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STRUCTURAL BEHAVIOR OF SCC BEAMS USING INCLINED STEEL PLATES FOR SHEAR REINFORCEMENT

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Abstract

This research undertaken to examine the impact of using 45° inclined steel plate as shear reinforcement on the strength of self-compacted concrete beams (SCC) as well as investigating their spacing impact. Testing four SCC beams under two-point loads with cross section of 0.3 m×0.2 m and overall length of (2 m). The results showed substantial changes in the beams unlimited loading ability and the weakness of cracks by using inclined steel plates 45° instead of stirrups. It was also observed that more stability was applied to the beams by using inclined steel plates. In those beams the yield loads were on average 2.17% higher than the reference beam (beam with stirrups) and the yield load deflection was also higher 15.05% on average. In addition, on average, the ultimate loads in the same beams were higher by 3.50% and the final deflection was also higher 6.02% on average. On average, ductility in the same beams was lower 9.51%and the strain was higher in the longitudinal reinforcement before achieving an applied load of 200 kN and lesser in the steel plates for shear and in an opposite way after achieving the loading of 200 kN. The efficient use of 45° inclined steel plates as shear reinforcement of self-compacted concrete beams in lieu of the use of conventional reinforcement bars (stirrups) that has been demonstrated by this study. Finally, it was recommended to do some relevant further studies.

Keywords: Beam, Self-compacting concrete, Shear reinforcement, Shear steel plates, Stirrups.

1. Introduction

Recently, it was found that several tries prepared to explore modern shear strengthening methods for concrete components. All of these new methods are the use of narrow disposed bars with both ends bent horizontally in a very short space of time, spliced, welded or bolted on both the top and bottom flexural bars [1, 2]. For the first time in Iraq 2015, using the internal steel plates as shear reinforcement of concrete beams are considered as modern techniques, which was studied and in the international scale for the second one that studied by the authors [3, 4].

In an attempt to improve them, the results of the previous study of the aforementioned authors encouraged analysis of the effect of using inclined instead of vertical interior steel plates as shear reinforcement on the strength and behaviour of self-compacted concrete beams. The emergence of new concrete technology such as self-compacting concrete introduced in Japan by Okamura in the late 1980s demanded modern construction criteria and generated considerable awareness among concrete technologists, engineers and research scholars [5].

In this study, this type of concrete was used to guarantee the concrete flow through the holes of the shear steel plate because it has the capacity to stream through its own pressure and extend into position to absolutely fill moulds flow across heavy strengthening with no inhibitory impacts with no need for vibrations [6, 7].

Amer et al. [3] investigated the effect of using internal steel plates for shear reinforcement on flexural behaviour of SCC beams instead of using traditional reinforcement bars (stirrups) and to study the effect of their spacing and thickness on strength.

Al et al. [4] studied the effect of steel plates on shear strength of wide reinforced concrete beams. The results showed that the steel plate improves shear capacity of wide beam a little in comparison to other ways of reinforcement and the failure comes to be sudden failure under this kind of reinforcement. Using steel plate causes increased shear capacity of wide beams significantly that in combination with stirrups there is increase in load capacity as well as ductility.

Amer et al. [8] investigated the effect of steel plates on shear strength of wide reinforced concrete beams. These Beams were designed to fail in shear. The ascent in the shear strength ranges from 9.52% to 47.62% as matched with the control sample.

This study aims to identify how the use of 45° inclined inner shear steel plates as shear reinforcement with various spaces could affect the strength of SCC beams and cracks behavior.

2. Practical Framework

2.1. Preparing the beams

Only four reinforced concrete beams were prepared by way of rectangular irritated division 0.3 m x 0.2 m and the same total length 2 m. The beams have been experienced under two point loads in compliance with ACI 318M-14 [9] where they were designed to fail in shear. Using conventional stirrups of Ø10 mm a reference beam B1 was prepared though the others B2, B3 and B4 have been prepare by using 45° inclined shear steel plates with various spaces to evaluate the impact of their uses on the action of cracks and concrete beams. The shear reinforcement descriptions of these beams are represented in Table 1. Steel bars 3Ø16 mm were used at the bottom of the beams for longitudinal flexure reinforcement, while steel bars 2Ø10 mm were used at the top of the beam for longitudinal reinforcement. Table 2 describes ultimate stresses and the mean yield elongations of the steel reinforcement bars. Figure 1 shows the form of the steel plates used, and their proportions as shown in Fig. 2.

