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Effect of Stirrups Shaped on Shear Capacity of Self-Compacting Concrete Beams Provided by External Steel Plate

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ABSTRACT

The stirrups are the major factor which resists the shear forces and others parameters like as aggregate and dowels are contribute with less than 7% of shear strength. Shear connectors transmit the shear forces in composite beams between steel parts and concrete, therefore these connectors can be used as vertical legs to assistance stirrups in their performance.

It was also noted that the change in the Shape of the stirrups does not have a significant effect on the shear capacity, and the decrease in endurance can be compensated by reducing the distance between the stirrups, and it was also noted that the horizontal parts of the stirrups may have a limited and negligible effect, and therefore the stirrups can be replaced by I shaped instead of conventional stirrups therefore the stirrups can be replaced by I shaped instead of conventional stirrup.

1. Introduction

When two or more dissimilar materials (having different moduli of elasticity) are joined together, a new member is formed from them known as the composite member, this composite member having better properties than each material individually. However, the original materials should be constructed with equivalent materials in order to take advantage of their properties to resist the external loads [1,2,3]. Self-Consolidating or Self-Compacting Concrete (SCC) is a highly flowable, deformable, non-segregating concrete that spreads and fills in the formwork under its own weight. For the construction of composite member, the shear connectors that connected the materials as the steel beam and concrete

slab are important. Shear connectors play a vital role in seismic response of the composite structure by provide the shear connection that is necessary for composite action in flexure, and they distribute [4], as shown in Figure (1). concrete. If this is unavailable, normal sand can be used. Some replacements like silica fume, blast furnace slag and fly ash can also be used for this concrete-making [6]. Flexible concrete requires higher workability, which hence demands superplasticizers. Some superplasticizers used for flexible concrete are Lignin, Naphthalene, Melamine formaldehyde, Sulphonate, Polycarboxylate ether, and Lignosulfonates [7,8]. An engineered cementitious composite (ECC) is a key to intruding the new type of concrete, which can

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resist more applied load before cracking and behave as ductile material; this behaviour will help to resist more applied load before failure and give more causer before the collapse. This

section briefly reviews the experimental studies investigating self-compacting bendable concrete SECC behaviour. Qian et al. 2010 [9]

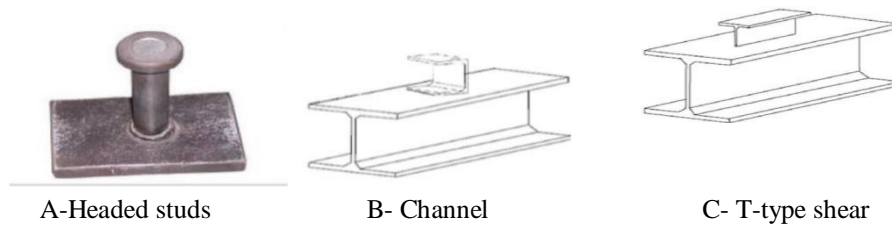


Figure (1): Types of shear connector [4].

Srinivasa Rao et,al 1996 [30] studied 20 cantilever beams with 300 mm 300 mm cross sections and 0.82 m height under cyclic and monotonic loads applied 0.66 m from the cantilever base. Including inclined bolted, inclined welded, rectangular, and single leg lacing. They utilized standard concrete with and without steel fibers. Inclinator lacing offered the best response, regardless of whether the concrete contained steel fibers. The lacing reinforcing system can secure ductile failure even under strong cyclic shear. The usage of lacing bars as shear reinforcement in reinforced concrete leads to high deflections and strain hardening (UFC 3-40-02, 2008).

Mosheer, K. A. M., & Hassoon, A. H. H. 2016 [6] tested eight models of concrete beams reinforced with external steel plates instead of shear stirrups with the same size and properties (length: 1000 mm, height: 200 mm, width 150 mm), nces . The beams are strengthened using steel plates from the outside and with an area equal to the missing area after they have been loaded until the first crack occurs in the beam. Depending on their thickness, the beams are separated into three groups with thickness (1, 1.5, and 2 mm thick). Beams are included in each group, one of which is epoxy-bonded and the other of which is epoxy-bonded together with screws. all beams, the reinforcement showed a significant improvement in strength,

especially when using screws with epoxy to fix the plates, of the results, the strengthened beams tested when using anchored bolts with epoxy glue to bond plates. Where the increasing in maximum load is higher than that in reference beam with no internal stirrups reach to (75.46 – 106.13)% and has a good agreement with the control beam with shear reinforcement reach to(76.06 – 89.36)% of ultimate load.

