Experimental Study of the Shear Behavior of Self Compacted Concrete T-Beams

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Abstract

Twelve self compacted concrete (SCC) T-section beams were design and tested to determine the effect of using SCC on the shear behavior under two concentrated loads. All beams have the same longitudinal steel ratio of (0.018823) and gross section area of (20000) mm^2. The tested beams were divided into two groups- with and without stirrups. The first group consists of three beams without stirrup and with different values of compressive strength (f'_c).While the second group consists of nine beams with stirrups. It were divided into three series according to the compressive strength (f'_c) each series have three beams with different value of clear span to effective depth ratio (ln/d). It was found that The ultimate shear strength predicated from ACI 318M-08 is conservative prediction than the experimental values, The clear span to the effective depth ratio (ln/d) has a significant influences on the ultimate shear strength, The ultimate shear strength of SCC T-beams with stirrups increased about 28.57%.10.714%and 10.169%; when the compressive strength (f'_c) increased from (29.36 to 49.2 MPa), the ultimate shear strength of SCC T-beams without stirrups increased about 55.55%; when the compressive strength (f'_c) increased from (29.36 to 49.2 MPa).

Keywords: shear strength, T-reinforced concrete beams, with and without stirrups, self compacted concrete

الخلاصة

اثنتا عشر عتبة خرسانية ذات مقطع (T) ذاتية الرص صممت وفحصت تحت حملين مركزين .تحوي جميع العتبات على نسبة حديد واحدة وهي(٠.٠١٨٨٢٣) ومساحة المقطع العرضي هي(٢٠٠٠٠) ملم٢ . قسمت العتبات المفحوصة إلى مجموعتين مجموعة مسلحة بحديد تسليح القص (الأطواق) والأخرى غير مسلحة بحديد تسليح القص(الأطواق). تحوي المجموعة الأولى على ثلاثة عتبات خرسانية ذاتية الرص بدون حديد تسليح القص(الأطواق) بمقاومة انضغاط مختلفة، بينما تحوي المجموعة الأخرى على تسعة عتبات خرسانية ذاتية الرص قسمت إلى ثلاثة متواليات حسب مقاومة الانضغاط كل متوالية تحوي على ثلاثة عتبات بنسب مختلفة من الطول الصافي إلى العمق الفعال.وجد خلال

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نتائج الفحص إن مقاومة القص القصوى المستحصلة باستخدام معادلة المدونة الأمريكية (318M-08) متحفظة مقارنة مع النتائج المستحصلة من الجانب العملي وان نسبة الطول الصافي إلى العمق الفعال ذات تأثير مهم على مقاومة القص القصوى وان مقاومة القص القصوى للعتبات الخرسانية المسلحة والحاوية على حديد تسليح القص (الأطواق) تزداد عند زيادة مقاومة الانضغاط حيث إن مقاومة القص القصوى تزداد بمقدار ٢٨.٥٧% و ١٠.٧١٤ % و ١٠.١٦٩% عند زيادة مقاومة الانضغاط من ٢٩.٣٦ إلى ٤٩.٢ نت/ملم٢ بينما مقاومة القص القصوى للعتبات الخرسانية الغير حاوية على تسليح القص (الأطواق) تزداد بمقدار(٥٥.٥٥%) عندما تزداد مقاومة الانضغاط للخرسانة من ٢٩.٣٦ إلى ٤٩.٢ نت/ملم٢.

1. introduction

Self Compacted concrete (SCC), is a new kind of high performance concrete (HPC) with very effective deformability and segregation resistance. The main advantage of SCC is; a flowing concrete without segregation and bleeding, capable of filling spaces in dense reinforcement or inaccessible voids without hindrance or blockage. The composition of SCC should be designed in order not to separate and not to excessively bleed. Concrete strength development is determined not only by the water-to-cement ratio, but also by the content and specification of mix materials. [1]

2. Research significance

Concrete has been used in the construction industry for centuries. Many modification and developments have been made to improve the performance of concrete, especially in term of strength and workability. Engineers have found new technology of concrete called self compacted concrete. The main objective of the work described in this study is to investigate and to get more information and more understanding about the behavior of shear strength of self compacted concrete T-beams.

3. Tested program

3.1 Description of specimens:

The tested T-beams were divided into three group according to the overall length1000, 1080 and 1140 mm long. The T-section has overall dimensions of 220 mm (width of flange) by 200 mm (total depth). The thickness of web is (60) mm and the thickness of flange is (50) mm. The longitudinal deformed steel reinforcement consist of four bars of 8 mm diameter laid in two layer at the bottom and four plane bars of 4 mm diameter laid in one layer at the top. The internal steel stirrups are 4 mm in diameter spaced of 89 mm center to center as shown in Fig.(1), and the total description of the beams which used in this study are listed in Table (1).

