Experimental Study on Shear Behavior of Reinforced Self-Compacted Concrete Tapered Beams

Ali Hameed Aziz[1] Hassan Falah Hassan[2] Faisal Muayad Abdul Razzaq[3*]
1.Assist Prof., Civil Engineering Department, Al-Mustansiriayah University, Baghdad, Iraq
2. Assist Prof. Civil Engineering, Civil Engineering Department, Al-Mustansiriayah University, Baghdad, Iraq
3.M.Sc. Student, Civil Engineering Department, Al-Mustansiriayah University, Baghdad, Iraq

Abstract
There are few researches about tapered reinforced concrete elements and it shear failure mechanisms is not well understood. In the present paper, tests were carried out on six beams, simply supported under the effect of two points loading at the ends. Five beam specimens where tapered (non-prismatic shape) while, the last one has a rectangular prismatic shape. The dimensions of the tapered beams were kept constant for all tested beams. The adopted variables were the shape of the tested beams, amount of shear reinforcement and strengthening by CFRP strips. Test results show that the tapered beams without web reinforcement have a superior shear capacity for about (12%) as compared with the prismatic beam, and the strengthening by CFRP strips for tapered beams, enhance the shear capacity for about (30%). Also, the increase of load capacity for tapered beam with half-minimum, and minimum web reinforcement, according to ACI-318 Code for prismatic beam, were (20%) and (33%) respectively as compared with tapered beam without web reinforcement.
Keywords: Shear, Reinforced Concrete, Self-Compacted Concrete, Tapered Beams, ACI-318.

1. Introduction

Since the first half of the 20th century, new form of beams had been arisen, this type of beams called hunched (or tapered) beam; This kind of beams uses usually for mid-rise framed building and in simply supported or continuous bridges as a lateral double cantilever hammer head beam Plate (1). Actually the design of reinforced concrete hunched beams (RCHBs) has been left to judgment and experience of structural engineers in professional practice because the available codes and specific recommendations such ACI-318M-11[1] (American Concrete Institutes) or BS-5400[2] (British Standard Institutes) does not cover these types of members. Structural engineers and architects are often tending to use such non-prismatic beams because of the following advantages with respect to prismatic beams: (a)-Hunched beams substantially increase the lateral stiffness of buildings, which allows the designer to control code drift limits; (b) Such beams lead to a more efficient use of concrete and steel reinforcement; (c) Reduce the weight of structure for a given lateral stiffness; (d) The utilization of hunched beams facilitates the placement of the air conditioning, building's electrical and sewage equipment … etc. [3, 4]

Plate 1. Thawrat Al Eshreen Bridge in Iraq.

Previous review of experimental and numerical studies of reinforced concrete beams show that the behaviors of hunched beams were interest by little researches. The shear strength of RCHBs with shear reinforcement was reported by Debaiky et al [5], El-Niema[6] and Stefanou[7]. While, the tests of RCHBs without shear reinforcement were reported by MacLeod et al [8].

Experimental investigation on shear behavior of reinforced self-compacted concrete tapered beams is presented in the current paper.

2 Significant of the Present Study

There are few researches about tapered reinforced concrete elements and it shear failure mechanisms is not well understood. The present study suggests a new shape of beams used commonly as a double cantilever cross head in bridges (hummer head beam), also strengthening technique by using CFRP strips to enhance the shear capacity were suggested

3 Experimental Study

3.1 Experimental program

Tests were carried out on six beams, simply supported under the effect of two points loading at the ends. Five beam specimens where tapered beams (non-prismatic shape) while, the last one was a rectangular prismatic shape. The dimensions of the tapered beams were kept constant for all tested beams. The variables were the shape of the tested beams, amount of shear reinforcement (stirrups) and strengthening by CFRP strips. For all tested beams, the span, concrete strength, and tension (flexural) reinforced bars at the top were kept constant. It may be noted that the tested beams have been designed to ensure shear failure

3.2 *Description of Beam Specimens*

The tapered specimens had an overall length of (2000mm), a width of (400mm) and a variable depth of (300mm) in the mid, then reduced linearly to be (150mm)at the tips. The prismatic beam had an overall length of (2000mm), a width of (400mm) and depth of (300mm). The amount of the top flexural reinforcement for all the tested beams was (5Ø 20mm) (ρmax = 0.0218), where ρmax is the maximum flexural reinforcement ratio according to ACI 318M-11 (used to ensure the shear failure to be take place for all tested specimens). For lower cord of the tested beams, (2 Ø10mm) had the same shape of compression cord were used. The web reinforcement (share reinforcement) consists of (Ø6mm) with different spacing, see Plate (2).