Table 1. Details of shear reinforcement for all beams.

Beam	Reinforcement	Thickness	Spacing
B1	Stirrups	-	200 mm
B2	Steel plates	4 mm	200 mm
B3	Steel plates	4 mm	175 mm
B4	Steel plates	4 mm	150 mm

Table 2. Stresses and elongations of steel bars.

Nominal bar diameter	Bar cross section area (mm^2)	Yield stress (MPa)	Ultimate stress (MPa)	%Elongation at ultimate stress
16	201.06	415	644	23.82
10	78.54	360	485	20.37

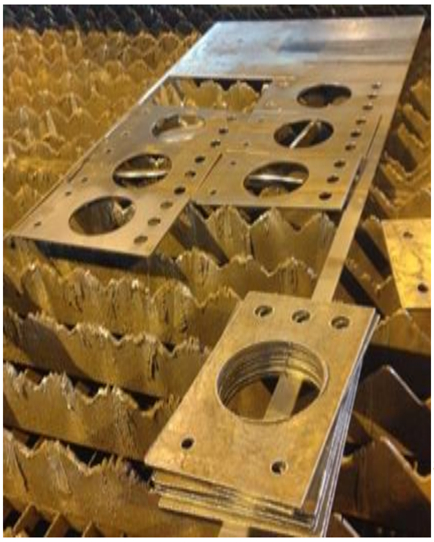

Fig. 1. Steel plates shape.

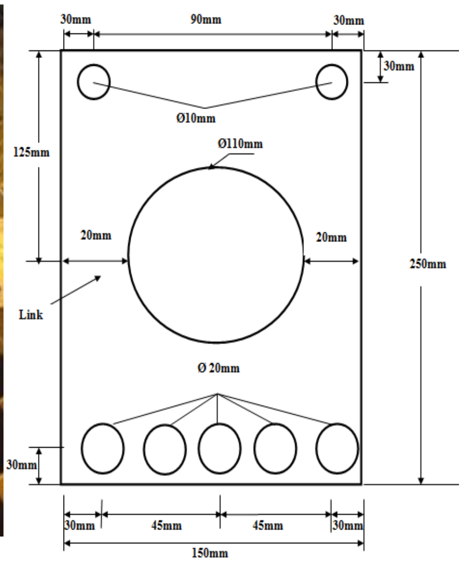

Fig. 2. Steel plates dimension.

In addition to the associated elongations. The yields and maximum tensile strengths of the steel plates are shown in Table 3. The materials used for the development of self-compacting concrete beams are crushed gravel of maximum size 10 mm, sand, ordinary Portland cement, pure tap water, metakaoline like mineral admixture and super plasticizer that classified as HWRE, modern generations of iodide-free adapted polycarboxylic ether compatible with ASTM C494-15 [10].

Table 3. Yield, ultimate tensile stress and elongation of steel plate.

Thickness of steel plate (mm)	Average yield tensile stress (MPa)	Average ultimate tensile stress (MPa)	%Elongation at ultimate stress
4	260	385	24

The entire width of the reinforced flexural strengthening is 2010 mm with an overall length of 1900 mm, so, the length that remained is bent at 90 ° similarly at both ends as regular hooks of 100 mm length. The reference beam (B1) has improved with straps that have bent as normal knobs at 90 °as seen in Fig. 3. Shear steel plates in the other beams (B2, B3 and B4) are used instead of stirrups as in the illustration seen in Fig. 4. Before the self- compacted concrete mix has poured and primed into the molds, the steel reinforcement had already been set in place. The beams were coated with canvas after the casting was done and sprinkled continuously with water for 28 days.

Fig. 3. Steel cage of beam (B1).