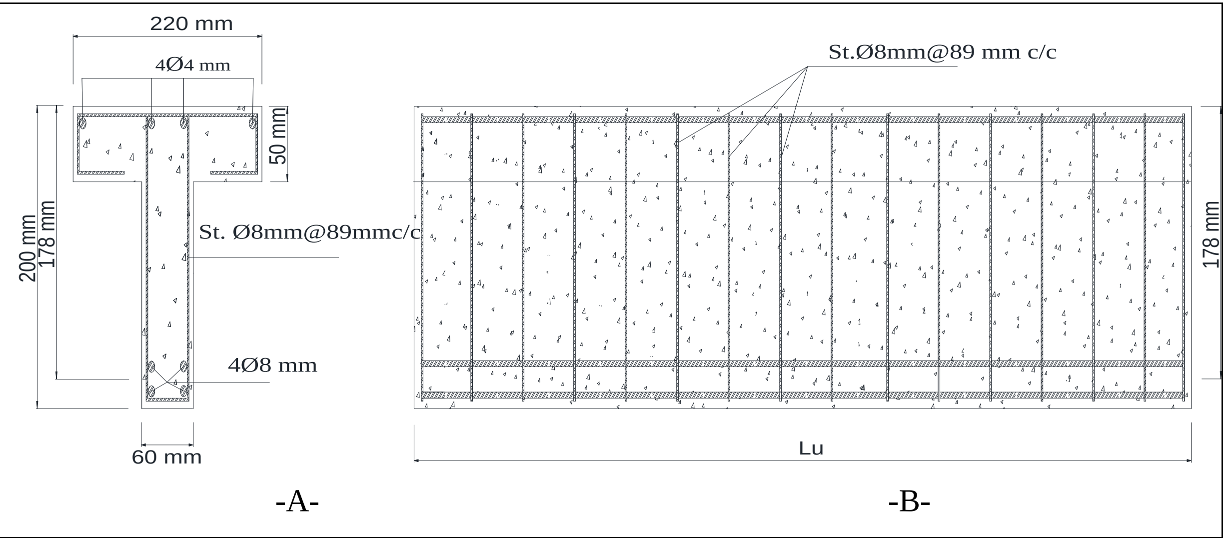

Fig. (1) Details of specimens all dimensions in mm: (A) cross-section; (B) Elevation

Table (1): Total description of the tested beams

Group	Beam	Comp. strength (f'_c) MPa	Clear span (ln) mm	Effective depth (d) mm	Clear span to effective depth ratio (ln/d)
Beams without stirrups	A10	29.39	1040	178	5.84
	B10	41.4	1040	178	5.84
	C10	49.2	1040	178	5.84
Beams with stirrups	A11	29.39	1040	178	5.84
	A12	29.39	980	178	5.5
	A13	29.39	900	178	5.05
	B11	41.4	1040	178	5.84
	B12	41.4	980	178	5.5
	B13	41.4	900	178	5.05
	C11	49.2	1040	178	5.84
	C12	49.2	980	178	5.5
	C13	49.2	900	178	5.05

3.2 Materials:

General description and specification of materials used in the tested beams are listed below; tests are made in the National Center For Constriction Laboratories and Research

- Cement: Ordinary Portland cement type I produced at northern cement factory (Tasluja-Bazian) is used throughout this investigation which conforms to the Iraqi specification No. 5/1984[2], Tables (2) and (3) show the chemical and physical properties of the used cement.
- Fine Aggregate: Al-Ukhaider natural sand is used. This complies with the Iraqi Standard Specification No.45/1984,[3] zone (2).The specific gravity, sulfate contents($SO_{3)}$ and absorption of the used sand were 2.66,0.4%,1.7% respectively.
- Coarse Aggregate: Crushed gravels maximum size 10 mm from Al-Nibaee area are used in this study. This complies with the Iraqi Standard Specification No.45/1984,[3] The specific gravity, sulfate contents($SO_{3)}$ and absorption of the used gravel were 2.65,0.07%,0.57% respectively.
- Water: Ordinary potable water is used throughout this work for both mixing and curing of concrete.
- Steel Reinforcement: Deformed longitudinal steel bars with nominal diameter of 8mm and 4mm were used in this study. Reinforcement were tested to determine the yield stress of 8mm and 4mm they were 400 and 350 MPa receptively
- Limestone Powder: A fine limestone powder (locally named as Al-Gubra) of northern origin with fineness (3100 cm^2/ gm) it has been used as a filler for concrete production for many years. It has been found to increase workability and early strength, as well as to reduce the required compaction energy. The increased strength is found particularly when the powder is finer than the Portland cement [4]. The cement in SCC mixes is generally partially replaced by fillers like lime stone powder in order to improve certain properties such as;
- Avoiding excessive heat generation.
- Enhancing fluidity and cohesiveness.
- Enhancing segregation resistance.
- Increasing the amount of powder (cement +filler), so it becomes more economical than using cement alone.
- Superplasticizer [5]: To produce SCC, a superplasticizer known as (High Water Reducing Agent) based on polycarboxylic ether is used; it has the trade mark Glenium 51. Glenium 51 is free from chlorides and complies with ASTM C494, types A and F. It is compatible with all Portland cements that meet recognized international standards. Table (4) shows

the typical properties of Glenium 51.

Table (2): Chemical Composition of Cement

Compound Composition	Chemical Composition	Percent	Limit of Iraqi specification No.5/1984 [2]
Lime	CaO	61.67	-
Silica	SiO2	20.69	-
Alumina	Al2 O3	5.20	-
Iron Oxide	Fe2 O3	4.61	-
Magnesia	MgO	2.43	< 5
Sulfate	SO3	2.21	< 2.8
Loss on Ignition	L.O.I.	3.31	< 4
Insoluble Residue	I.R.	0.5	< 1.5
Lime Saturation Factor	L.S.F	0.90	0.66 – 1.02
Main Compounds (Bogue's Equation) Percentage by Weight of Cement			
Tricalcium Silicate	C3S	38.55	
Dicalcium Silicate	C2S	33.15	
Tricalcium Aluminate	C3A	7.12	
Tetracalcium Alumina Ferrite	C4AF	10.73	