Plate 2. (a) Putting Steel Reinforcement Cage in Mold
(b) Beam Specimens Casting

The beam specimens were tested under two symmetric point loading with an overall clear span of (1800mm). To prevent load concentration (any local crushing in concrete), bearing plates under each load and above the support have been. It may be noted that, each beam was designated in a way to refer to the beam type (Tapered Beam=TP or Prismatic Beam=PB), quantity of web reinforcement (stirrups) (Without=0S, Half-minimum web reinforcement =0.5S, Minimum web reinforcement=1S) and present or absent of CFRP (Without CFRP=WC, With CFRP inclined in an angle of 45o= C45º). Therefore, for example, the beam (TB-0S-C45°) is a tapered beam specimen made without web reinforcement and strengthening by CFRP inclined in an angle of 45o.Details of the tested beams are shown in Table (1) and description of beam specimens are shown in Figures (1) to (7).

Table1. Beam Specimens Details

Beams Designation	Shape of Beam	Shear Reinforcement (Stirrups)	Strengthening By CFRP Strips
TB-0S-WC	Tapered	Without web reinforcement	Without
TB-0.5S-WC	Tapered	Half-minimum web reinforcement	Without
TB-1S-WC	Tapered	Minimum web reinforcement	Without
TB-0S-C45 °	Tapered	Without web reinforcement	With
TB-0.5S-C45°	Tapered	Half minimum web reinforcement	With
PB-0S-WC	Prismatic	Without web reinforcement	Without

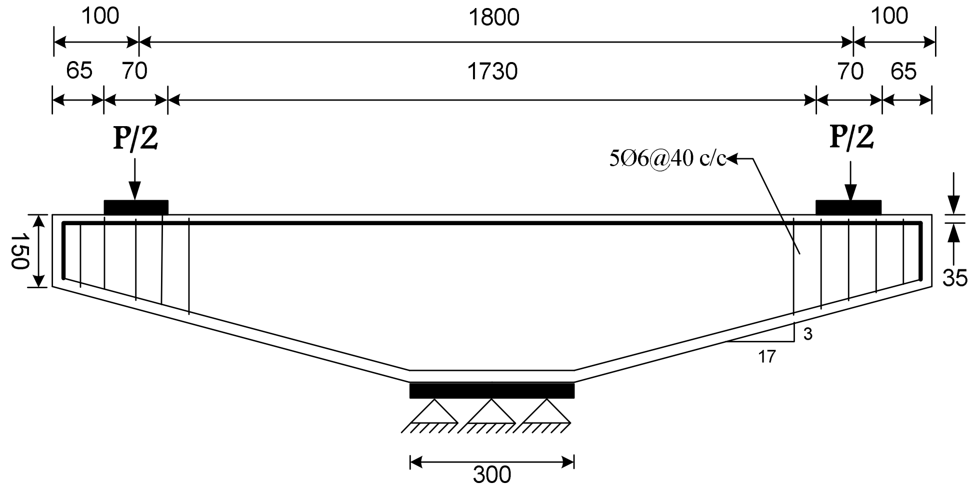

Figure 1. Details of Tapered Beam (TB-0S-WC)

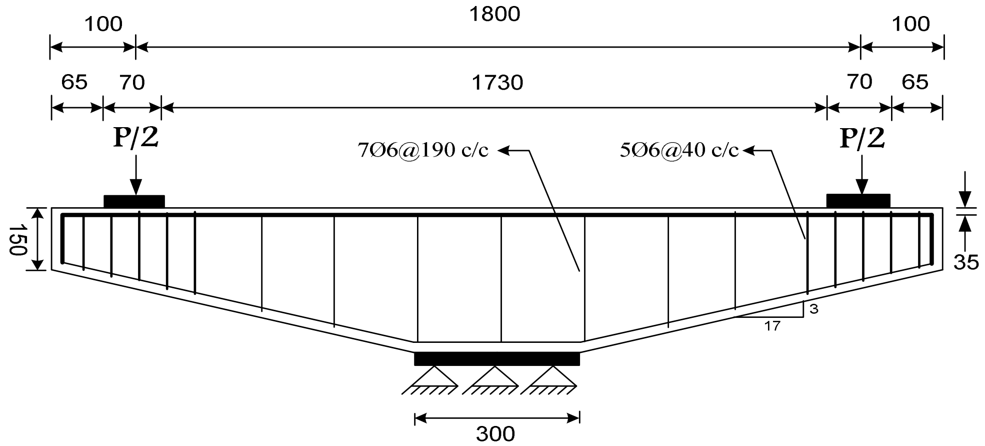

Figure 2. Details of Tapered Beam (TB-0.5S-WC)

