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Punching Shear Strength Characteristics of Flat Plate Panels Reinforced with Shearhead Collars: Experimental Investigation

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Abstract

This paper presents an experimental investigation on the punching shear strength of reinforced concrete flat plate slabs with shearhead collars. Eight reinforced concrete slab specimens were casted and tested under static load test, the load was applied at the center of slab by 100x100 mm steel column. The effect of the shapes, diameter and number of stiffeners has been discovered for shearheads through studying its effect on the load-deflection behavior, ultimate capacity, cracking load, failure mode, stiffness, ductility and energy absorption of tested specimens. The experimental results indicates that using square shearhead had achieved a slight increase in punching shear strength about 3% over that circular shearhead using the same surface area. Also, utilize 550 mm shearhead diameter will contribute to increase the punching shear strength about 14.5%. The increase in the number of stiffeners in specimen (CS4) had reduced the ultimate punching shear capacity by 20.3% over reference specimen. The first crack was decreased from 12.5kN to 7.5kN, when increases the number of stiffeners from one to two. The cracking load was increased with the increase of the diameter of circular shearhead from 10kN to 15Kn in specimens of 336mm and 550mm respectively. The specimen with 336mm diameter and 30mm height circular shearhead achieved 427 kN.m energy absorption, it is higher than the energy absorption of reference specimen by 2.6%. Also, using two stiffeners improved the energy absorption by 110.2% higher than the specimen with one stiffener.

Keywords: Punching Shear; Shearhead; Flat Plate; Stiffeners; Stiffness and Ductility.

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1. Introduction

Slabs are two-dimensional structural elements that can be defined as a flat pieces of concrete supported by beams, columns or walls, and these are made of reinforced concrete, steel or building stones. One-way action of slabs obtains when the bending occurs in direction perpendicular to the supported edges. Two-way action of slabs obtains when the bending occurs in two directions [1].

In slab-column system, there are two main types of shear failures: the first type is one-way type and referred to "beam type"; the crack in this type of shear failure is often appear along whole width of the concrete slab. The second type is two-way shear failure and commonly known as "punching"; its common pattern. The occurrence of punching is generally either as a result of applying concentrated loads or due to the presence of columns. In flat plate slabs, punching shear at slab-column connection is the govern design criterion, which is a complex three dimension stress state [2].

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The shape of punching failure surface at slab-column joint is similar to a truncated cone shape. The brittleness nature of this failure type, and hence sudden loading redistribution to surrounding columns is occurred, the collapse becomes a high dangerous possibility [2].

The arrangement of events happened in concrete slab under monotonically increasing in central load that can be briefly described as follows:

- Creation of a roughly circular crack around the column boundary on the tension side of the slab;
- Creation of new lateral and diagonal flexural cracks;
- Beginning of shear cracks at mid-depth of the slab at approximately (50-70) % of the ultimate load [2].

Shearhead can be formed using I- or wide flange- sections beams that cut and welded at the crossing point with ensuring that the arms extend through the column. There are two major advantages for utilizing shearheads; firstly, to widen the effective perimeter of shear critical section (bo); secondly, to enhance the negative bending strength of the slab. The steel rods bottom end near the shearhead, top rods (negative reinforcement) extend up over the structural steel. The main reinforcement column continues at column corners vertically [3].

Different types of shearhead reinforcement are available; however, each type has its own pros and cons regarding issues such as anchorage effectiveness, ease of placement and detailing, and finally total cost. Nevertheless, it is worthwhile mentioning that lots of available types of reinforcement enhance both of shear and flexural strength forces. It should be noticed that the increasing of flexural capacity could leads to failure in the brittle-nature when seismic loads are highly expected [4].

Typical types of shearheads used in different countries includes [5]:

- Two couples or single crossed channel or wide flange steel sections.
- Collars from steel channels (Giellinger shearheads).
- Steel plate.

Conventional shearhead systems, such as the ACI-type [6], are “fully integrated” in the sense that the shearhead is entirely cast into the slab. Recent research [7] and [8] into fully integrated shearheads has focused on increasing shear capacity under static gravity loading through improved composite action achieved by means of shear studs and anchor plates. These systems typically have high punching capacities but low ductility since failure is through punching in the concrete. The assemblages consisted of four I-shaped steel profiles with various lengths welded to the four faces of the rectangular columns. They showed improved punching shear strengths in comparison with conventional RC flat slabs [9]. Tests were also reported on shear-head systems that improve the ductility of the connection under cyclic loading in which, the behavior of the slab was controlled by the strength and stiffness of the shearhead.

The Geilinger collar closely related development in Europe in the field of punching shear strengthening. It consists of steel channel sections creating a rectangle larger than the column size, the load transfers from the slab to the collar and from there to the column by thick steel plates welded to the channels. Since the bearing stress under these plates is excessive, so an additional horizontal steel plate is required.

The Geilinger collars have many problems; first, there are concentration of stresses at corners of shearhead, second, the collar may conflict with the longitudinal reinforcement of the column and may be hard to place. Third, the depth of the structural steel sections must be significantly smaller than the slab thickness, usually there are two layers of reinforcement bars to be placed above and below the structural steel sections [10].