Table (3): Physical Properties of the Cement Used in this Work

Physical properties	Test Results	Limit of Iraqi specification No. 5/1984[2]
Specific Surface area (Blaine Method , cm^2/gm)	3043	≥ 2300.0
Setting time (Vicats Method) Initial Setting time, hrs. : min Final Setting time, hrs. : min	 174 3:54	 45 min> ≤ 10:00 hr
Compressive strength of mortar 2 days (MPa) 7 days (MPa)	 21.61 30.75	 ≥ 15 ≥ 23

Table (4): Typical properties of Glenium 51 [5]

No.	Main action	Concrete super plasticizer
1	Color	Light brown
2	pH. Value	6.6
3	Form	Viscous liquid
4	Subsidiary effect	Hardening
5	Relative density	1.1 at 20°C
6	Viscosity	128 ± 30 cps at 20°C
7	Transport	Not classified as dangerous
8	Labeling	No hazard label required

3.2.3 Mix Design for Self- Compacted Concrete

Mix proportioning is more critical for SCC than for NSC and HSC. Many trials are carried out on mixes incorporating superplasticizer by increasing the dosage of the admixture gradually, adjusting the w/c ratio to ensure the self compact ability[6]. Table (5) indicates the mix proportion of SCC mixes. For each concrete mix, three standard cube specimens (150×150×150) mm are taken, they were tested at 28 days of age, the test result of fresh concrete properties are shown in Table (6) these results are within the acceptable criteria for SCC given by ACI committee-363 [7] and indicate excellent deformability without blocking .

Table (5): mix design of SCC mixes by weight

Group	comp. strength of cylinder (f'_c) MPa	W/C Ratio	Mix proportions kg/m^3					lit /m^3	
			Cement	Limestone powder(lsp)	Total powder	Sand	Gravel	Water	Glenium 51
A	29.63	0.55	346	204	550	743	833	190	6.6
B	41.42	0.55	474	105.3	357.3	758.4	833	180	8.1
C	49.2	0.38	535	64	599	814	833	155	18

Table (6): Results of testing fresh SCC property in experimental work

Mix symbol	Slump flow (mm)	T50 Sec.	L-box (H2/H1)	T20 Sec.	T40 Sec.
A	750	2.6	0.96	1.8	3.5
B	715	3.8	0.90	2.1	3.9
C	685	4.9	0.88	2.3	4.2

Acceptance criteria for Self-compacted concrete (SCC) [8]

NO.	Method	Unit	Typical range of values	
			Minimum	Maximum
1	Slump flow	mm	650	800
2	T50	Sec	2	5
3	L-Box	(H2/H1)	0.8	1

4.Test procedure of T-beams

All the beams were white washed in order to aid the observation of the crack development during the testing. Beams were tested under gradually increasing load up to failure under two point symmetric top loading in universal-Testing machine (MFL systems) at the structural laboratory of the college of the engineering , Al-Mustansiriya university as shown in Fig.(2) ,the tested beams were simply supported at ends over an effective span of (50 mm) the distance between the two point loads at the third of the clear span length. A dial gauge of (0.01 mm) accuracy with (30 mm) capacity was fixed at the middle of the bottom of the beam to measure the mid span deflection, the test set-up is shown in Fig. (٣). Loading procedure was started by the application of single point load from the testing machine to the upper midpoint of the loading bridge . The single load was then divided equally between the two point loads that were transferred to the concrete beam through two (Φ 30 mm) steel bars loaded at the end of the bridge. Beam specimens were placed at the testing machine and adjusted so that the centerline, supports, point loads and dial gauge was fixed at the correct and proper location. Loading was applied in small increments of (4 KN).At each load stage the deflection readings at the mid span was recorded. The loading increments were applied until failure.