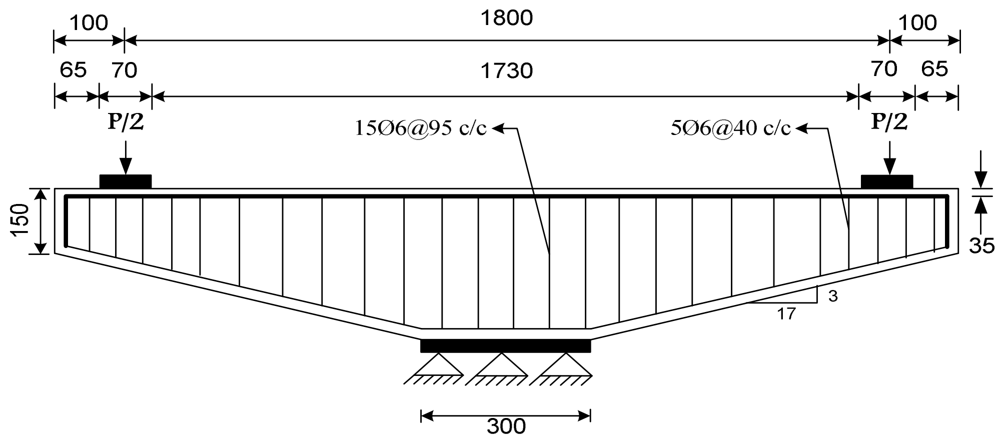

Figure 3. Details of Tapered Beam (TB-1S-WC)

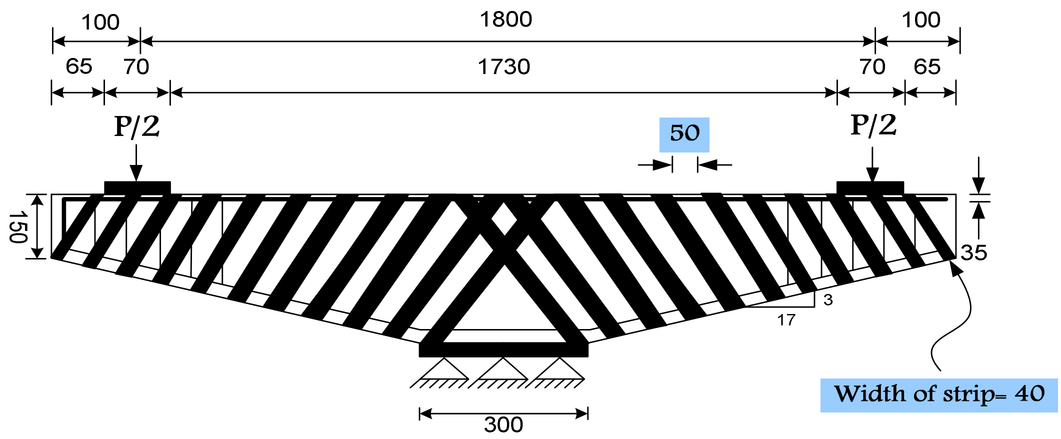

Figure 4. Details of Tapered Beam (TB-0S-C45°)

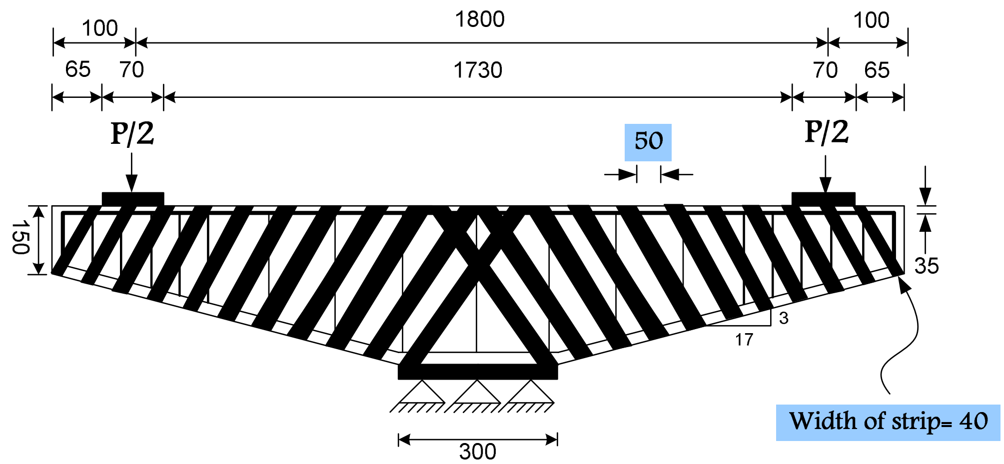

Figure 5. Details of Tapered Beam (TB-0.5S-C45°)

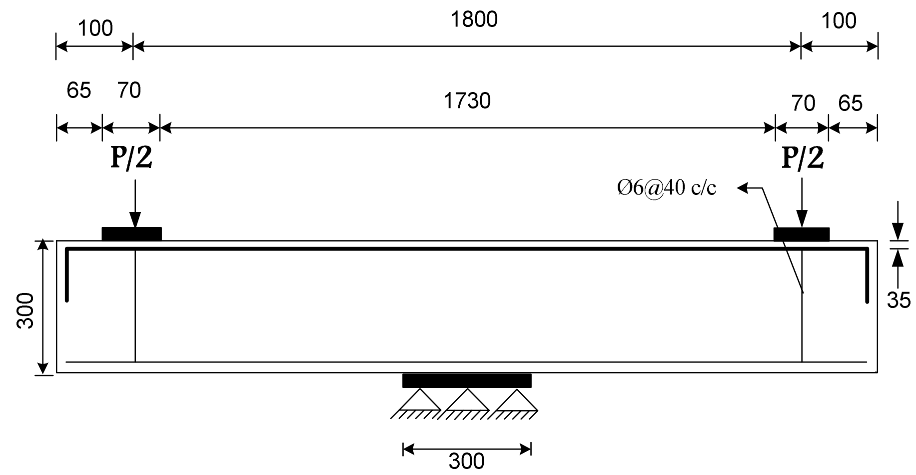

Figure 6. Details of Prismatic Beam (PB-0S-WC)