In the present investigation, the collars from steel channels (Giellinger shearheads) is used as punching shear reinforcement, this type of shearhead needs some modifications such as make a shearhead in circular shape to avoid the concentration of stresses on concrete at the corners of the shearhead. Abdu AL-Rahman, 2010 [11] investigated the effect of embedded shearhead steel plate as shear reinforcement in normal and steel fiber reinforced concrete. This investigation studied the effect of this shearhead and the quantity of steel fiber on reinforced concrete slab specimens behavior in punching case. Test results show for models with fiber contents of (0.25% and 0.75%), the ultimate load capacity at failure increases by (17.1% and 28.6%) respectively. Ultimate load capacity in specimens without steel fiber increase by (20%) for specimens with square steel plate, and by (31.4%) with cross-shape steel plate in comparison with reference slab. Better results can be obtain by using both steel fibers and steel plate as shear reinforcement by about (32.8% and 65.7%) to improve deformation characteristics in slab-column connections. Bompa et al. 2016 [12] investigated the structural behavior of hybrid members consisting of six reinforced concrete flat slabs with and without shear reinforcement .Fully integrated shearhead were used in the slab-steel column joint area. The isolated members were made of a closed section steel column stub that had four shearheads welded directly to it and fully embedded in the concrete flat slab. The study concluded that the addition of continuity plate surrounding column contributed to the increase punching shear strength from (1655 to 1830) kN. The structural form developed incrementally over the course of the research [13] and [9] during which time three types of shearhead were tested. The initial tests were carried out on a pair of hybrid flat slab specimens with fully embedded ACI type shearheads, which were tested to failure under gravity and combined gravity and cyclic lateral loading. They failed in punching shear and exhibited relatively little ductility under cyclic lateral loading. The tests with this arrangement [9] demonstrated the validity of the shearhead concept but the performance was impaired by localised concrete failure around the edge of the shearhead. Therefore, the circular shearhead mentioned in this study may be adopted as a solution for local concrete failure at shearhead edges. Chana and Birjandi also carried out an extensive testing programme on typical cruciform systems having various arrangements of steel beams, including a closed-type system provided with edge beams [14].

2. Experimental Work

2.1. Specimens Details

The experimental work of this study is based on three tested groups; group one (G1) contains four specimens that studied the shape effect of collar shearhead, group two (G2) contains two specimens that studied the number effect of stiffeners and group three (G3) contains two specimens that studied the diameter effect of collar shearhead. Simply supported panels having 80 mm thickness and 1000×1000 mm sides dimensions. The c/c span between supports was 900 mm in both directions. Also, the flexural reinforcement was considered constant. The load was applied centrally by a steel column having dimensions 100×100 mm. The specifications and details of these slabs are listed in Table 1.

Table 1. Characteristics of the tested slabs

Group No.	Specimens	Type of Shearhead	Dimensions of Shearhead (mm)	No. of Stiffener in Each Direction
G1	So	—	—	—
	SS1	Square	300×300×30	1
	SS2	Square	400×400×30	1
	CS1	circular	336 mm diameter with height 30 mm	1
G2	CS3	circular	450 mm diameter with height 30 mm	1
	CS4	circular	450 mm diameter with height 30 mm	2
G3	CS2	circular	336 mm diameter with height 30 mm	2
	CS5	circular	550 mm diameter with height 30 mm	2

2.2. Materials and Methods

2.2.1. Cement

In this investigation type-I ordinary Portland cement was used, it was kept in a dry condition. The chemical and physical properties of this cement are conform to the ASTM C-150 [15].

2.2.2. Coarse Aggregate

A coarse aggregate of maximum size 12 mm and with 2.58 specific gravity, see Figure 1. The coarse aggregate was crushed and elongated to ensure the durability of concrete. The grading of coarse aggregate is conforming to the BS882 [16].

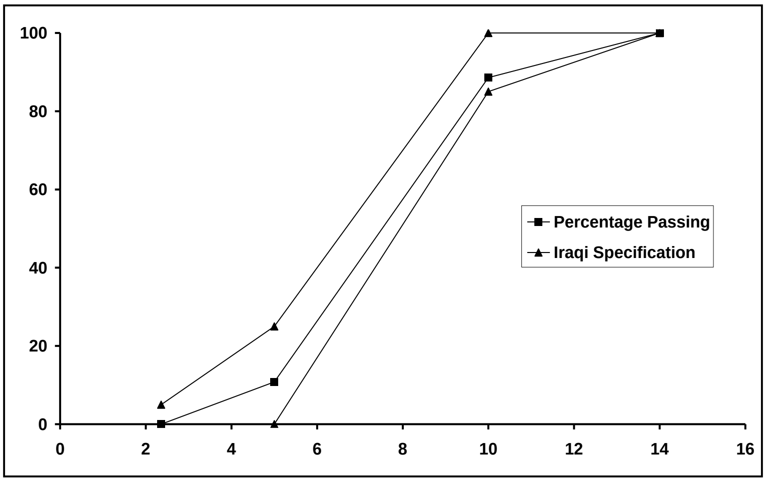

Figure 1. Grading curve for coarse aggregate

2.2.3. Fine Aggregate

A fine aggregate of maximum size 5 mm and with 2.7 specific gravity, see Figure 2. The grading of sand is conforming to the BS882 [16].

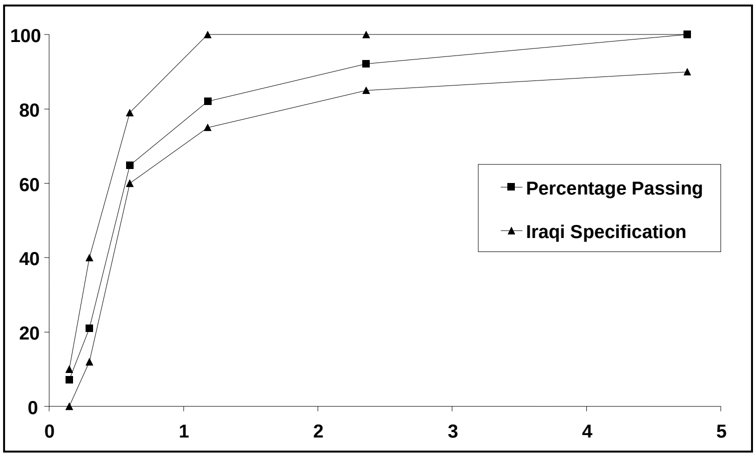

Figure 2. Grading curve for fine aggregate with grading limits in zone 2

2.2.4. Concrete Mix Proportions

The mixing procedure was performed according to ACI committee 211.1-09 [17]. The fine and coarse aggregates were whished and dried, then the large particles was removed and the weights were prepared, then the compounds were mixed for 6-8 minute by drum mixer.