Asmaa et. al. 2022 [7] conducted an alternative shear reinforcement technique has been proposed which is the flamingo technique, instead of the traditional vertical stirrup it is made prefabricated. Five reinforced concrete beams were used with dimensions (200 x 300 x 1800) mm, two reference (with stirrups and without stirrups) and three beams using flamingo technique having free ends, constant inclination angle (45°), and fixed length of effective depth were used by (80%, 60%) mm. This study aims to determine how a change in diameter affects the Flamingo technique. The diameters used are (6, 8, 10) mm. According to the results, found that there was a significant improvement in the shearing capacity of the beams by (13.88%,25%and 40.55%)from reference beam, as well as the end cracks, and the behavior of the cracked beam. , when compared with the control (RCWS) beam, the (FD6, FD8 FD10) beams showed deflection

decreases of 32.8%, 11.3% and 14.8%, respectively.

Shear connectors transmit the shear forces in composite beams between steel parts and concrete, therefore these connectors can be used as vertical legs to assistance stirrups in their performance. The vertical legs of the stirrups (the area perpendicular to the forces exerted) are the main parts responsible for carrying those forces. In this paper, z and I-shaped stirrups will be used instead of the traditional u-Shaped stirrups in order to reduce the amount of used rebar and ease of forming it.

2. Significance of research

The primary aim of this study is to assess and analyse recent experimental findings investigating the properties of self-compacting concrete (SCC). And The Effect of change Stirrups Shaped on Shear Capacity of Self-Compacting Concrete Beam, which significantly impact concrete's structural behaviour and durability.

3. Experimental Program

Six RC beams were constructed for monotonic tests under one point load with span shear ratio 3.0, including one RC beam were also produced for comparison goals, to achieve the objective of use the new technique of shear reinforcement. The beam details are presented in Table (1) and Figure (2), all the beams' specimens had the same dimensions, the overall length was 1200 mm and rectangular cross section with 150 mm width and 220 depth.

The beams are provided by external steel plate with 2mm thickness along the longitudinal axis of beam and connected to the main beams by T shape shear connectors made locally at laboratory as explain later. Two variables were studied in this study:

1. Shape of stirrups, U, Z and I
2. Spacing between Z and I stirrups.

3.1 Materials

3.1.1 Cement

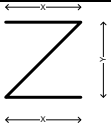
Ordinary Portland cement (CEM I 42.5R) was used and its properties are in compliance with the requirements of the Iraqi Specification No. 5/2019 [8].

3.1.2 Fine and Coarse Aggregate

Natural fine aggregate is used with fineness modulus is 2.87 and lies in zone No.2. Crushed gravel is the type of gravel that used in the concrete mix to improve the strength of structure by the interlocking of the angular particle which size was between (5-12) mm. The advantage of using coarse aggregate in SCC is to achieve a good flow. The grain size distribution and physical properties for this aggregate were in compliance with the requirements of the Iraqi Specification (No.45/1984) and revision (No.1/2015 and No.2/2016)[9].

(I.Q.S NO 45 of 1984) [14], as shown in Table (3). According to the test, the grading zone of fine aggregate is zone 3.