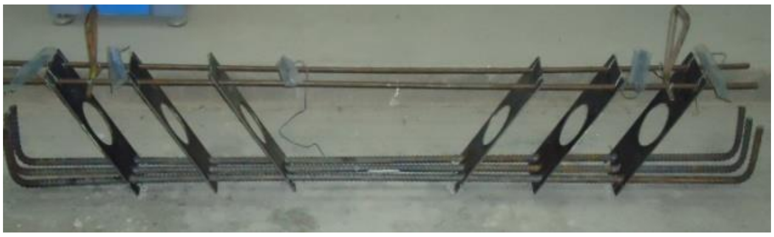

Fig. 4. Steel cage of beam (B2).

2.2. Mix design

To meet the *SSC* requirements and the designed compressive strength, many trial mixes were carried out. The final mixes which have been used for casting the tested samples. The mix was designed according to EFNARC, 2002 [11]. The proportions of the mix used to cast the beams are shown in Table 4.

Table 4. Proportions of SCC mix components.

Materials	Mix. proportions
Cement (kg/m^3)	500
Kaolin (kg/m^3)	91.5
Fine aggregate (kg/m^3)	758
Coarse aggregate (kg/m^3)	890
Water (L/m^3)	200
Superplasticizer (L/m^3)	10

2.3. Testing of SCC

The SCC properties were tested using normal protocols and specimens in both fresh and hardened states. Fresh state tests of SCC involved slump flow and test of T50 cm and test of L-box SCC as shown in Table 5. featured hard bitten state test compressive and tensile strength and modules of rupture as shown in Table 6.

Table 5. Tests results of fresh SCC.

Type of test	Tests results	EFNARC requirements
Slump flow (mm)	690	650-800
T50 cm (s)	3	2-5
L-box (H2/H1)	0.82	0.8-1.0

Table 6. Tests results of hardened SCC.

Beam No.	Compressive strength, (f'_c) MPa	Modulus of rupture (f_r) MPa	Splitting tensile strength (f_t) MPa
B1	46.12	4.29	4.15
B2	46.134.23	4.12	
B3	46.15	4.25	4.14
B4	46.11	4.28	4.13

2.4. Test measurement and instrumentation

Order to show the measurement of the strain developments in concrete and steel as a result of loads that used, in which TML type have used by the five strain gauges immersed in the concrete. So, the frame structure has been designed with some other strain gauges placed on the concrete beam central top surface. The strain gauges that are immersed are four, which have spread in beams B1 and B2 in the middle region of the shear reinforcement limbs, as shown in Fig. 5. These gauges from both left and right supports were placed at 100 mm and 300 mm as seen in Fig. 6 where the sign applies to gauge positions. In the beam B3, in the middle of the shear reinforcement limbs 212.5 mm and 387.5 mm of both the right and the left supports, four submerged strain gauges have assigned within the beams. In beam B4 at the centre of the shear reinforcement limbs at 225 mm and 375 mm from both right and left supports, the four immersed strain gauges were assigned within the beam. Finally, one submerged strain gauge from both supports was installed at the lower part of the use around longitudinal reinforcing bars 900 mm in each of these beams. The beams were extracted and left to dry when the normal curing period is over, then painted with white pigment.

Fig. 5. Strain gauges' locations.

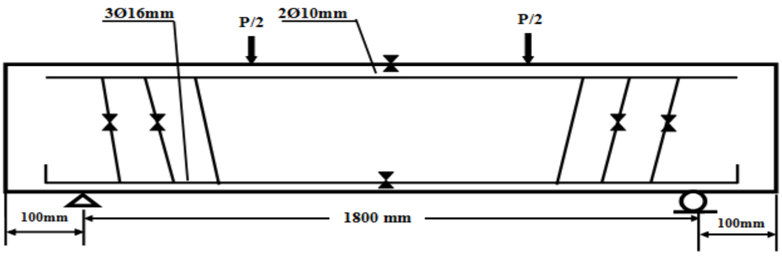

Fig. 6. Locations of strain gauges in all beams.

As shown in Fig. 7 by using a hydraulic universal measuring system all the beams have been tested 2000 kN capacity. A micro crack meter system was used to measure the production of crack widths at all loading levels. The device has a measurement length of 4 mm with an accuracy of 0.02 mm. In order to measure the deflection of the checked beams, three vertical dial gauges were used. One is centered at the beam's center and the other two are 300 mm apart from both sides of the center. The overall measurement of these dial gauges is 5 mm, and the accuracy is 0.01 mm.

Fig. 7. The beam location in the loading test machines.