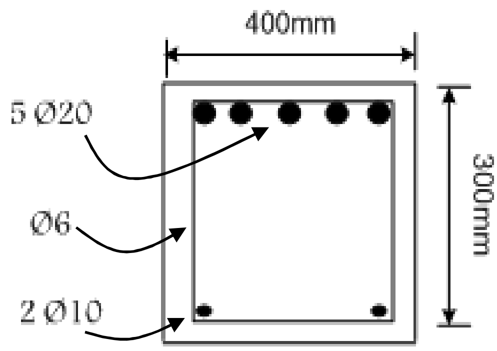

Figure 7. Cross Section at mid span
(for all beam specimens)

3.3 *Materials*

Several raw materials were used in manufacturing the test specimens; properties and description of used materials are reported and presented in Table (2); and the concrete mix proportions are reported and presented in Table (3).

Table 2. Properties of Construction Materials

Material	Descriptions
Cement	Ordinary Portland Cement (Type I)
Sand	Natural sand from Al-Ukhaider region with maximum size of (4.75mm)
Gravel	Crushed gravel of maximum size (19 mm)
L. S. P	fine limestone powder (locally named as Al-Gubra) of Jordanian origin
Super plasticizer	Glenium 51 manufactured by BASF Construction Chemicals, Jordan.
Reinforcing Bars	(ϕ20mm) deformed steel bar, having (512MPa) yield strength (fy) (ϕ10mm) deformed steel bar, having (490MPa) yield strength (fy) (ϕ6mm) deformed steel bar, having (456MPa) yield strength (fy)
Water	Clean tap water

Table 3. Proportions of Concrete Mix

Material	**Cement (kg/m^3)**	**450**
	Fine Aggregate (kg/m^3)	**797**
	Course Aggregate (kg/m^3)	**767**
	Limestone Powder* (kg/m^3)	**170**
	Water (kg/m^3)	**170**
	W/C Ratio	**0.38**
	Superplasticizer (L/m^3)**	**10**

* Limestone (LSP)(0.37% of cement)
** Super plasticizer (2.23% of cement)

3.4 *Test Procedure*

All beam specimens have been removed from curing at the age of (28 days) (except two strengthened beams were removed two days before). The beam specimens have been cleaned and paint with white paint before the testing day in order to clarify the crack propagation. Each beam specimen has been labeled and then putting in test machine so that the supports and load points in its correct location. It may be noted that, to satisfy test requirements, the beam specimens have been rotated in an angle of (180°) for more stability before and during the test as shown in Plate (3). Vertical deflection was measured at the tips of beam specimens by using a dial gauge of (0.01mm/div.) accuracy at every load stage, Plate (4). The load in test machine was applied by hydraulic pressure on the bottom side and the upper partition is only to restrain the tested specimens and stops directly after touch occurs with specimen.

All beam specimens have been tested under static loading with double concentrated load applied at the opposite tips. The dial gauges were mounted in their marked position (over the tips) to touch the surface beam in their correct locations. All beam specimens have been loaded up to failure. Each beam has been initially "exercised" by applying a small load to ensure that the test setup and the instrument worked properly. The beam specimens have been loaded in increments of (10kN), the rate of load increment was about (1.5kN/sec).The positions and extents of the first and the other consequent cracks were marked on the surface of the beam. When failure occurred, the beam failed abruptly at simultaneity with the load indicator stopped in recording or return back and the deflection increased very fast. The failure load has been recorded, and the hydraulic load has been removed.