Table (1): Beam Details

Beam No	Shear connector length mm	a/d	Shear reinforcement				
			Shape	Spacing	Y (mm)	X (mm)	
B1	100	3.0	U	100	185	110	No steel plate
B2	100	3.0	Z	100	185	110	Spacing

B3	100	3.0	Z	80	185	110
B4	100	3.0	Z	120	185	110
B5	100	3.0	I	100	185	80
B6	100	3.0	I	80	185	50

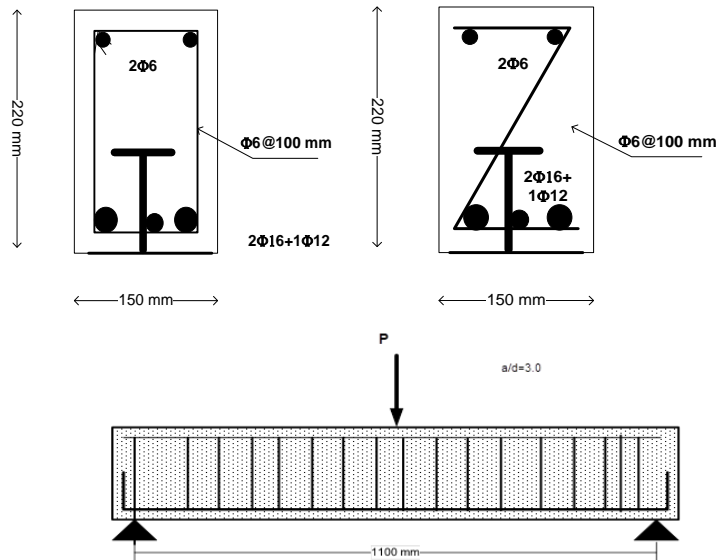


Figure (2): Longitudinal Sections and Cross Sections of Tested Beams

3.1.3 Fillers

The nature and amount of fillers used in order to response strength and durability requirements, to avoid excessive generation of heat, it limits the segregation and bleeding of mix, and to improve concrete performance but reduce the workability.

3.1.4 Superplasticizer

The super plasticizer that was used in the preparation of concrete is Glenium 51 manufactured in the United Arab Emirates with a value of PH 6.8, a light brown color, free of chlorine.

3.1.5 Steel Reinforcing Bars

The main tension reinforcement is consisted of (2Ø16mm+1 Ø12mm) to ensure shear failure of the section in addition to 2Ø6mm

longitudinal smooth steel bars were used as a holding for transverse reinforcement. Transverse reinforcement (stirrups) consisted of Ø6mm . The longitudinal reinforcement and transverse steel reinforcement designed according to ACI318-19[10].

3.1.6 Steel Plates and Shear Connectors

The thickness of the plate must be equal to / or less than the plate thickness at balance load conditions and the maximum plate thickness to ensure a ductile flexural failure (11).

$$\frac{b_p}{t_p} \geq 50$$

Therefore, steel plate with thickness 2.0 mm and width 145 mm and total length 1200 mm was used. Homemade shear connectors using a deformed steel rod with a diameter of 12 mm

were used by welding the stem of 88 mm shear connectors with a flange length of 80 mm to form a T-shape had a total height of 100 mm in most beams, while shear connectors with a height of 150 mm and 180 mm are used in two

beams and these shear connectors were placed at distances of 200mm center to center to transfer forces from concrete to steel plate, Figure (3).



Figure (3) steel plate and shear connectors

3.2 Mixtures

The mixes were used in casting the specimens are based on the research Saraa'a[12],Table (2), modify and trial mix done with this mix until reached to the following SCC mixes of the

contents by weight is 1:1.57:1.94 with w/p ratio is 0.34, this mix proportion. Mix design method for SCC must satisfy the properties as passing ability, filling ability, and segregation resistance. (EFNARC, 2002)[13].

Table(2): Quantities by Weight of Materials

Mixes	Cement (kg/m ³)	Sand (kg/m ³)	Gravel (kg/m ³)	Limestone (kg/m ³)	Super Plasticizer (l/m ³)	Water (l/m ³)
SCC	425	670	825	150	10	150

4. Curing

All beams and specimens were covered by plastic bags to prevent evaporating water and reduce shrinkage from the surface. The beams specimens were demolded subsequently 48 hours later, while the cylinders, cubes, and prisms were demolded after 24 hours. For normal concrete, water curing was used. On the other hand, ambient curing regime in a laboratory temperature was utilized for SCC specimens until testing day

5. Result

5.1 Mechanical Properties

5.1.1 Fresh Properties

To ensure the mix is SCC mix, the fresh properties results must be in the range of the limitations. In this study, two tests as T50 slump flow test and slump flow test, V-funnel test and V-funnel at T5min test. Table (3) illustrates the results of these tests and compared the results with limitations of (EFNARC, 2002) [13] and (ACI-237, 2007) [14].