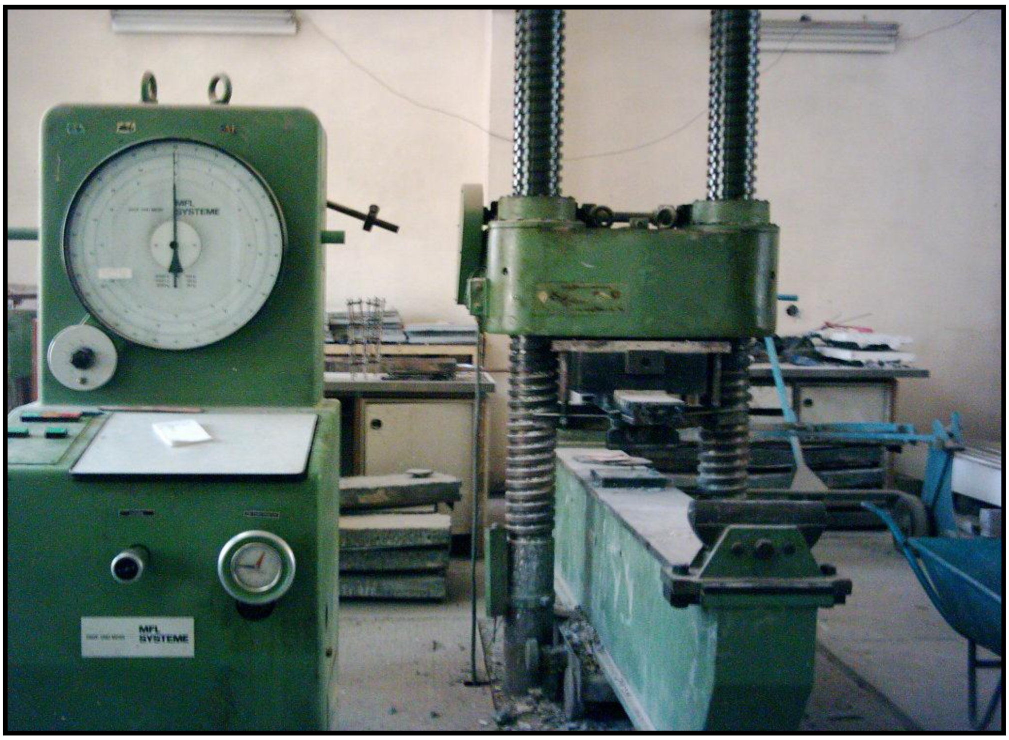

Fig. (2) Tested Machine

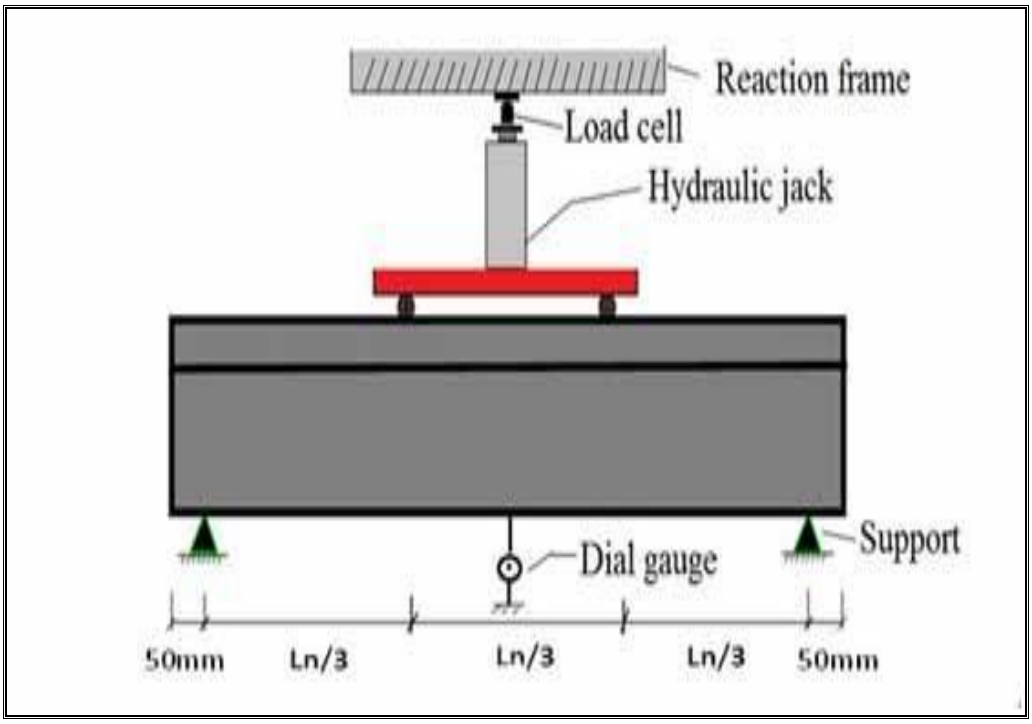

Fig. (3) Schematic diagram of test set-up

5. Shear strength of beam in Code provisions:

ACI 318M-08 estimates the nominal shear capacity (V_n) of beam as follows [9]:

$$V_n = V_c + V_s \qquad \text{.....................} (1)$$

$$V_c = \frac{\sqrt{f'_c}}{6} b_w \ d \qquad \text{....................} (2)$$

$$V_c = (\sqrt{f'_c} \ + 120\ell wV_u d/M_u)b_w d/7 \qquad \text{.......................} (3)$$

$$V_s = Av \ f_y \ d / S \qquad \text{......................} (4)$$

Where:-

V_c and V_s are shear transfer capacity of concrete and shear reinforcement respectively; Mu and Vud are factored moment and shear force; ℓ_w = As/b_wd is the longitudinal bottom reinforcement ratio; As is the longitudinal bottom reinforcement area; b_w is the width of the web; d is the effective depth; A_v is the vertical shear reinforcement area, S is the spacing between the vertical stirrups reinforcement; f'_c is the compressive strength of concrete and f_y the yield strength of shear reinforcement According to clear span to effective depth ratio (ln/d) the main variable in this research , Eq.(3) will be used since the shear stress at cracking will depend on the bending moment and shear force at critical section ratio (Vud/Mu)and the longitudinal steel ratio (ℓ_w) that lead to reduced the shear crack and improved the ultimate strength.

6. Results

6.1 Carrying capacity of the tested beams- Load

The relationship between the applied load and the deflection for the tested beams is shown in Fig.(4) to Fig.(7). At every stage of loading, the deflection at mid-span is obtained by using dial gage at mid span, it can be noticed that:

- During the early stage of loading no interface slip is recorded and this continue until the applied loading is equal to first crack loading approximately, Beyond the first crack loading each beam has behaved in a certain manner.
- The ultimate shear strength obtained from tested of SCC T-beams were compared with that obtained by using the ACI code provisions see Table (7), by the inspection of this table it can be noted that the ultimate shear strength predicated from ACI 318M-08 is conservative in comparison with experimental values because of the SCC will improved

durability, and increased bond strength [10].

