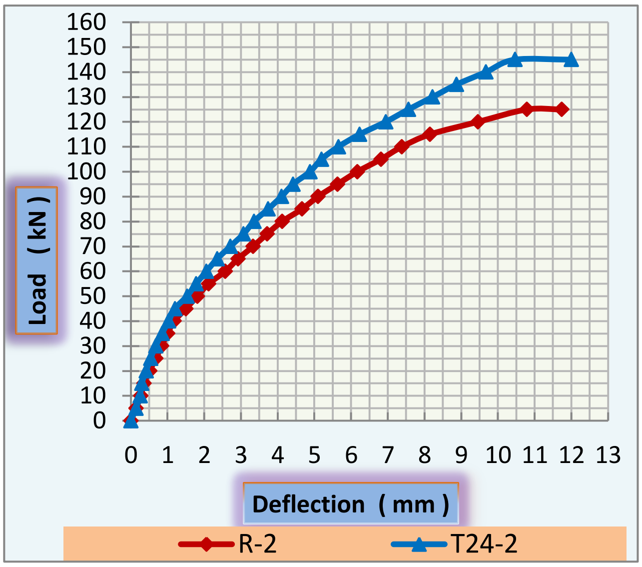
Figure (10): Effect of cross-section shape on ultimate load capacity

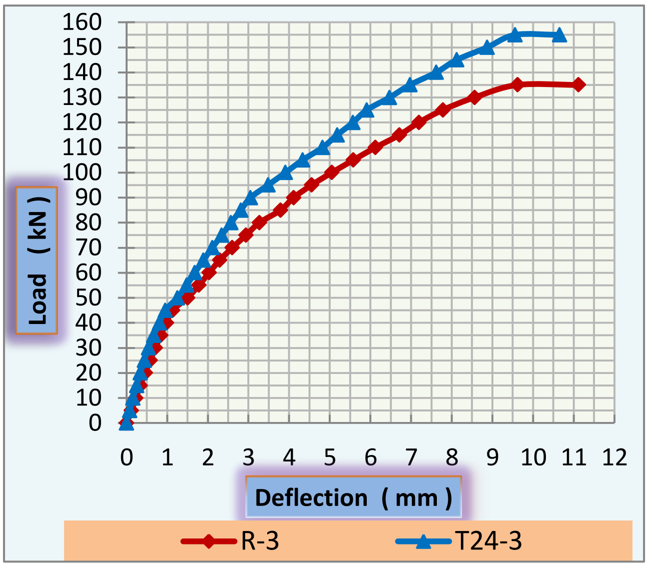


a) Control beams

b) One strip

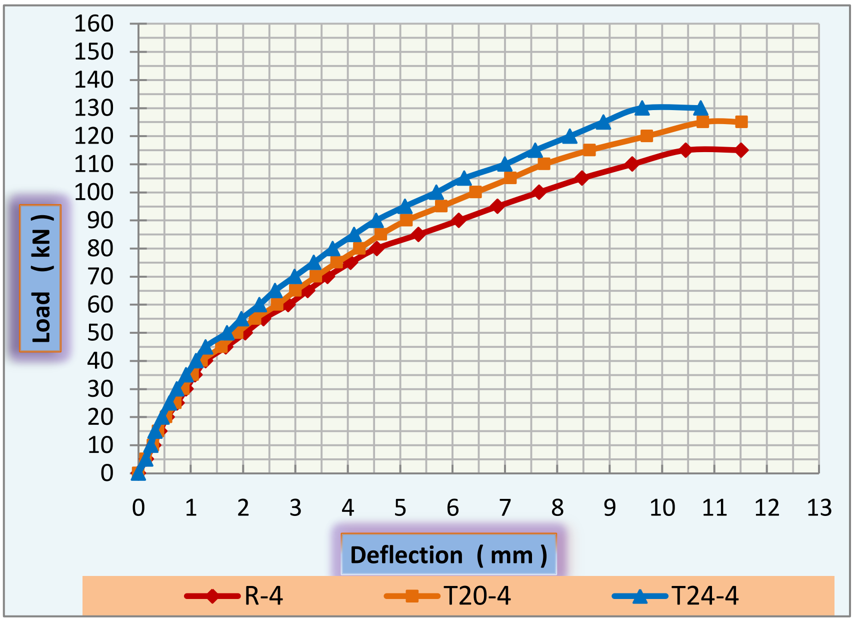


c) Two strips



d) Three strips

Figure (11): Effect of cross-sections shape on deflection at mid span.



e) Two opposite strips

Figure (11): Effect of cross-sections shape on deflection at mid span.