Table (3):Tests Results of Fresh Properties for SCC.

Tests	T50 Slump p Flow (sec)	Slump Flow (mm)	V-Funnel (sec)	V-Funnel at T5min (sec)
SCC	4.5	740	8.5	9
EFNARC Limitations	2-5	650-800	8-12	+3
ACI-237 limitations	2-5	450-760		

5.1.2 Hardened Properties

The results of mechanical properties (compressive strength and modulus of rupture, splitting, and modulus of elasticity) of the concrete used in the casted beams are listed in Table (4) .

The results are compared with value suggest by ACI 318M, 2019[10],

$$f_r = 0.62\sqrt{f'c} \quad \dots (1)$$

$$f_t = 0.56\sqrt{f'c} \quad \dots (2)$$

$$E_c = 4700\sqrt{f'c} \quad \dots(3)$$

Table (4): results of mechanical properties.

fcu (MPa) exp.	f'c (MPa) exp.	f'c'/fcu	ft (MPa) exp.	ft (MPa) (ACI)	fr (MPa) exp.	fr (MPa) (ACI)	Ec (MPa) exp.	Ec (MPa) (ACI)
44.15	37.51	0.85	3.42	3.43	4.50	3.80	31457	28785

Table (5): Results of Experimental Program

Beam No.	Pcr KN	%B1	Δcr mm	%B1	Pu KN	%B1	Δu at Pu mm	%B1
B1	72		0.74		250		7.95	
B2	75	4	1.28	73	210	-16	8.1	2
B3	80	11	1.23	66	225	-10	9.45	19
B4	65	-10	1.58	114	170	-32	10.95	38
B5	80	11	0.93	26	235	-6	8.4	6
B6	82	14	1.17	58	265	6	9.45	19

The Figure (4) shows the relation between cracking and ultimate applied load for the beams according to considered variable. It was noticed the reduction in shear capacity of

beams with about 16% when replaced the stirrups from U to Z shaped and this reduction may be rare when the spacing between Z stirrups become lesser.

The Figure (5) show the relation between the applied load and the deflection at mid span point for the beams according to considered variable. the increasing in the ultimate load of the SCC beams related to increase of transverse reinforcement contribution to shear strength when the spacing between Z or I stirrups was decreased. When compared the central deflection of beams in this group at the service load of beams, it was noticed the decreased values about 1% and 8% compared with B1, as the shape of stirrups change from U to Z shape with spacing between stirrups are 100 and 80 mm for B2 and B3, respectively, while central deflection of

beams was changed by about -13% and +2% compared with B1, as the shape of stirrups change from U to I shape (links) with spacing between stirrups are 100 and 80 mm for B5 and B6, respectively.

5.2. Shear Response of SCC Beams

The current section presents the beams responses in terms of load-deflection ($P-\delta$) relationship, load capacity, failure modes, and cracking patterns, under different levels of monotonic loads. Six reinforced self-compacting concrete beams. The loads were increased incrementally by about 10 kN/min up to the failure. See the all results at Table (5).

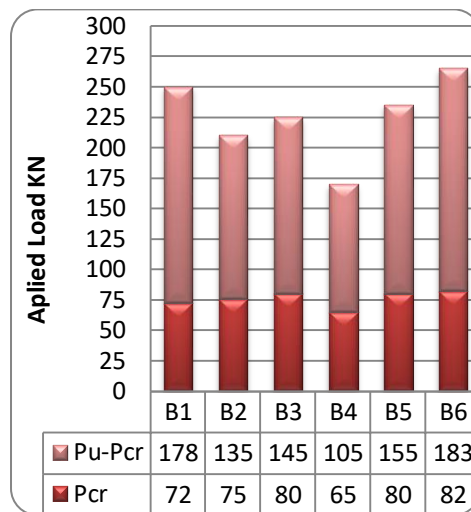


Figure (4): Cracking and Ultimate Applied Load

The decisive comparison of central deflection conducted at the value of service load of B1, the values are increased by 6% and 16% as the shape of stirrups change from U to Z shape with spacing between stirrups are 100 and 80 mm for B2 and B3, respectively and decreased by 4% and 2% as the shape of stirrups change from U to I shape (links) with spacing between stirrups are 100 and 80 mm for B5 and B6, respectively. From the results, it can be noted, there is a limited effect of using Z and I shapes instead of