- The ultimate shear strength of SCC T-beams with stirrups increased when the compressive strength of the SCC increased as shown Fig.(8). The ultimate shear strength increase about 28.57%.10.714%and 10.169% when the compressive strength increased from (29.36 to 49.2 MPa) at clear span to effective ratio (ln/d) 5.84, 5.5 and 5.05 respectively see Table (8) .
- The ultimate strength of SCC T-beams without stirrups increased when the compressive strength of the SCC increased as shown in Fig.(9), the ultimate shear strength increased about 55.55% when the compressive strength increased from (29.36 to 49.2 MPa).
- The clear span to the effective depth ratio (ln/d) has a significant influences on the ultimate shear strength as shown in Fig (10), the ultimate shear strength of SCC T-beams increased about 40.47%,35.789%and 20.37% when the clear span to the effective depth (ln/d) decreased from (5.84 to 5.05) at compressive strength (fc) 29.36, 41.42 and 49.2 MPa respectively as shown in Table (9)
- The ultimate shear strength of SCC T-beams with stirrups is greater than SCC T-beams without stirrups as shown in Fig.(١1),the ultimate shear strength of SCC T-beams with stirrups increased about 133.3%, 97.916% and 92.857% as compared with ultimate shear strength without stirrups at compressive strength 29.36,41.42 and 49.2 MPa respectively, as shown in Table (10).

6.2 Failure mode

As was expected, all the tested beams failed in shear as shown in Fig. (12), the diagonal cracks form independently. The beams remain stable after such cracking. Further increase in shear force causes the diagonal crack to penetrate into the compression zone at the loading point, until eventually crushing failure of concrete occurs there [11].

Table (7) comparisons of tested results

Beam	Ultimate shear strength (V_u kN)tested	Nominal shear strength (V_n kN) ACI	V_u tested/V_n ACI ratio
A10	18.0	11.7	1.5
A11	42.0	29.3	1.4
A12	56.0	29.3	1.9
A13	59.0	29.3	2.0
B10	24.0	13.3	1.8
B11	47.5	30.9	1.5
B12	60.0	30.9	1.9
B13	64.5	30.9	2.0
C10	28.0	14.1	1.9
C11	54.0	31.7	1.7
C12	62.0	31.7	1.9
C13	65.0	31.7	2.0

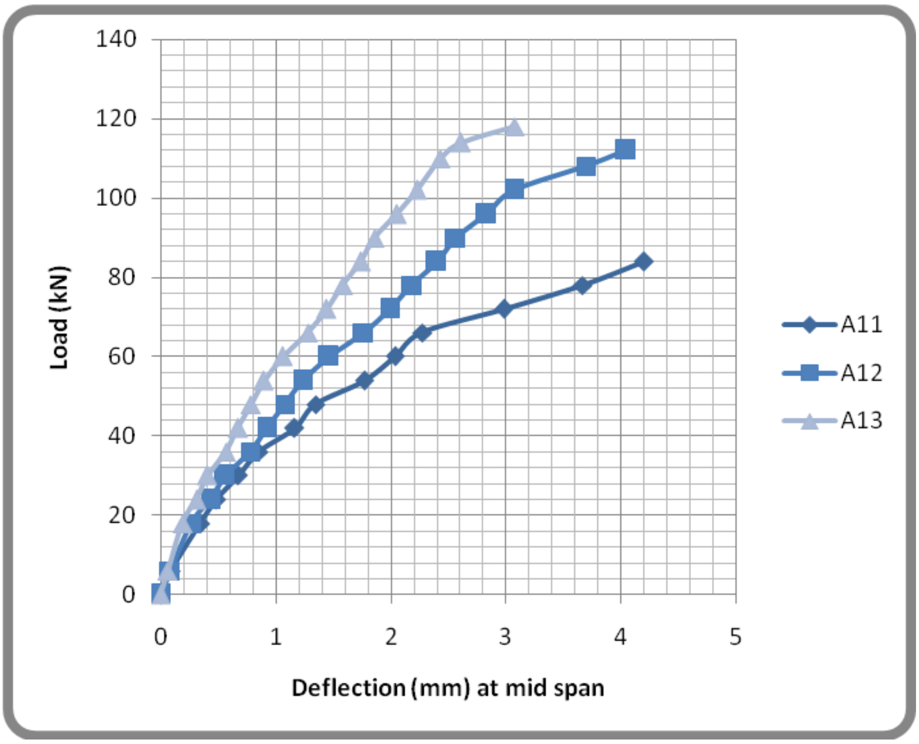

Fig.(4) load –deflection curve for SCC T-beams with stirrups of 29.36 MPa (f'_c)

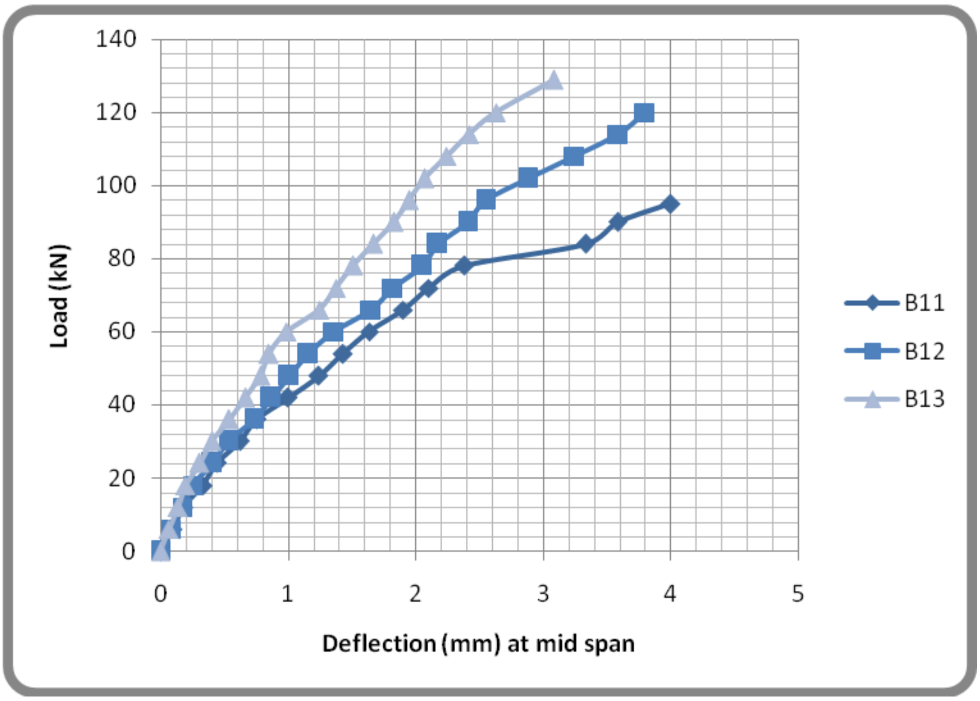

Fig.(5) load –deflection curve for SCC T-beams with stirrups of 41.42 MPa (f'_c)