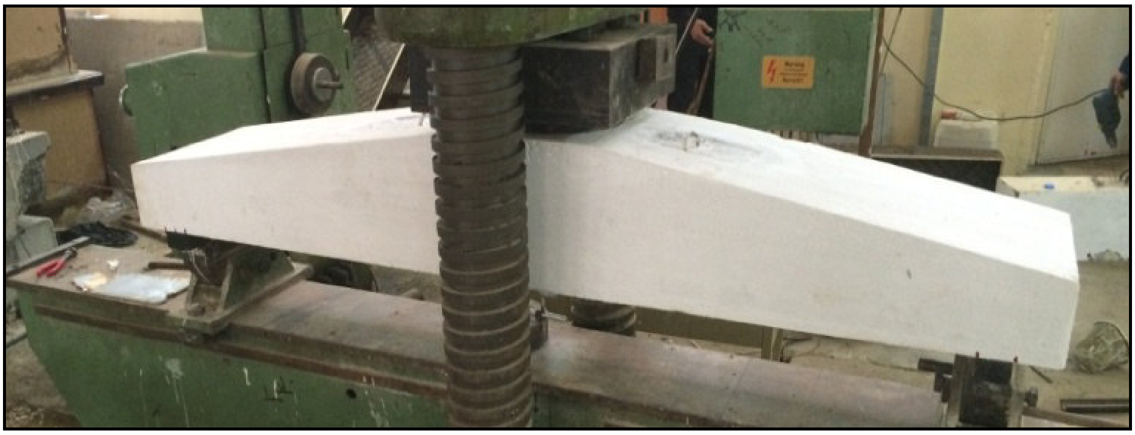

Plate 3. Test Procedure

Plate 4. Position of Dial Gauges

4 Experimental results

4.1 *Control Specimens Tests Result*

To understand the structural behavior of SCC tapered beams, one should identify the mechanical properties of hardened SCC which are used in construction (poured) of these beams. The compressive strength test has been carried out for cylinders, in accordance with ASTM C39-96[9]; while, for cubes the compressive strength test has been carried out in accordance BS 1881-116- 1983[10].The indirect tensile strength (splitting test) has been carried out according to ASTM C496 / C496M-11[11] and the flexural strength (modulus of rupture) tests have been carried out on SCC specimens in accordance with ASTM C78-75[12]. Table (4) shows test results of mechanical properties for hardened SCC obtained for each mix of beam specimens at age of (28 days).

Table 4. Properties of Hardened SCC

Beam Designation	(fcu)* (MPa)	(f'_c)* (MPa)	($f$ct)* (MPa)	(f_r)* (MPa)
TB-0S-WC	31.7	25	3.35	3.94
TB-0.5S-WC	32.1	25.6	3.52	4.07
TB-1S-WC	30.8	24.9	3.33	3.92
TB-0S-C45 º	30.4	24.2	3.13	3.67
TB-0.5SC45º	31.2	25.3	3.41	4.01
PB-0S-WC	30	24.8	3.22	3. 89

*Each Value is an Average of Three Specimens.

4.2 *Test Results of Beam Specimens*

4.2.1 *General Behavior*

At low load levels, all the tested beams behaved in an elastic manner. At this stage of loading, the beam specimen were free of cracks, deflections were small and proportional to the applied loads, consequently the stresses were small and the full cross section was capable to carrying the load. As the load increased, the first crack appears at the mid span (the region of maximum shear and bending moment); as the load was further increased, new cracks appeared. At load levels close to failure, existing cracks began to widen and propagate into the compression zone until failure took place by opening up of diagonal crack over the entire depth of the tested beams. For beam specimens(TB-0S-WC),(TB-0.5S-WC),(TB-0S-C45º)and(PB-0S-WC) failure inclined crack appeared in mid high of region diagonally bounded between load points and support then extended quickly up to failure, while for the beam specimens (TB-1S-WC) and (TB-0.5S-C45º), the failure inclined crack initiates in extreme of tension cord and extended gradually as load increased up to failure. Table (5) summarized the results of first cracking load (Pcr), ultimate load (Pu) and deflection at tips (Δ) for all tested beams together with their modes of failure.

Table 5. Test Results of Beam Specimens

No.	Beam Designation	Load (kN)		Deflection (mm)		Mode of Failure
		P_{cr}^{*}	P_{u}^{**}	Δ_{cr}^{*}	Δ_{u}^{**}	
B1	TB-0S-WC	100	322.5	1.4	6	Shear Failure
B2	TB-0.5S-WC	130	386	1.8	7.15	Shear Failure
B3	TB-1S-WC	150	430	2	8	Flexural-Shear Failure
B4	TB-0S-C45 º	140	437	1.85	7.35	Shear Failure
B5	TB-0.5S-C45º	190	485	2.75	8.65	Flexural-Shear Failure
B6	PB-0S-WC	197	287.5	2.17	4.1	Shear Failure

*At First Crack **At Ultimate Load

4.2.2 *Mode of Failure*

The failure modes of all tested beams are reported in Table (5) and shown in Plates (5) to (10). All tested beams have a similar failure mode by sudden diagonal shear failure (diagonal crack which is connects between load and support position), except the beam specimens (TB-1S-WC) and (TB-0.5S-C45º) which failed as a combine failure (flexural- shear failure). For the beam specimen (TB-1S-WC), the cracks firstly initiate in the tensile cord and significantly as the load increase another new cracks appears and propagate diagonally in the area that connects between load and support (shear span) finally the failure occur when the cracks reach to the compression tapered cord; this shape of cracks are may be due to the presence of a minimum satisfactory amount of web reinforcement that have been able to resist the applied load.

While, for the beam specimen (TB-0.5S-C45º), the cracks was initiate around the neutral axis position and extended diagonally between the load points and support and propagate in the two opposite sides towards the load and support, this pure shear failure means that the amount of web reinforced is considered inadequate and essential factor in the type of control failure where the decrease of this amount leads to decrease the resistance of beam to the applied load and accelerate the failure. Although the beam specimen (TB-0S-C45 º) is strengthened by CFRP, the mode of the failure (diagonal shear failure) dos not changed, and this means that in case of absent of stirrups, the carbon fiber strips cannot effectively effect in mode of failure but led to a marked increase in bearing capacity, resistance and increase the confidence of beams.