2.2.5. Testing Procedure and Instrumentation

After ending curing period of all cast specimens, specimens were kept in dry place for few hours for attaining surface dry condition. Thereafter, test was carried out in a hydraulic compression testing machine of capacity 3000 kN. All slabs are tested under eccentric load applied at the top of the specimen until failure. Vertical deflections were measured using dial gauges within the accuracy of 0.01 mm.

3. Results and Discussion

3.1. Load-deflection Relationships of Group I

The load–deflection histories of group one are shown in Figure 3. it was observed that the deflection at the center of the reference slab (So) was larger than that of strengthen specimens SS1 ,CS1 and SS2. These curves show that the load–deflection curves were initially linear which represent the load–deflection elastic relationship, and have a specific slop different than the slop of the straight line which appeared after crack stage. Next linear stage represents the relationship between load and deflection, this stage starts at first crack load until yielding of reinforcement steel, the slabs appeared large deformations due to propagation of cracks towards the slab edges and weakness of bond between concrete and reinforcing steel bars. In post–yielding stage (failure stage) produces non-linear relationship between load and deflection. The deflection was increased significantly and the cracks increased in its dimensions length and width, until failure of tested specimens. The load-deflection curves give an indication on the stiffness degradation of tested slab under loading.

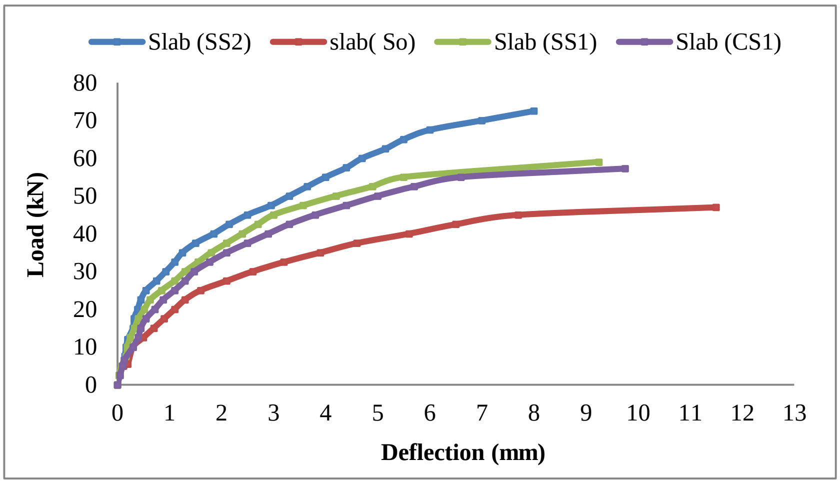

Figure 3. Load–deflection curves for group one

3.2. Load-deflection Relationships of Group II

Figure 4 shows the load–deflection curves comparison for reference panel (CS3) with panel (CS4) that have one stiffener and two stiffers respectively. Typically the specimen behavior passes through three stages; stage one, its linear elastic stage, starts at load applying and extend until appearance of first crack, the specimens recorded good response to load, and there is a convergence in load-deflection curves of two specimens. The second stage (elasto-plastic stage) starts after appearance of first crack until yielding of reinforcing steel, this stage characterized by appearance new cracks extend to the outer edges of the slab. The post-cracking stage characterized by increasing the deformations increments corresponding to the load increments. The later stage starts after yielding reinforcing steel until failure of the specimens. The last part of load–deflection curve characterized by large deflections increments through loading. At the same load level, it is significantly noticed that the specimen CS4 with double stiffeners have deflection larger than the deflection of slab CS3 with single stiffeners. It may be attributed to creation two cracks starts at the free ends of flange through the confined concrete between flanges. The concrete contribution between flanges was reduced to resist the applied stresses due to the separation from the concrete outside the stiffeners, as shown in Figure 5.