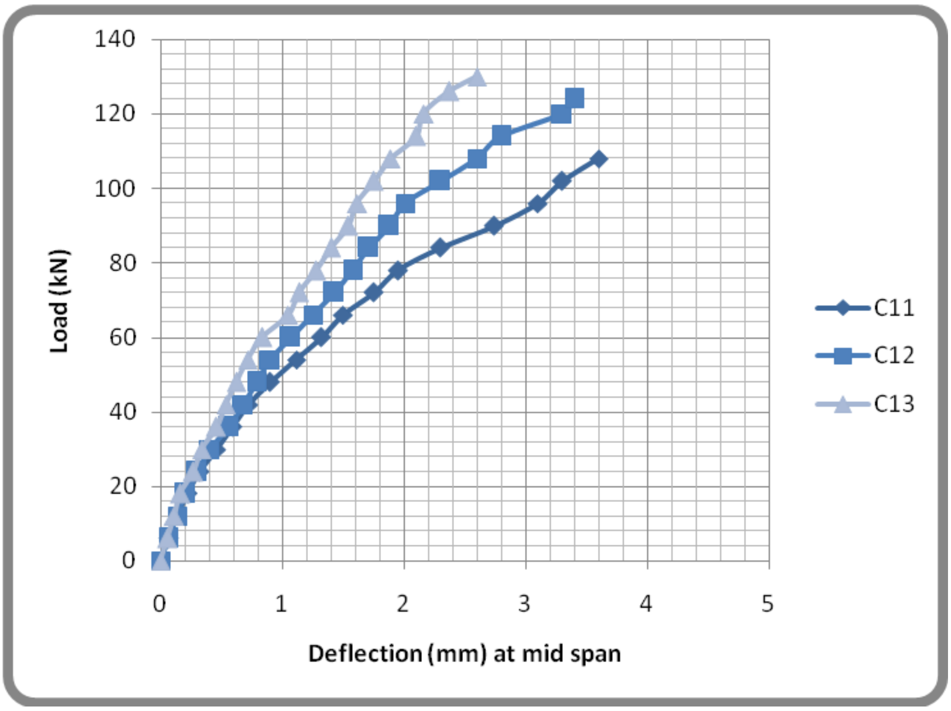

Fig.(6) load –deflection curve for SCC T-beams with stirrups of 49.2 MPa (f'_c).

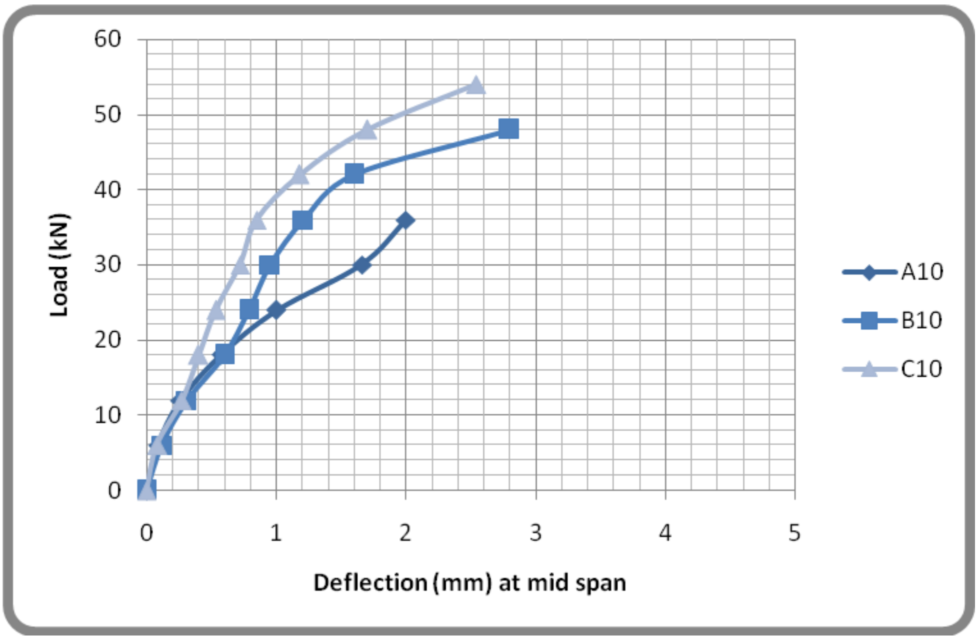

Fig.(7) load –deflection curve for SCC T-beams without stirrups at clear span to effective depth ratio (ln/d)=5.84.