Plate 5. Crack Pattern for Beam Specimen (TB-0S-WC)

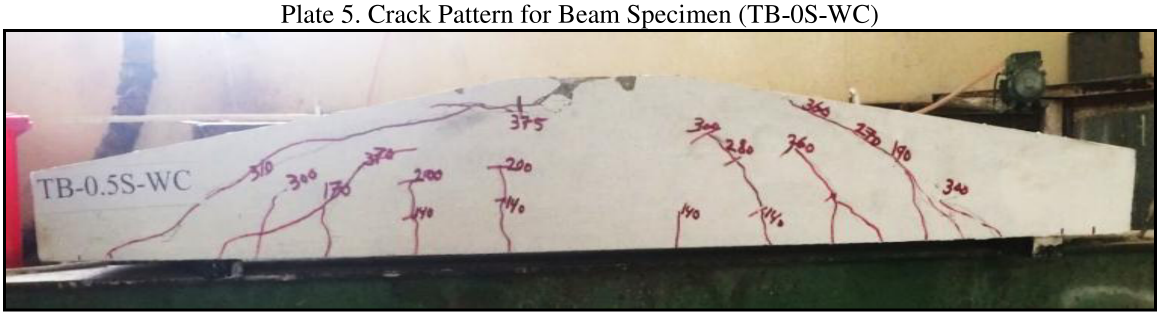

Plate 6. Crack Pattern for Beam Specimen (TB-0.5S-WC)

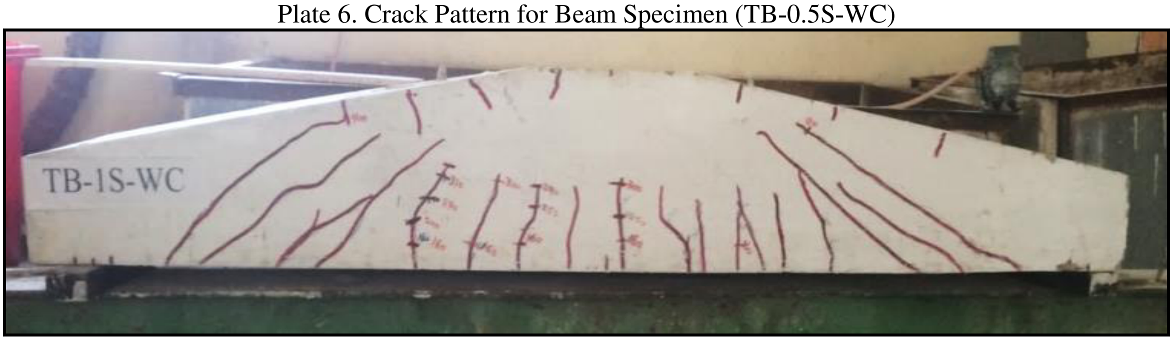

Plate 7. Crack Pattern for Beam Specimen (TB-1S-WC)

Plate 8. Crack Pattern for Beam Specimen (TB-0S-C45º)

Plate 9. Crack Pattern for Beam Specimen (TB-0.5S-C45º)

Plate 10. Crack Pattern for Beam Specimen (PB-0S-WC)

4.2.3 *Effect of Web Reinforcement*

The effect of web reinforcement on cracking and ultimate loading is shown in Table (5) and Figure (8), it can be seen that the deflection decreased as amount of the web reinforcement increased. This may be due to increase the compatibility and resistance of beams and its ability to consistently load capacity, as well as the ductility. It's interesting to notice that as the amount of web reinforcement (stirrups) increase the load capacity and deflection increase but at the same load step one can see that the stiffer beam specimen has less deflection.