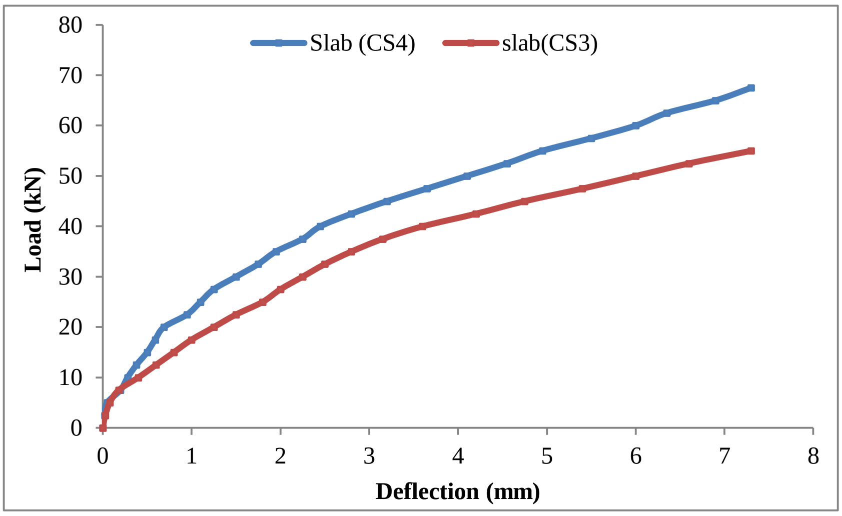

Figure 4. Load–deflection curves for group two

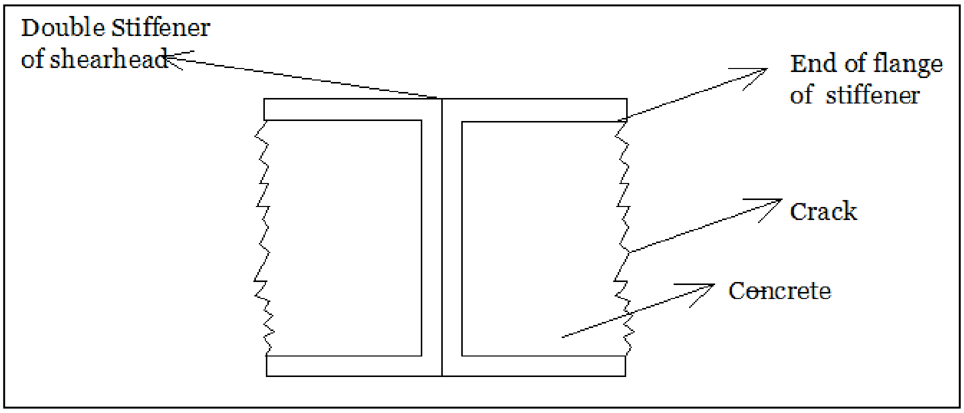

Figure 5. Creation of crack in specimen (CS4)

3.3. Load-deflection Relationships of Group III

In group three, the diameter of shearhead effect toward reducing the deflection of the specimen, i.e., the deflection decreased by using larger shearhead collar diameter. As shown in Figure 6, three stages can be distinguished through observation of load–deflection curves; first linear stage, represent the elastic rang of the member, other linear stage represent the elasto-plastic behavior and third stage (failure stage) can be seen in post-yielding stage. At the same level of loading, the specimen CS2 with small diameter has large deflection than specimen CS5 with large diameter respectively.

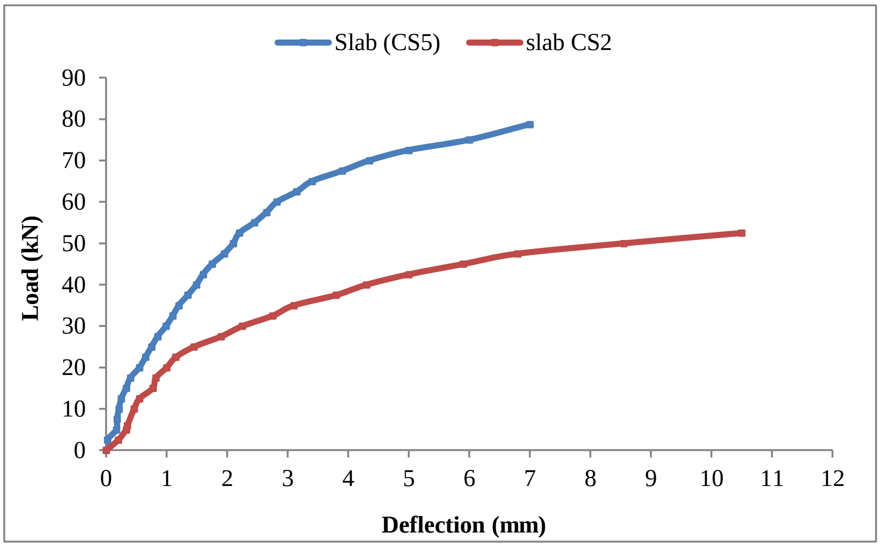

Figure 6. Load–deflection curves for group three

3.4. Ultimate Punching Shear Capacity

The main aim of this study is to determine the ultimate punching shear capacity of specimen with proposed shearhead reinforcement and make comparison with reference slab (without shearhead). The observed load capacities of the tested slabs are shown in Table 2. The experimental results indicate that the slab in group (1) SS1, SS2 and CS1 give an increase in ultimate load capacities over that the reference specimen (So) by about 21.8%, 25.5% and 54.2%. The specimen CS1, SS1 and SS2 were reinforced with circular shearhead (336mm diameter), square shearhead 300×300 mm and square shearhead 400×400 mm respectively. The shearheads of these specimens is enough to resist the punching stress, and the punching shear stresses is low due to the increasing in loaded area.

For group two, experimental results showed that the increase in the number of stiffeners in specimen CS4 reduced the ultimate punching shear capacity by about 20.3% over reference specimen CS3; specimen CS3 contains one stiffener and specimen CS4 contains two stiffeners.

Finally, the ultimate load was increased about 14.5% when increasing the diameter of shearheads from 336 mm to 550 mm in specimens CS2 and CS5 respectively.

Table 2. The load capacity and first crack of the tested slabs

Group No.	Specimen	First Crack	Improvement of Pcr (%)	Ultimate Load (Pu)	Improvement of Pu (%)	Pcr/Pu %	Mode of failure
G1	So	13	R	47	R	27.6	flexure
	CS1	6.5	50*	57.25	21.8	11.3	flexure
	SS1	7.5	42.3*	59	25.5	12.7	punching
	SS2	11.5	11.5*	72.5	54.2	15.8	punching
G2	CS3	12.5	R	73.75	R	16.9	combined
	CS4	7.5	40*	58.75	20.3*	12.7	combined
G3	CS2	10	R	68.75	R	14.5	combined
	CS5	15	50	78.75	14.5	19	flexure

* Decrease of improvement and R is the reference specimen of each group.