U-stirrups, and this effect becomes negligible especially when using the spacing between them equal to 80% of the spacing between U-stirrups, This is due to the fact that it is mainly the legs that resist the shear forces and the effect of the flange length may be negligible, and the difference in the central deflection may be due to the difference in the stiffness values of the beams through the variation of using different shapes of stirrups

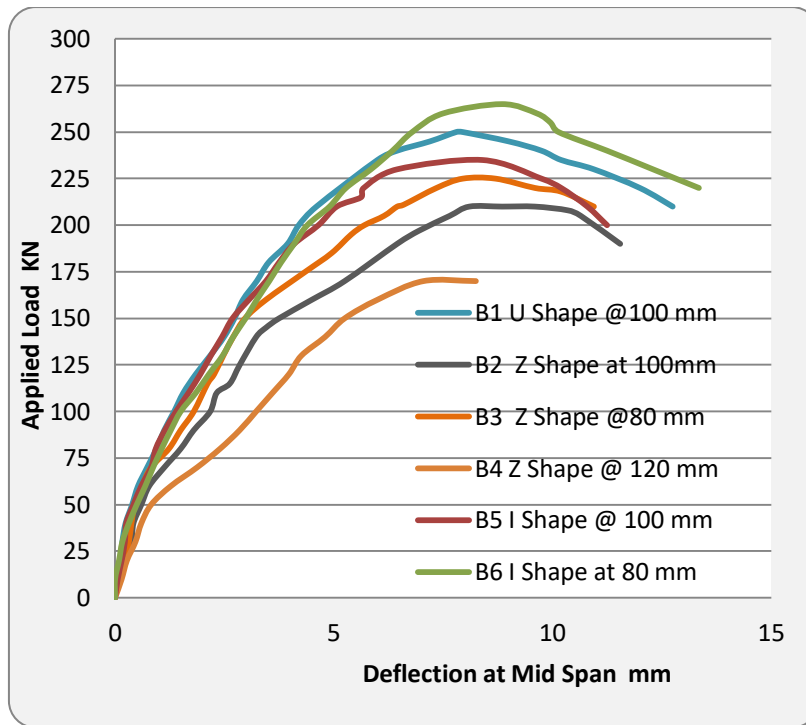


Figure (5): Applied Load and Central Deflection.

5.3 Ductility, Stiffness and Energy Absorption

Figure (6) provides the ductility ratio, stiffness and energy absorption of the beams. Ductility is the ability to absorb the energy of deformation without brittle fracture which is a significant property of members in concrete structures and is defined as the ability of a member to experience large deformations before failure. Several mathematical approaches have been proposed and the traditional approaches, Paulay, 1978[15] based on the calculation of the ratio of the deflection at the ultimate limit state to its equivalent at the elastic limit state of the steel in tension

$$\mu = \Delta u / \Delta y \quad \dots \quad (4)$$

Where μ = ductility index

Δu = ultimate deflection

Δy = yielding deflection

The stiffness of a structural member is considered to be one of its fundamental attributes. The resistance of a body to deformation under the influence of an applied force is measured by an index known as its degree of deformation resistance. Figure (6) illustrate Initial and Service Stiffness of Tested

Beams. it was noted from the results that stiffness increases by increasing the shear reinforcement ratio for concrete beams. The control beam, made of regular concrete, had an initial stiffness of 58.59 kN/mm and became higher stiff after having the longer shear connectors.

Mechanical energy is converted into internal potential energy of reinforced concrete members, and this is due to those members' inherent ductility and energy absorption. In addition, concrete members have to deal with many complicated processes, like the fracture mechanics of concrete cracking and the deformations caused by elastic and plastic forces (Hanoon et al., 2019)[16].