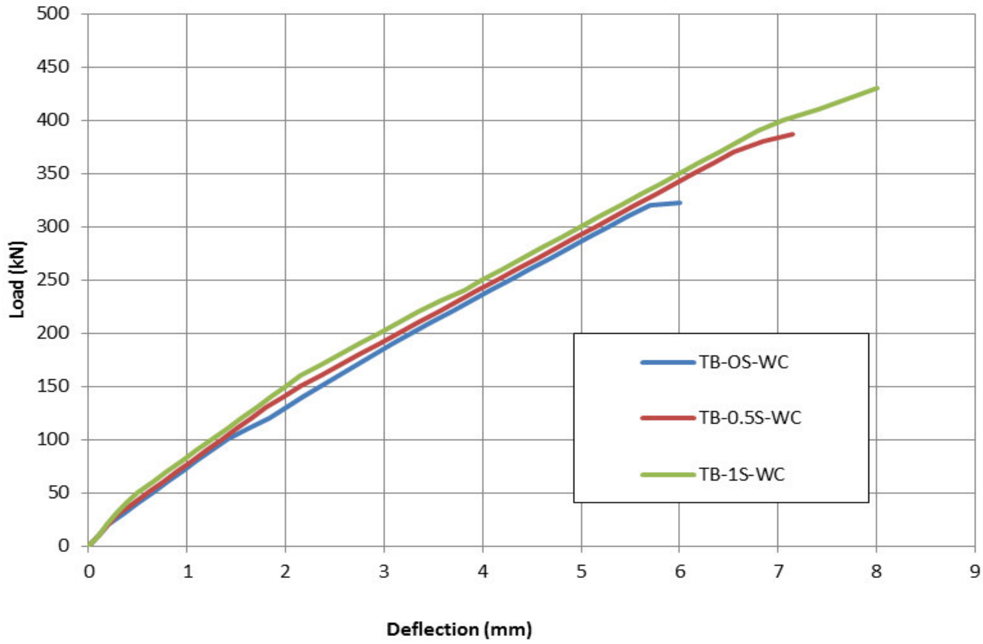

Figure 8. Load-Deflection Curves for Beam Specimens (TB-1S-WC),(TB-0.5S-WC)and(TB-0S-WC)

4.2.4 *Effect of Beam Specimens Shape*

The effect of beam specimens shape on cracking load, ultimate load and ductility are shown in Table (5) and Figure (9). The increasing in ductility of beam specimen (TB-0S-WC) was observed when comparing with the beam specimen (PB-0S-WC), despite the increase in the load of tapered beam, this was due to the difference in beams shapes in both specimens; also which affected the behavior of the specimens. The tapered beams without web reinforcement have a superior shear capacity (about12%) and more deformation response (about 46%) as compared with the prismatic one.

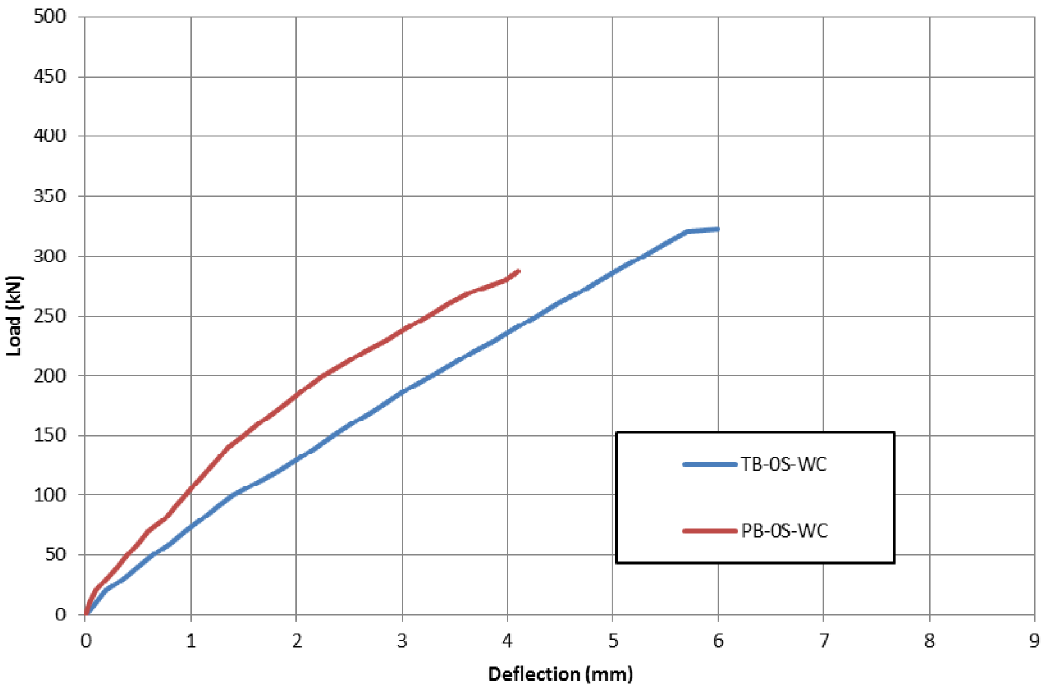

Figure 9. Load-Deflection Curves for Beam Specimens (TB-0S-WC) and (PB-0S-WC)

4.2.5 *Effect of CFRP Strengthening*

The presence of CERP with an inclined strips perpendicular to the cracks leads to improve the level of load, this effective of CFRP are shown in Table (5) and Figures (10) and (11).Strengthening by CFRP strips for tapered beams, enhance the shear capacity of such beams (about 30%) by increase the confidence of member.