3.5. Cracking Load

The experimental results of tested slabs with first crack load are mentioned in Table 2, the crack opened when the applied stress reached to the tensile strength of concrete. For group one, the first crack was opened at 6.5, 7.5 and 11.5 kN for specimens CS1, SS1 and SS2 respectively. While the reference specimen achieved first crack at load 13 kN. The decrease in first crack load of specimens CS1, SS1 and SS2 is may be due to weak of bonding between concrete and steel shearhead.

The group two includes two specimens CS3 and CS4 the first crack was deceased from 12.5 to 7.5 kN when increase the number of stiffener from one to two stiffeners.

In group three, the cracking load was increased with increase the diameter of circular shearhead from 10 to 15 kN in specimens CS2 and CS5 respectively; specimens CS2 and CS5 have diameter 336 and 550 mm respectively.

3.6. Mechanical Behavior of Slabs

3.6.1. Group One

Four specimens were tested concentrically under static load; two of tested specimens failed in flexural mode; reference specimen So and CS1. While other two specimens SS1 and SS2 failed in punching shear mode. A punching failure was attained when a cone of concrete completely punching out of the slab, see Figures 7, 8, 9 and 10. The failure was brittle with no prior warning; the suddenness of the failure can be concluded from load–deflection curve. On the other hand, the flexural failures of specimen So and CS1 was characterized by ductility more than other specimens, the specimen can absorb a large part of energy at the advanced stage of loading.

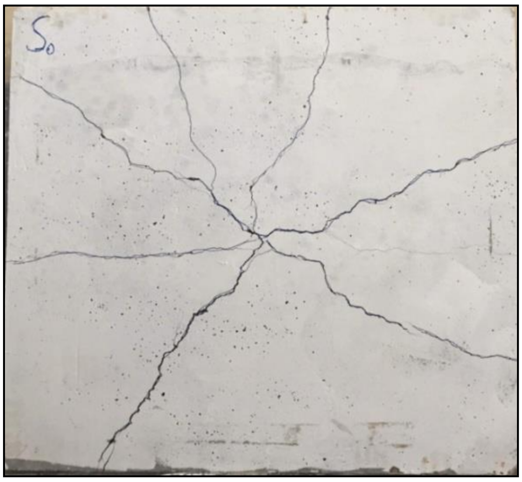

Figure 7. Crack pattern of reference specimen (So)

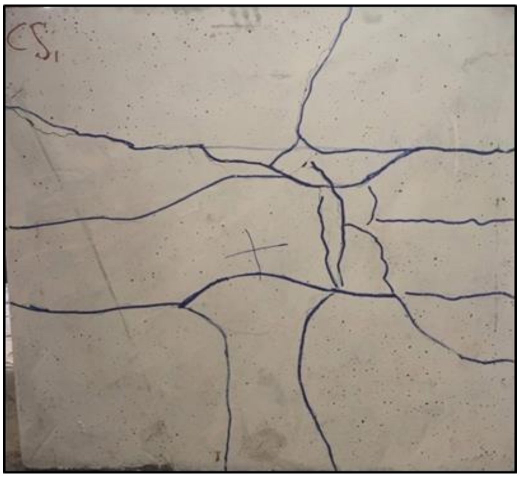

Figure 8. Crack pattern of specimen (CS1)

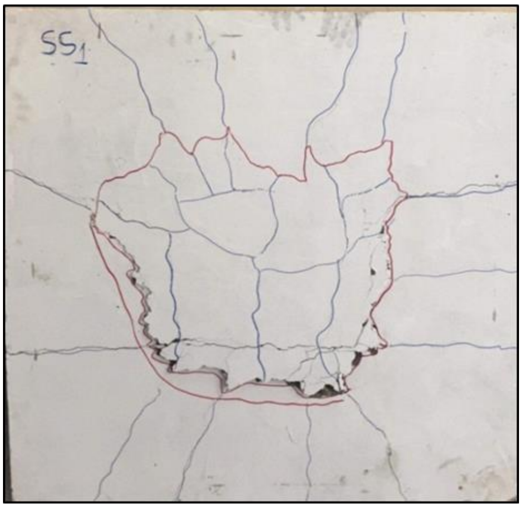

Figure 9. Crack pattern of specimen (SS1)

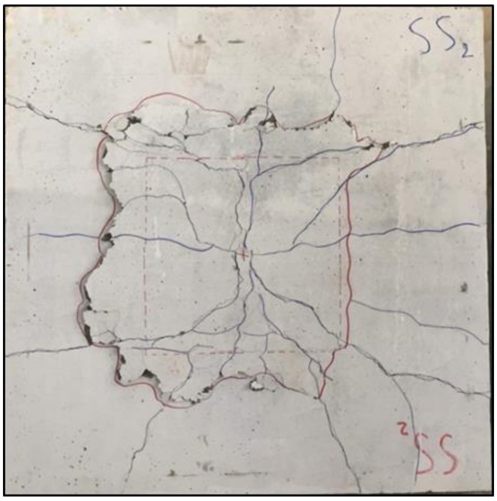

Figure 10. Crack pattern of specimen (SS2)

3.6.2. Group Two

Two specimens were tested under static load. The failure mode of two specimens may be considered as flexural-punching shear failure (combined failure) in which both flexural and punching shear crack were observed at tension face of the slabs. The failure of specimens was moderately ductile failure and the formation of complete failure was gradual. See Figures 11 and 12.