The findings on the energy absorption are presented in Figure (6), so the reference beam (B2) was compared to the beam (B1) that was generated using U stirrups shape, it was discovered that the energy absorption decreased to 1661 kN.mm, which is equivalent to 71% of B1. When the control beam (B2) was compared to the other beams that was created with a Z stirrups shaped.

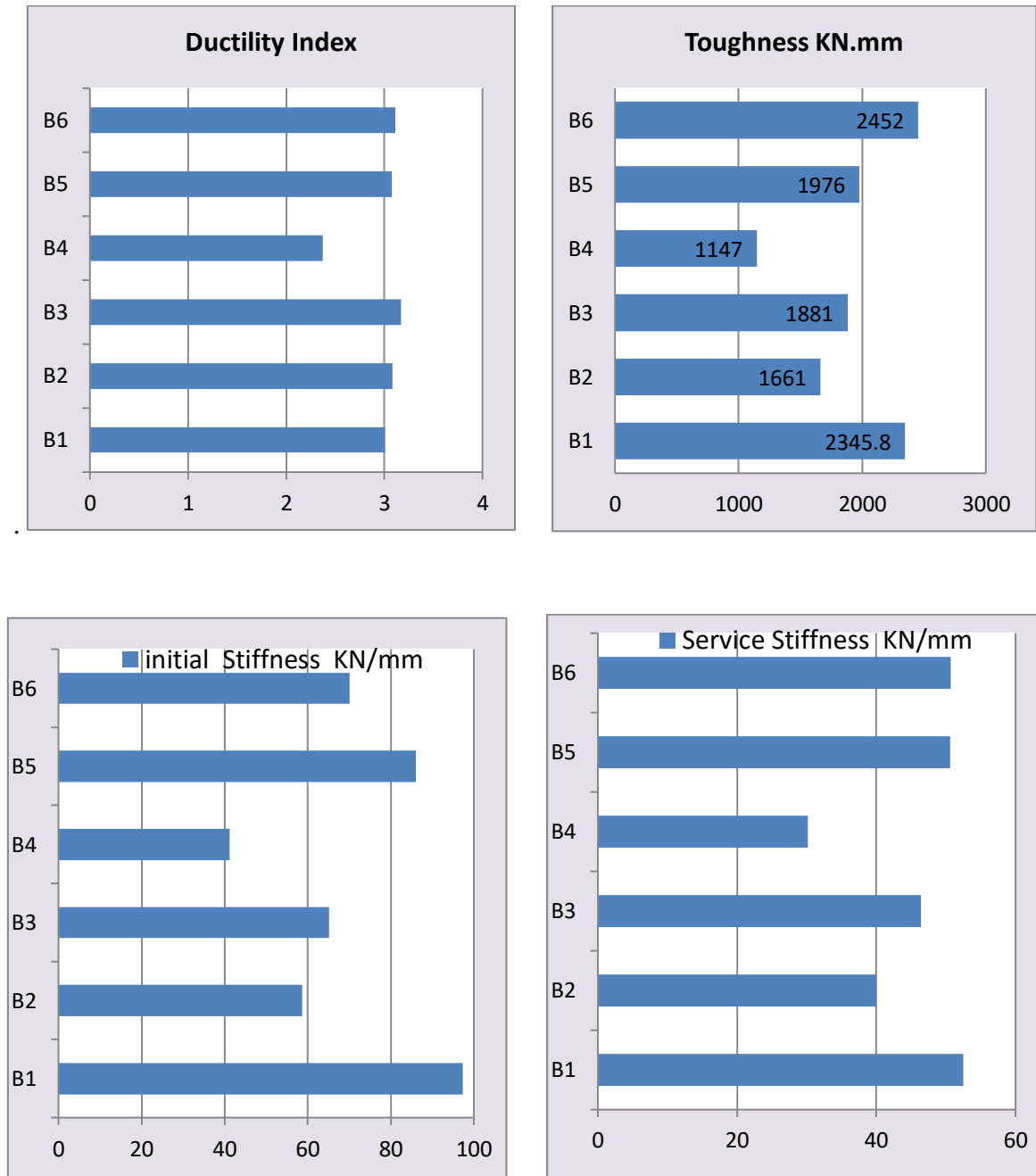


Figure (6): Ductility ratio, Stiffness and Energy Absorption of the Beams

6. Crack Pattern and Failure Mode.

Table (5) shows the load that causes the appearance of the first crack in beams. It was increased by the range (4-60) % as compared with B1 except for beams B4 was decreased by 10%. It was discovered that cracks appeared first in the central region, with the load and the onset of the crack in the middle averaging 20% for all samples. This is due to the increase in