3. Results and Discussion

3.1. Yield load

Table 7 displays the values of the loading yield in accordance with the values of the yield strain, which gained by using 45° inclined shear steel plates with a cross-sectional area equal to the cross-sectional area of the stirrups in the narrowest portion of the steel plate limbs. It is clear that the yield load of the longitudinal reinforcement was greater than the reference beam B1 in the beams B2, B3 and B4 using inclined shear steel plates. This is because in the beam middle part, the shear steel plates have the effect of redistributing the compressive stresses that create extra depth for the compression region, particularly when the load exceeded 200 kN [3]. Until this stage was reached, when both were compared to beam B1, the neutral axis raise was faster than the case of the previous aforementioned authors' study. That because the area of contact of the segmentation is more than the area of contact of the porous surface, particularly in the lower zone (tension zone).

Table 7. The characteristics of the ductility and strength beams.

Beams	*P_y (kN)	%diff. of P_y	P_u (kN)	% diff. of P_u	**Δ_y (mm)	% diff Δ_y	Δ_u (mm)	% diff. of Δ_u	Ductility	% diff.of ductility
B1	165	-	266	-	7.48	-	37.48	-	5.01	-
B2	168	+1.79	275	+3.27	9.10	+17.80	38.60	+2.90	4.24	-15.37
B3	171	+3.51	274	+2.90	9.15	+18.25	43.41	+13.66	4.74	-5.39
B4	167	+1.20	278	+4.32	8.23	+9.11	38.05	+1.50	4.62	-7.78

* Py: Yield loading of longitudinal reinforcement as it exceeds the strain of yield.
** Δy: Deflection at loading yield

However, the neutral axis continued to descend, and the compressive forces consequently rose after the load of 200 kN was achieved. Thus, when using inclined steel plates, the yield load equivalent to longitudinal reinforcement was higher.

3.2. Ultimate loads

Table 7 displays the final load values that derived from load deflection diagrams. The ultimate beam loads B2, B3 and B4 are clearly greater than the reference beam B1. This is due to the fact that as discussed earlier, the neutral axis drops down after meeting the 200 kN load. Hence, when using inclined shear steel plates, the compressive forces increase and the load that induces beam collapse is higher. The results showed a noticeable increase in the reinforced concrete beam ultimate bearing capability for the use of inclined shear steel plates relative to both conventional shear reinforcement (stirrups) and vertical shear steel plates used in the previous research of the authors [3].

3.3. Load deflection behavior

Table 7 also displays the deflection values at ultimate and yield loads derived from the details of the dial gauge. It was apparent that the deflections in beam at yield loads are larger than the reference beam B1.

According to the interlocking effect between longitudinal reinforcement and shear steel plates, the stresses centralization in the central parts of the beam induces some decrease and delay in the creation of cracks and the production of stress on all the sides of concrete beams.

There are increases of the cracks that found in the central section of the beam, accompanied with a rise in the center line and a decrease in the depth of the compression region in which the cracking rotational inertia also increased. Thus, although it reduces in the other pieces, the pressure in the middle section increases.

It is also clear that the deflection of the final beam loads B2, B3 and B4 is greater than that of the reference beam B1. That is because of the transmission of stress due to strain hardening in the longitudinal reinforcement after reaching the load of 200 kN and the creation of diagonal cracks on both sides of the concrete beam that cause less intertwining between the longitudinal reinforcement and the plates. These bring down the neutral axis of beams, which raises the compression zone's range and the cracked inertial moment. Figure 8 shows the specimens load-deflection curves.