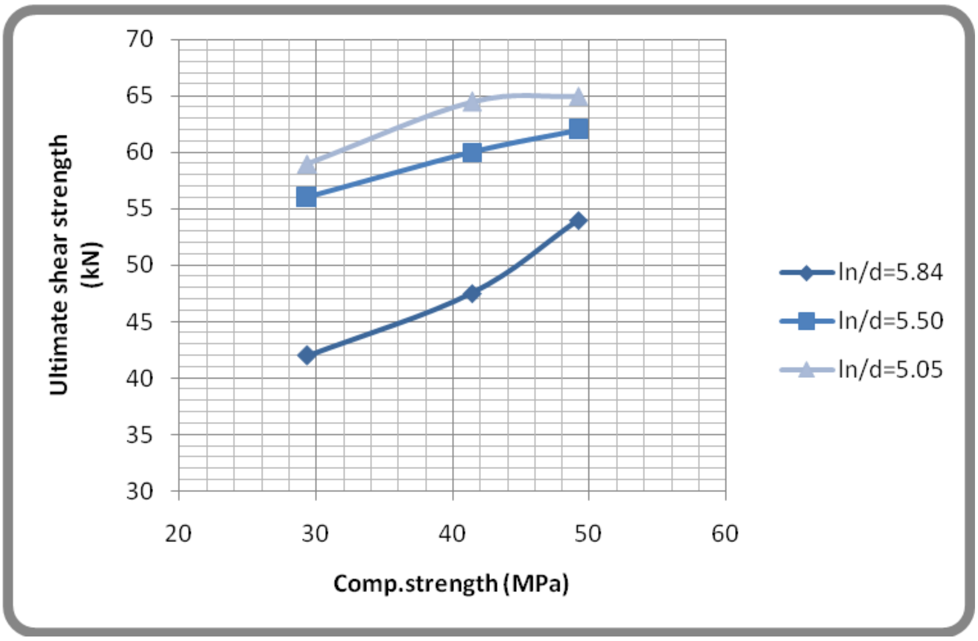

Fig.(8) effect of compressive strength (f'_c) for SCC T-beams with stirrups on the ultimate shear strength.

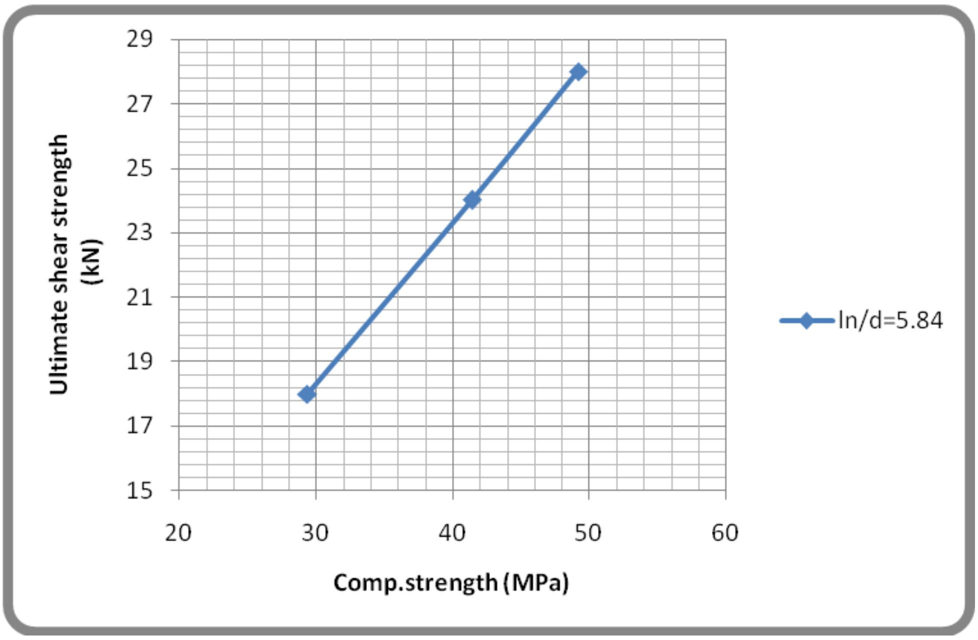

Fig.(9) effect of compressive strength (f'_c) for SCC T-beams without stirrups on the ultimate shear strength.

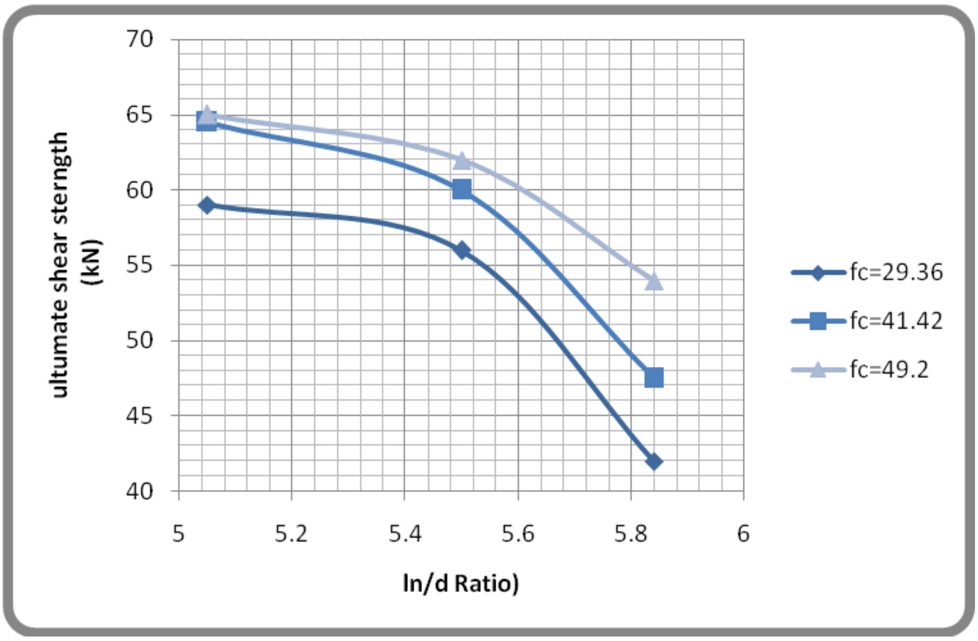

Fig.(10) effect of clear span to the effective depth ratio(ln/d) on the ultimate shear strength.