stresses in the middle as a result of the applied load, which then caused the cracks to develop upwards and spread to the sides. It was discovered that cracks appeared first in the central region, with the load and the onset of the crack in the middle averaging 20% for all samples. This is due to the increase in stresses in the middle as a result of the applied load, which then caused the cracks to develop

upwards and spread to the sides. One failure pattern was observed in all the beams examined, which is shear failure, where the beams were initially designed to withstand greater bending forces than shear forces, in

addition to the contribution of the external steel plate to increase the bending capacity it gave more emphasis on studying the shear behavior of beams, Figure (7).

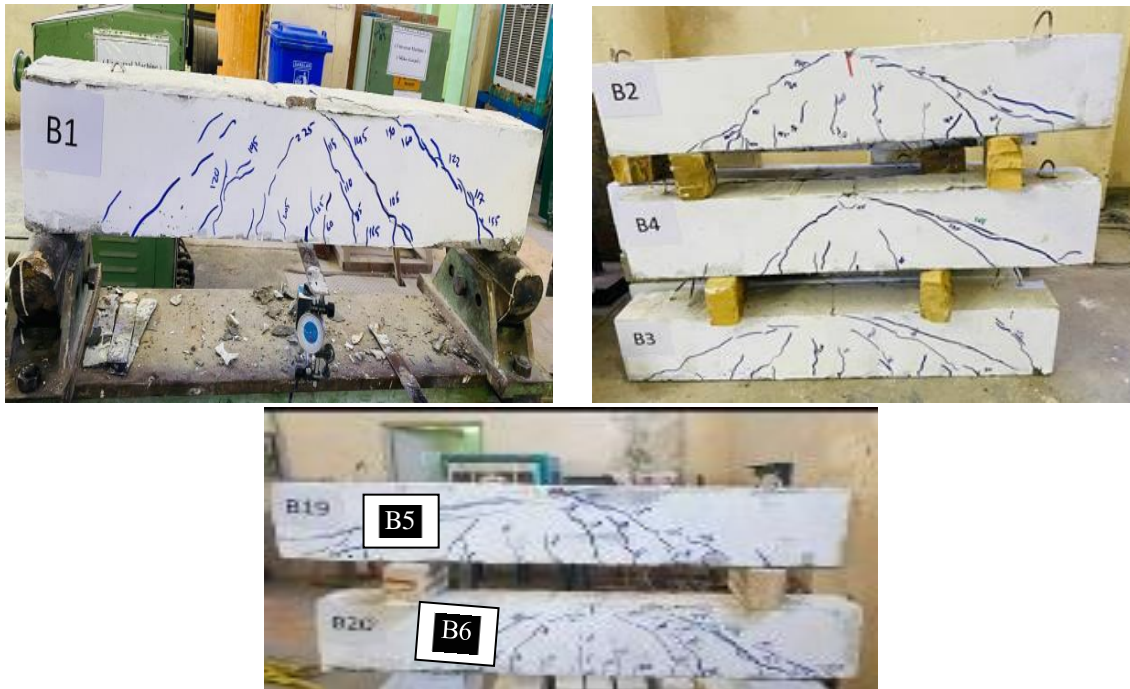


Figure (7): Crack Pattern and Failure Mode of the Beams.