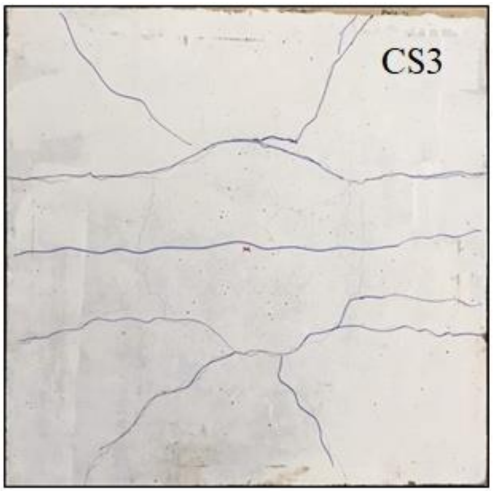

Figure 11. Crack pattern of specimen (CS3)

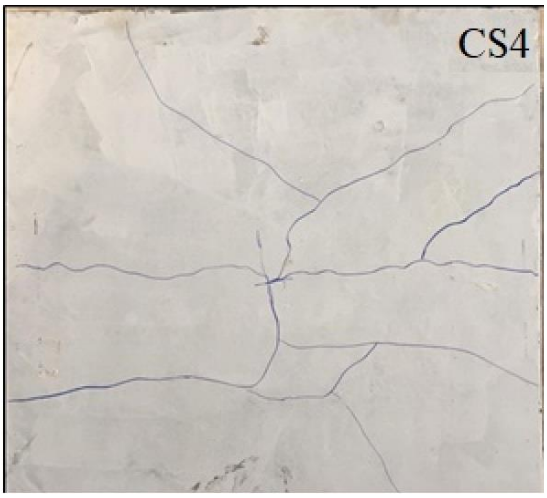

Figure 12. Crack pattern of specimen (CS4)

3.6.3. Group Three

Two specimens were tested under static load with shearhead diameters 336 and 550 mm for specimen CS2 and CS5 respectively. The failure of specimen CS5 was flexural failure mode, the flexural crack clearly observed at the tension face of the slab, several cracks were extended to the compression face. Figures 13 and 14 shows other specimens with small diameter were failed by flexural-punching shear failure, in which the flexural and punching cracks were appeared at the tension face of the slab.

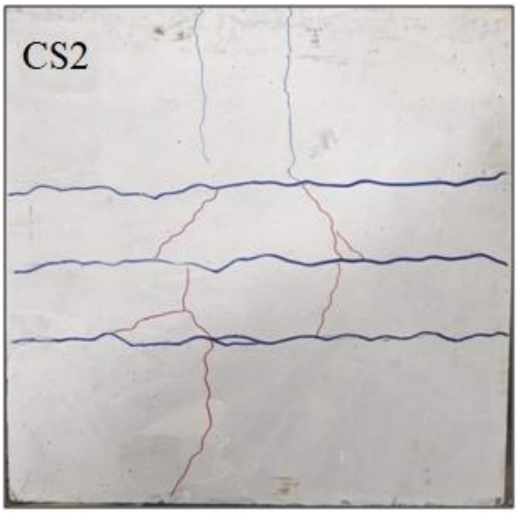

Figure 13. Crack pattern of Specimen (CS2)

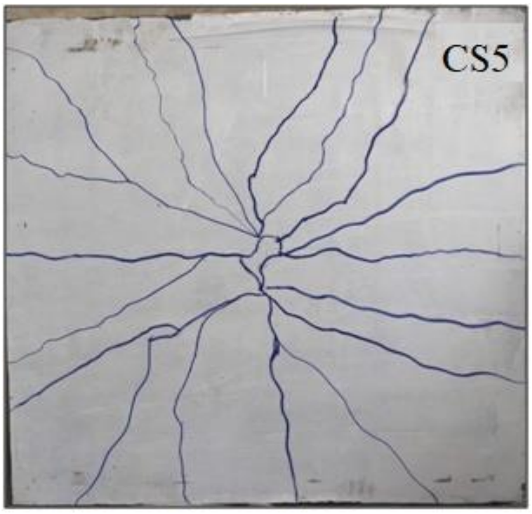

Figure 14. Crack pattern of specimen (CS5)

3.7. Crack Pattern and Failure Modes

3.7.1. Group One

The first crack of all the tested specimens in group one was observed at the tension face of the slab near the column stub in case of unreinforced panel (without punching shearhead reinforcement), while the first crack of the specimen with punching shear reinforcement was observed at the tension face of the slab near the shearhead edges.

At the initial stage of loading cracks extended along the tension reinforcement in two directions. These cracks extend gradually to the slab edges accompanied with increasing its width, a new cracks appeared in the diagonal axis of the panel and extended to the corners. The first flexural cracks initiated at 27.6% of the ultimate load as shown in Table 2. At this stage, the tensile stresses of concrete in specimen equal to the applied stresses. At advanced stage of loading, the reference specimen failed by flexural mode as a result of increasing the crack width interestingly. The slab with circular shearhead have first crack load 11.3% of ultimate load, the cracks appeared at the tension face of the slab approximately under shearhead edges. These cracks extended with the same direction of flexural reinforcement. With loading, the diagonal cracks extend toward the slab corners. At the advanced stage of loading, secondary cracks speared from the primary crack with direction perpendicular to the main crack and create a punching zone pulled out from the slab.

The square shearhead slabs achieved cracks load at 12.7% of ultimate load in specimen SS1 and 15.8% in specimen SS2 of ultimate load. By the same way, the first crack appeared at the tension face of the slab near shearhead edges and extended with the same direction of flexural reinforcement. With loading, new cracks appeared between the later cracks approximately at the shearhead edges cause failure of slabs by punching shear.