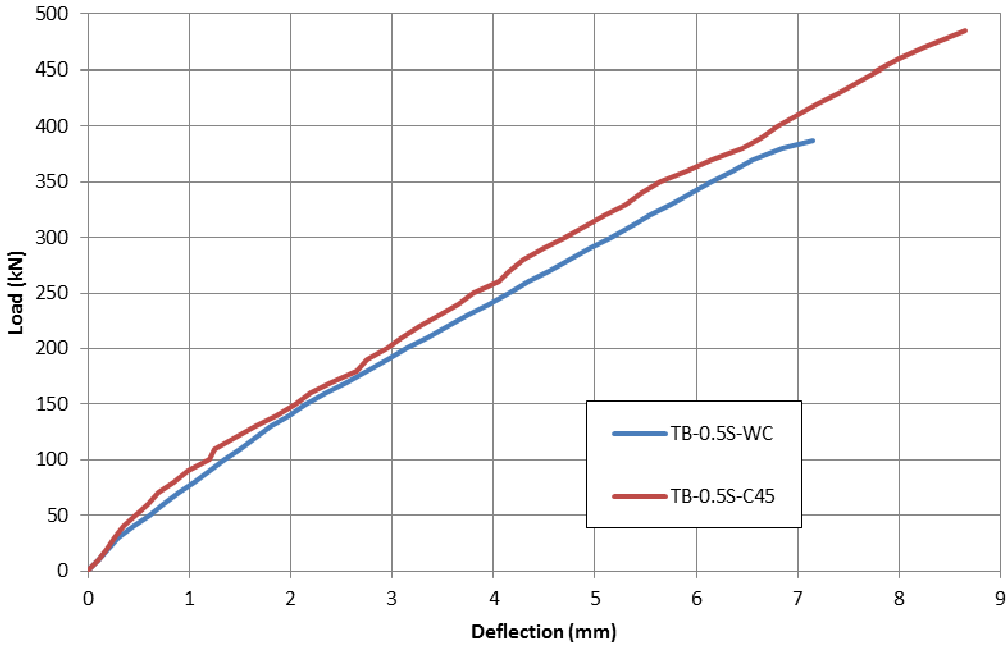

Figure 10. Load-Deflection Curves for Beam Specimens (TB-0.5S-W) and (TB-0.5S- C45°)

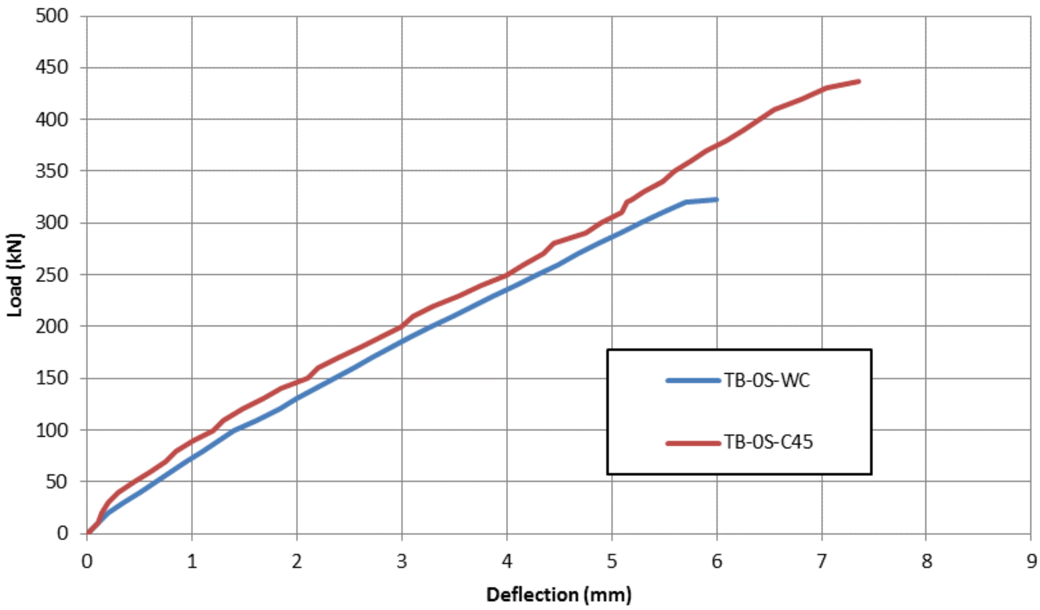

Figure 11. Load-Deflection Curves for Beam Specimens (TB-0S-WC) and (TB-0S- C45°)

5 Conclusions

Based on the results obtained from the experimental work, the following conclusions are presented:-

1- The tapered beams without web reinforcement have a superior shear capacity (about12%) and more deformation response (about 46%) as compared with the prismatic one.
2- The tapered beams develop an arch mechanism which allows the damage to be distributed in terms of several fissures along the tapered length before the main diagonal crack grows, then causing a failure mechanism that is less brutality than the same sudden shear failure observed in prismatic beam.
3- Strengthening by CFRP strips for tapered beams, enhance the shear capacity of such beams (about 30%) by increase the confidence of member.

4- As the web reinforcement increase in tapered beams, the ultimate shear capacity and maximum deflection increase. The increment ratio of load capacity for tapered beam with half-minimum, and minimum web reinforcement according to ACI-318 Code for prismatic beam was (20%) and (33%) respectively as compared with tapered beam without web reinforcement, and this load capacity increment is associated with an increment in deformation response for about (18.3%) and (33%) respectively.

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