7. Conclusions

1. The beams with Z shaped stirrups demonstrated ductility values more than the value of U shaped stirrups.
2. The first crack appeared bottom or top surfaces. The cracks begin at the tension face and propagate inclined to the member's axis. The initiation of the first cracks in the beams occurs when the tensile stress imposed on the concrete exceeds its tensile strength.
3. Use Z stirrups technique with the spacing equal to 80% of spacing of U shaped stirrups gave approximately 90% of shear capacity.
4. Through the use of various forms of stirrups, it was encouraged acceptance of the idea of the weak contribution of horizontal

pieces of stirrups to shear capacity, so these parts can be dispensed with in specific places and specific conditions

References

- [1] N. Mossahebi, A. Yakel, and A. Azizinamini, "Experimental investigation of a bridge girder made of steel tube filled with concrete," *J. Constr. Steel Res.*, vol. 61, no. 3, pp. 371–386, 2005, doi: 10.1016/j.jcsr.2004.07.004.
- [2] M. A. Shallal and A. M. K. Al Musawi, "Non-linear analysis of composite beam subjected to fire," *J. Eng. Appl. Sci.*, vol. 13, no. 22, pp. 9643–9650, 2018, doi: 10.3923/jeasci.2018.9643.9650.
- [3] M. A. Shallal, A. M. K. Al Musawi, and F. I. Mussa, "Non-linear analysis of continuous composite beam subjected to fire," *Int. J. Civ. Eng. Technol.*, vol. 9, no. 9, pp. 521–532, 2018.

- [4] Ali Shariati, "Various types of shear connectors in composite structures: A review," *Int. J. Phys. Sci.*, vol. 7, no. 22, pp. 2876–2890, 2012, doi: 10.5897/ijpsx11.004.
- [5] Srinivasa Rao, P., Sarma, B. S., Lakshmanan, N., & Stangenberg, F. (1996). Seismic behavior of laced reinforced concrete beams. In *Eleventh World Conference on Earthquake Engineering*
- [6] Mosheer, K. A. M., & Hassoon, A. H. H. (2016). Strengthening of reinforced concrete beam in shear zone by compensation the stirrups with equivalent external steel plates. *Engineering Sciences*, 24(3), 604-617.
- [7] Asmaa Shaker Mahmood, Suhad M.Abd," Effect of Bar Diameter on Shear Capacity of Reinforced Concrete Beams with Flamingo Shear Reinforcing Technique" *Mathematical Statistician and Engineering Applications Journal*, Vo; 72, No1, 2022, PP719-729.
- [8] IOS No.5, "Portland Cement", Central Agency for Standardization and Quality Control, Planning Council, Baghdad, IRAQ, 2019.
- [9] IOS No.45, Iraqi Specification, "Aggregate from Natural Sources for Concrete and Construction", Central Agency for Standardization and Quality Control, Baghdad, 1984 .
- [10] ACI Committee 318, —Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19), American Concrete Institute, Farmington Hills, MI, 2019, 519 pp.
- [11] Ziraba, Y. N., Baluch, M. H., Basunbul, I. A., Sharif, A. M. and Al-Sulaimani, G. J. , "Guide lines Towards The Design of Reinforced Concrete Beams with External Steel Plates", *ACI Structural Journal*, V. 91, No. 6, Dec. 1994, PP. 639–646.
- [12] Sarra'a Dhiya'a Jaafer " Experimental Study to Investigate the Behavior of Self Compacting Axially Constrained Reinforced Concrete Deep Beams "MSc thesis, Mustansiriyah University, Iraq-Baghdad, 2017, pp. 112 .
- [13] EFNARC: European Federation Dedicated to Specialist Construction Chemicals and Concrete System" *Specification and Guidelines for SCC*", February 2002, pp. 32 .
- [14] ACI Committee 237R, 2007 " Self Consolidating Concrete", Reported by ACI Committee 237 (ACI237R-07), *Emerging Technology Series*, April, pp 30.
- [15] Paulay, T. "A consideration of P-delta effects in ductile reinforced concrete frames." *Bulletin of the New Zealand society for earthquake engineering* 11.3 (1978): 151-160.
- [16] Hanoon, Ammar N., Abdulhameed Ali A., Abdulhameed Haider A., and Mohaisen Saad K. (2019), "Energy Absorption Evaluation of CFRP-Strengthened Two-Spans Reinforced Concrete Beams under Pure Torsion." *Civil Engineering Journal* 5, no. 9 (September 23): 2007–2018. <https://doi:10.28991/cej-2019-03091389>.