3.7.2. Group Two

The tested results of crack and ultimate loads of tested slab in group three were mentioned in Table 2, the first crack of specimen CS3 was create at 16.9% of ultimate load. The first crack was appeared around the edges of shearhead collar on the tension face of the slab panel. The crack was propagated parallel to the flexural reinforcement toward the slab edges until appearing secondary cracks connect the flexural cracks together, these secondary cracks positioned around the shearhead edges and continue to increase in width until failure of the specimens by flexural and punching shear cracks (combined action of flexural and punching shear failure). The failure was moderate in the progressive collapse.

On the other hand, the specimen CS4 which strengthened by shearhead with two stiffener in each direction, the first cracks appeared around the edges of shearhead at 12.7% of ultimate load. The cracks extend gradually to the outer edge of the slab parallel the flexural reinforcement in addition to create new cracks extend diagonally to the slab corners. At the advanced stage of loading, the slab failed in ductile mode by flexural and punching shear cracks.

3.7.3. Group Three

The first crack appeared at about 14.5% and 19% of ultimate load for specimens CS2 and CS5 respectively. The specimen CS2 failed by combined failure of punching and flexural, while specimen CS5 failed by flexural failure.

3.8. Energy Absorption

The use of shearhead as punching shear reinforcement in slabs increasing the energy absorption of tested specimens, the amount of improvement in energy absorption of specimen SS1 (square shearhead with 300×300×30 mm dimensions) almost negligible (about 0.4%) over the reference specimen So. For specimen SS2 (square shearhead with 400×400×30 mm dimensions), the amount of improvement in energy absorption reached 274.2% as compared with reference specimen So. The specimen CS1 (circular shearhead with 336 mm diameter ×30 mm height of shearhead) achieved an energy absorption 427 kN.mm higher than the reference specimen So by about 2.6%, see Table 3.

Table 3. The energy observation of tested slabs

Specimen	Energy absorption (kN.mm)	Percentage (%) Improvement of energy absorption
So	415.9	R*
SS1	417.6	0.4
SS2	1556.3	274.2
CS1	427	2.6
CS3	355	R*
CS4	746.5	110.2
CS2	1163.6	R*
CS5	1363.5	17.1

*R: is the reference specimen of each group.

The energy absorption of specimen with two stiffeners more than that specimen of one stiffeners by about 110.2%, this improvement in the amount of energy absorption is may be attributed to increase the elasticity of the shearhead in specimen of one stiffener, the specimen with two stiffeners have more rigidity, the specimen with one stiffener failed with large displacement in comparison with specimen of two stiffeners.

The increase in the shearhead diameter gives a beneficial effect in increasing the energy absorption of the tested specimens; the specimen CS5 and CS5 of diameter 450mm and 550mm respectively gives largest energy absorption than specimen CS2 and CS2 of dimensions (336mm), large diameter gives high load capacity with small deflection made the area under the load-deflection curves increased accordingly.

3.9. Ductility

Ductility could be calculated from the ratio of the maximum deflection at ultimate load to the deflection at yielding load [18]. Table 4 shows the deflection readings at ultimate carrying capacity and at yield load in addition to the ductility index for each specimen. For group one the reference specimen recorded minimum ductility in comparison with specimens has shearhead reinforcement.

All types of shearhead were not recorded largely different in ductility index; slight decrease in ductility of square shearhead SS2 was observed.

Slight increases in ductility for group two when increasing the number of stiffeners may be neglected. The ductility of slabs of group three was decreased with increasing of shearhead diameter; 20%, the amount of decreasing in ductility of specimen CS5 with respect to reference specimens CS2.

Table 4. The ductility of tested slabs

Specimen	Δu (Deflection at Failure) (mm)	Δy (Deflection at Yield) (mm)	Ductility Index	% Increase in Ductility Index
Group one				
So	11.5	4.6	2.5	R
SS1	9.25	2.4	3.8	52
SS2	8	2.95	2.7	8
CS1	9.75	2.9	3.3	32
Group two				
CS3	7.75	4.1	1.8	R
CS4	9.5	4.75	2	11.1
Group three				
CS2	8.6	3.35	2.5	R
CS5	7	3.4	2	20

*R: is the reference specimen of each group.

3.10. Stiffness

The stiffness of each tested slab is shown in Figure 15 and Table 5, it is significantly appeared that the initial stiffness of references slab (So) is lower than the strengthened specimen CS1, SS1 and SS2.

The amount of reduction in stiffness in the references slab So between 25 and 50% of the ultimate load was 38%. In contract, the reduction in the stiffness of strengthened specimen SS1, SS2 and CS1 was 45.1, 49.6 and 36.6% respectively. The rate of degradation in stiffness of slabs with square shearhead is higher than that of the reference slab. On the other hand, the rate of degradation in stiffness of slab with circular shearhead is less than the reference specimen, also, it is noticed that the references panel slab (So) suffers large deterioration as result of punching shear and flexural cracks.

At 75% of ultimate load the specimen (So) recorded 8.81 kN/mm stiffness. At this stage, the specimen lacked 66.2% of its initial stiffness. At the failure, the reference specimen lacked about 83.9% of its initial stiffness.