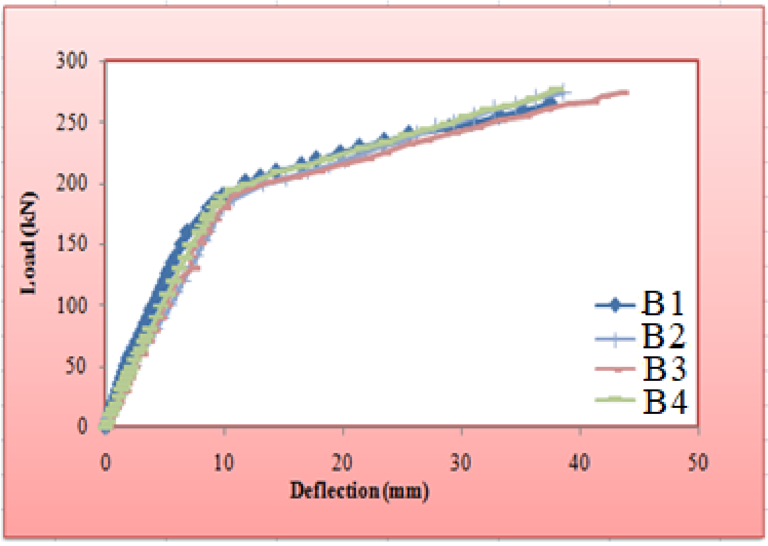

Fig. 8. Load deflection curves of beams.

3.4. Ductility

Table 7 indicates that ductility (Δ_u / Δ_y) was smaller than the reference beam B1 in beams with inclined shear steel plates B2, B3 and B4. This is since, for the specific explanation alluded to in 3.3, the deflection at yield and final loads increased.

3.5. Characteristics of strain in the longitudinal reinforcement

The values of strain that have obtained by strain gauges attached to the data logger at the longitudinal reinforcement center in all beams in loads 120, 140, 150 and 210 kN, as displayed in Table 8.

The strain values of the longitudinal reinforcement of the beams B2, B3 and B4 below aforementioned loads were found to be higher than those of the reference beam strain values B1. This is because inclined plates are caused by increased interlocking with longitudinal reinforcing. Therefore, when using inclined plates, the pressure in the longitudinal reinforcement before reaching the load of 200 kN is greater than when using vertical plates [3].

Because of the strain transformation and stresses allocation in the main reinforcement, this might minimize shear cracks. In addition, owing to the stresses transfer due to the strain hardening of the longitudinal reinforcement, the strain in 210 kN loading was lower than the reference beam B1.

There is also an increase in the flexural tension on both parts of the concrete beam, causing less adhesion between longitudinal reinforcement and plates, leading in the central part of permanent changes. This takes down the beam neutral axis and raises the compression zone's depth and the inertia cracking moment. Thus, in the middle part of the beam, it reduces the pressure and raises it in the other parts. The beams' strain profiles are seen in Fig. 9.

Table 8. The characteristics of strain in the beams longitudinal reinforcement.

Beams	ε*10^{-3} at load 120 kN	%diff. of ε at load 120 kN	ε*10^{-3} at load 140 kN	%diff. of ε at load 140 kN	ε*10^{-3} at load 150 kN	%diff. of ε at load 150 kN	ε*10^{-3} at load 210 kN	%diff. of ε at load 210 kN
B1	1.461	-	1.741	-	1.868	-	10.66	-
B2	1.536	+4.88	1.828	4.76	1.973	+5.32	4.811	-54.87
B3	1.584	+7.77	1.890	+7.88	1.973	+5.32	1.178	-88.95
B4	1.648	+11.35	1.930	+9.79	2.067	+9.63	4.601	-56.84