CONCLUSION

Depending on the experimental results of ten SCC beams with rectangular and trapezoidal cross-sections unstrengthen and strengthen by using (1-3) CFRP strips which differs in number, locations and placing methods, it can be concluded that:

1. Trapezoidal cross-section give higher ultimate load capacity by (13 % - 19%) comparing to rectangular cross-section reinforced concrete beams.
2. Strengthening beams with CFRP strips increase their ultimate load capacity by (4.8 % - 28.6 %) for rectangular cross-section, and (4 % - 24 %) for trapezoidal cross-sections beams. also reduce their deflection measured in the middle of beams at working load by (13.4 %-17.57 %) for rectangular cross-section beams and (6.4 %-17 %) for trapezoidal cross-section beams and delay the appearance of first crack in concrete
3. When unstrengthen or strengthen by one or two strips of CFRP beams, the cracking failure modes occurred in mid span of beams. While when beams strengthen by two opposite strips or three strips of CFRP, cracking failure modes occurred in weak region beside end of CFRP strips.
4. Location of CFRP strips is very important, where comparing between first method which used CFRP strips along beams (R-1, R-2, T_{24}-1 and T_{24}-2) and second method which strengthen by CFRP strips on the maximum and high moment regions with the same total length of CFRP in beams(R-4, R-3, T_{24}-4 and T_{24}-3). The second method gives higher ultimate load capacity by (4.5 % - 8 %) in rectangular cross-section beams, while (4 % - 6.9 %) in trapezoidal cross-section beams, in addition to reduce the deflection. Also cracking position that causes failure in first method occurred in the middle of beams, while in second method has changed to end of CFRP strips.
5. Strengthening rectangular cross-section beams by CFRP strips increase their cracking load.
6. Strengthening trapezoidal cross-section by CFRP strips has no clear effect on increasing cracking load unless using two CFRP strips.

REFERENCES

[1] ACI 237R-07 2007 Self-Consolidating Concrete. *American Concrete Institute®*. ACI Committee 237. C. S.

[2] Howard. C. S. 1923 Formulas, Tables and Graphs for Trapezoidal Reinforced Concrete Beams. Bachelor's thesis. *California Institute of Technology*.

[3] Badr. H. A. 2016 Experimental Study and Finite Element Modeling for the Flexural Behavior of Self-Consolidating Reinforced Concrete T-Beams Strengthened with Carbon Fiber Reinforced Polymer. M.Sc. Thesis, *the Department of Building and Construction Engineering of University of Technology*, PP: 123.

[4] Soudki. K. El-Salakawy E & Craig B 2007 Behavior of CFRP Strengthened Reinforced Concrete Beams in Corrosive Environment. *Journal of Composites for Construction*© ASCE.

[5] Sika 2008 data sheet Sikadur-330. 7 PP

[6] ACI 440 2R-08 2008 Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures. *USA: American Concrete Institute*.

[7] EFNARC 2002 Specifications and Guidelines for Self- Compacting Concrete. UK: Association House,99 West Street, Farnham, Surrey GU9 7EN.

[8] ASTM C39/C39M-03 2003 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, West Conshohocken, PA: *ASTM International*

[9] ASTM C496/C496M-04 2004 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, West Conshohocken, PA: *ASTM International*.

[10] ASTM C469-02 2002 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. West Conshohocken, PA, *ASTM International.*

[11] ASTM C78-10, 2010. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), West Conshohocken, PA : *ASTM International*.