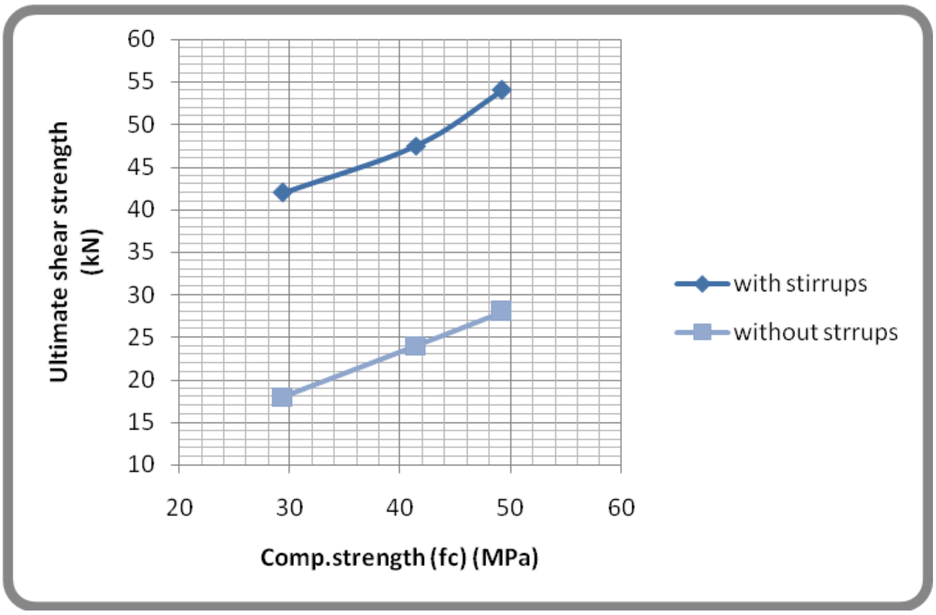

Fig.(11) effect of absence of stirrups on the ultimate shear strength.

Table (8) effect of compressive strength (f'_c) on the percentage increased in the ultimate shear strength

Group	Clear span to effective depth ratio (ln/d)	Compressive strength (f'_c) MPa	Ultimate shear capacity (Vu)kN	Percentage of increased %
Without stirrups	5.84	29.36	18	-------
		41.42	24	33.33
		49.2	28	55.55
With stirrups	5.84	29.36	42	-------
		41.42	47.5	13.09
		49.2	54	28.57
	5.5	29.36	56	-------
		41.42	60	7.142
		49.2	62	10.714
	5.05	29.36	59	-------
		41.42	64.5	9.322
		49.2	65	10.196

Table (9) effect of clear span to effective depth ratio (ln/d) on the percentage increased in the ultimate shear strength.

Group	Compressive strength (f'_c) MPa	Clear span to effective depth ratio (ln/d)	Ultimate shear capacity (Vu)kN	Percentage of increased %
With stirrups	29.36	5.84	42	-------
		5.5	56	33.33
		5.05	59	40.47
	41.42	5.84	47.5	-------
		5.5	60	26.315
		5.05	64.5	35.789
	49.2	5.84	54	-------
		5.5	62	14.814
		5.05	65	20.37

Table (10) effect of absence of stirrups on the percentage increased in the ultimate shear strength

Beams	Compressive strength (f'_c)MPa	Ultimate shear capacity (Vu)kN	Percentage of increased %
A10	29.36	18	-------
A11	29.36	42	133.33
B10	41.42	24	-------
B11	41.42	47.5	97.916
C10	49.2	28	-------
C11	49.2	54	92.857

6 . Conclusions

Based on the tested results of this experimental investigation for evaluation of shear strength of SCC T-beams, the following conclusions are drawn:

- The ultimate shear strength predicated from ACI 318M-08 is conservative prediction than the experimental values for the SCC T-beams.
- The clear span to the effective depth ratio (ln/d) has a significant influences on the ultimate shear strength, the ultimate shear strength of SCC T-beams increased about 40.47%,35.789%and 20.37% when the clear span to the effective depth (ln/d) decreased from (5.84 to 5.05) at compressive strength (f'_c) 29.36, 41.42 and 49.2 MPa respectively .

- The ultimate shear strength of SCC T-beams with stirrups increased when the compressive strength (f'_c) of the SCC increased, The ultimate shear strength increase about 28.57%.10.714%and 10.169% when the compressive strength(f'_c) increased from (29.36 to 49.2 MPa) at clear span to effective ratio (ln/d) 5.84, 5.5 and 5.05 respectively.
- The ultimate shear strength of SCC T-beams without stirrups increased when the compressive strength(f'_c) increased, the ultimate shear strength increased about 55.55% when the compressive strength (f'_c) increased from 29.36 to 49.2 MPa.
- The ultimate shear strength of SCC T-beams with stirrups is greater than SCC T-beams without stirrups, the ultimate shear strength of SCC T-beams with stirrups increased about 133.3%, 97.916% and 92.857% as compared with ultimate shear strength without stirrups at compressive strength (f'_c) 29.36,41.42 and 49.2 MPa respectively.

Fig (12) crack pattern of SCC T-beams

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