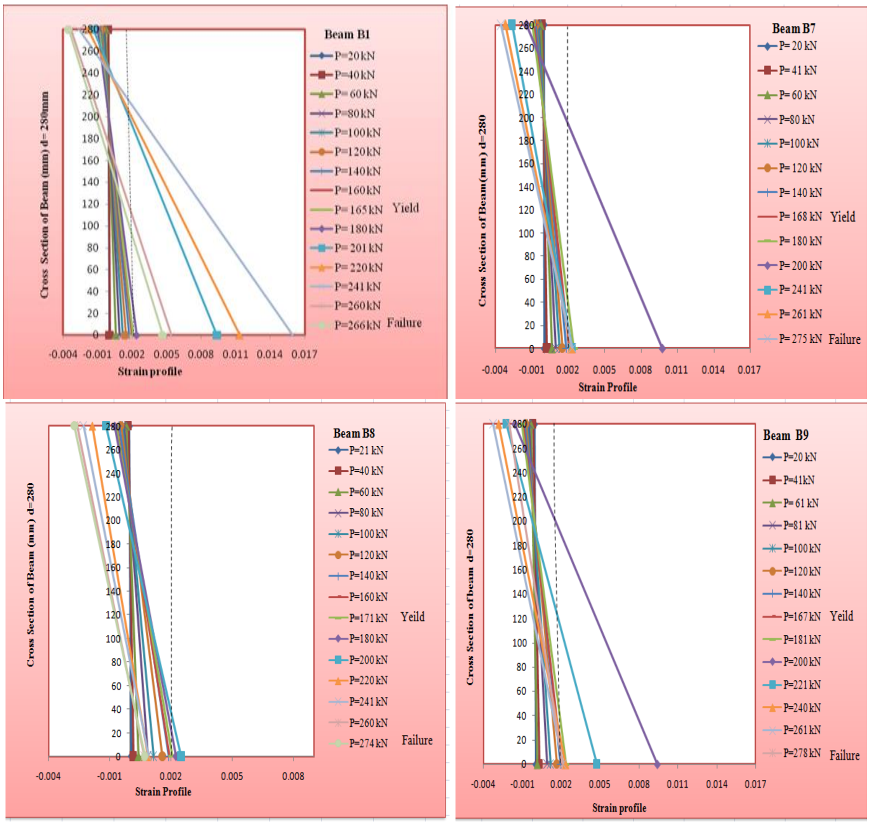

Fig. 9. Longitudinal strain and concrete compression face pressure profiles for beams B1, B2, B3 and B4 respectively.

3.6. Characteristics of strain in shear reinforcement at all the beams sides

Tables 9 and 10 indicate the values of strain that collected from strain gauges attached to the data logger for shear reinforcement (steel plates and stirrups) on the left and right sides of loading beams of 120, 140, 150 and 210 kN. The strain was observed to be lower than the reference beam B1 on shear steel plates on the left and right sides of the beams B2, B3 and B4 under the above loads. This is because of the corresponding reason stated in 3.5 above. Although the strain values were higher than the reference beam B1under the load of 210 kN on the left and the right sides of the beams B2, B3 and B4. This is also due to the relevant reason given in 3.5 above.

Table 9. The characteristics of strain in |shear reinforcement at beams right side.

Beams	ε*10^{-3} at load 120 kN	%diff. of ε at load 120 kN	ε*10^{-3} at load 140 kN	%diff. of ε at load 140 kN	ε*10^{-3} at load 150 kN	%diff. of ε at load 150 kN	ε*10^{-3} at load 210 kN	%diff. of ε at load 210 kN
B1	0.666	-	0.718	-	0.805	-	1.017	-
B2	0.365	-45.20	0.432	-39.83	0.583	-27.58	1.522	+33.18
B3	0.312	-53.15	0.418	-41.78	0.490	-39.13	1.618	+37.14
B4	0.301	-54.80	0.405	-43.59	0.519	-35.53	1.702	+40.25

Table 10. The characteristics of strain in shear reinforcement at beams left side.

Beams	ε*10^{-3} at load 120 kN	%diff. of ε at load 120 kN	ε*10^{-3} at load 140 kN	%diff. of ε at load 140 kN	ε*10^{-3} at load 150 kN	%diff. of ε at load 150 kN	ε*10^{-3} at load 210 kN	%diff. of ε at load 210 kN
B1	0.690	-	0.791	-	0.857	-	1018	-
B2	0.393	-43.04	0.443	-43.99	0.612	-28.59	1.578	+35.49
B3	0.377	-45.36	0.421	-46.76	0.501	-41.54	1.618	+37.08
B4	0.352	-48.96	0.412	-47.91	0.534	-37.69	1.725	+40.99

3.7. Pattern of cracks

The cracking patterns in all beams at various loading points are seen in Figs. 10 to 13. It can be seen from these plates that the series of cracks forming begins randomly at the bottom face of the middle third beams, then as the load applied grows, they grew downwards. Because of the pure minute added to this beam zone, cracks forming in the middle third of the beams is almost vertical, while inclined cracks induced on all beam sides, which are more inclined than those more distant from the middle zone due to the involvement of shear forces as well as the moment.

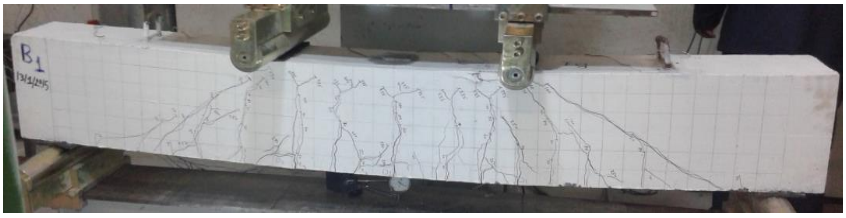

Fig. 10. Cracking pattern of beam B1.

Fig. 11. Cracking pattern of beam B2.

Fig. 12. Cracking pattern of beam B3.

Fig. 13. Cracking pattern of beam B4.

3.8. Width at yield loading of the first crack

The diameter of the first crack throughout all beams at the yield loading is seen in Table 11. The first crack diameter in beams B2, B3 and B4 with inclined shear steel plates was observed to be 31.03% smaller than the reference beam B1 because inclined steel plates were more prone to the expansion of cracks.

Table 11. Width of the first crack in all beams.

Beams	Load (kN)	Width (mm)	% diff. of width
B1	165	0.29	-
B2	168	0.2	-31.03
B3	171	0.2	-31.03
B4	167	0.2	-31.03

3.9. Progression of the neutral axis depth

In accordance with the strain reported at the opponent's position in the bottom longitudinal reinforcement, the positions of the neutral axes are determined in accordance with the strain reported at the mid-span of the uppermost stress fiber of the concrete beam. The difference in the depth of the neutral axis (*c*/*d*) where (*c*) is the depth of the compression region and (*d*) is the effective depth of the concrete beam was seen in Fig. 14 towards the difference in the load applied to the beams. It is apparent that the depth of the neutral axis increased further in the beams with inclined shear steel plates than in the reference beam B1. This is because of the corresponding explanation stated in 3.1 above.

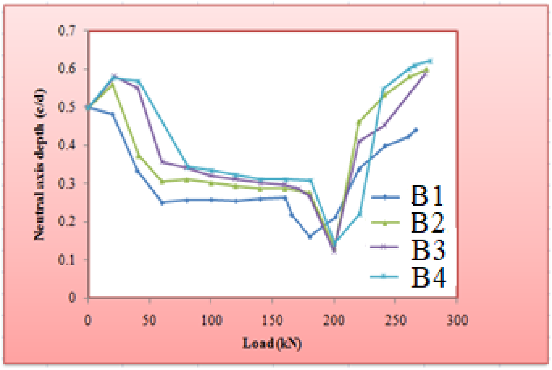

Fig. 14. Variations of the beams neutral axis depth.

4. Conclusions

Through the result obtained out of the analysis, the researchers have come up with the following conclusions:

- It can be inferred based on the experimental results that achieved by this study that the yield loads of beams using 45° inclined shear steel plates is higher than the reference beam by 2.17% which implies that 45° inclined shear steel plates work effectively.
- In beams using 45° inclined shear steel plates the deflection at yield loads was higher than the reference beam where stirrups were used by 15.05% on average which is a very significant change. The ultimate beam loads using 45° inclined shear steel plates were higher than the reference beam by 3.50% on average demonstrating that 45° inclined shear steel plates work effectively.
- Using 45° inclined shear steel plates the ultimate deflection in beams is greater than the reference beam by 6.02% on average, which also indicates that 45° inclined shear steel plates function effectively. In beams using 45° inclined shear steel plates, ductility was smaller than the reference beam by 9.51% on average. The use of 45° inclined shear steel plates added more rigidity to the concrete beams and increased the overall carrying power of the beams. It can also be stated that 45°inclined steel plates can be effectively used for SCC beam .
- The strain in the longitudinal reinforcement in beams using shear steel plates seemed to increase the strain in the steel plates simultaneously to decrease under a load less than 200 kN and then vice versa next the loading of 200 kN.

Nomenclatures

d	Effective depth of concrete beam
P_u	Ultimate load of the beam
P_y	Yield load of longitudinal reinforcement

Greek Symbols

ε	Strain
σ	Stress
Δ_u	Deflection at ultimate load
Δ_y	Deflection at yield load

Abbreviations

ACI	American Concrete Institute
SCC	Self-compacted concrete
ASTM	American Society for Testing and Material

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