In specimen SS1, the stiffness at 25% of ultimate load reached to 44.7kN/mm, so it is larger than the stiffness of references specimen at the same loading level. At loading level 50% of the ultimate load, the specimen recorded 45.1% reduction in its stiffness in comparison with the state of specimen at 25% loading level. The reduction of stiffness of specimen SS1 at 75% of ultimate load reached to 65.8% with respect to its stiffness at 25% of ultimate load. At failure, the reduction of stiffness reached 85.7% of its stiffness at 25% of ultimate load. It is significantly noticed that the initial stiffness of references specimen is smaller than the stiffness of the specimen with shearhead. But, the amount of reduction in the stiffness of shearhead specimen was larger than that of reference specimen. This large deterioration may be attributed to concentration of stresses at corners of shearhead to make the cracks propagation faster than that of references specimen, this leads to significant reduction in stiffness through loading.

A similar behavior can be observed in specimen CS1 related to the degradation in its stiffness; at 50% of ultimate load, the stiffness reduction was about 36.6% in comparison with specimen stiffness at 25% of ultimate load, in consequence, the specimen CS1 recorded stiffness reduction about 61.2% with respect to its stiffness at 25% of ultimate load. Finally, 83% of stiffness reduction was achieved at ultimate failure load when increasing the dimensions of shearhead in specimen SS2. The behavior did not significantly differ in comparison with the same type of shearhead; 49.6, 73.1 and 83%, amount of stiffness reduction at 50, 75 and 100% of ultimate capacity respectively.

In group two, increasing the number of stiffeners didn't affect clearly on the rate of the stiffness loss of the tested slabs. The specimen CS3 lost 42.8% from its stiffness at 50% of ultimate load, 62.3% at 75% of ultimate load and 67.4% at 100% of ultimate load in comparison with specimen stiffness at 25% of ultimate load. While the specimen

CS4 achieved a decrease in its stiffness about 33.4% , 54.5% and 68.5% at 50% ,75% and 100% of ultimate load respectively in comparison with its stiffness at 25% of ultimate load .

In group three, a comparison between two specimens has different circular shearhead diameters (336 and 550 mm). The specimen CS5 lost about 41.7% from its stiffness at 50% of ultimate load. At 75% of ultimate load, the specimen lost about 58.2% of its stiffness at 25% of ultimate load. At failure (100% of ultimate load), the specimen lost about 71.3% of its stiffness at 25% of ultimate load. Briefly, the specimen has large diameter tend to loss it's stiffness faster than that of the specimen with small shearhead diameter.

Table 5. The stiffness of tested slabs

Specimen	Stiffness at 25% (1)	Stiffness at 50% (2)	% Decrease between (1) and (2)	Stiffness at 75% (3)	% Decrease between (1) and (3)	Stiffness at 100% (4)	% Decrease between (1) and (4)
Group one							
So	26.11	16.2	38%	8.81	66.2%	4.2	83.9%
SS1	44.7	24.5	45.1%	15.25	65.8%	6.37	85.7%
SS2	53.3	26.85	49.6%	14.3	73%	9.06	83%
CS1	32.52	20.59	36.6%	12.6	61.2%	5.87	82%
Group two							
CS3	29.2	16.7	42.8%	11	62.3%	9.5	67.4%
CS4	20.9	13.9	33.4%	9.5	54.5%	6.18	68.5%
Group Three							
CS2	25.6	14.9	41.7%	10.7	58.2%	8	68.7%
CS5	39.2	28.12	28.2%	21	46.4%	11.25	71.3%

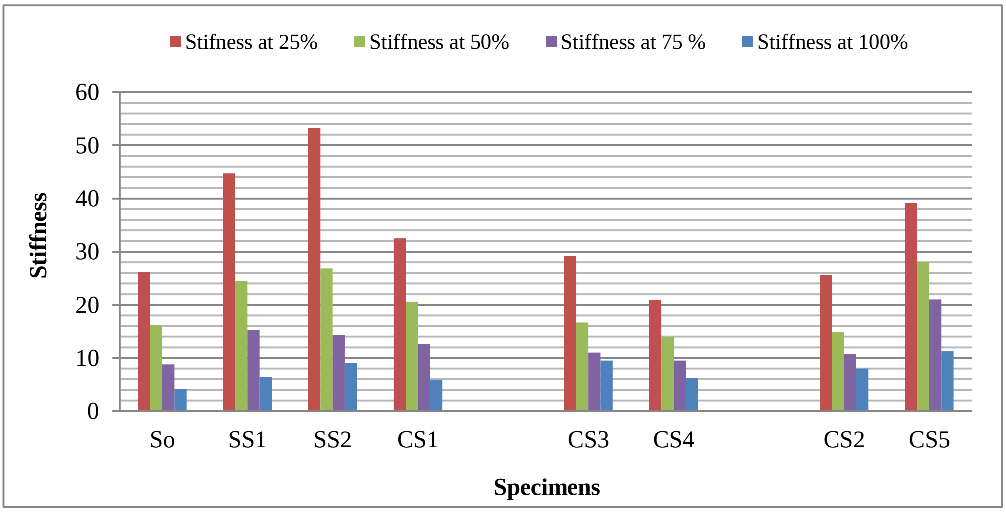

Figure 15. Stiffness of tested slab at different levels

6. Conclusions

- Both square and circular shearheads increased the punching shear strength of tested flat plate panels, punching shear strength of panels have circular shearhead and square shearhead is found to increase by about 83.5% and 54.2% over reference specimen.
- The first crack load value is found by decrease about 50% for circular shearhead and about 11.5% for square shearhead in comparison with reference specimen.
- Number of stiffeners is found to decrease the punching shear strength and first crack load by about 20.3% of ultimate load and 40% of first crack load respectively.
- Punching shear strength and first crack load were increased as the diameter of shear head increased by about 50% and 14.5% respectively.
- In general, there is an increase in ductility due to the use of shearhead reinforcement.

- Curvature ductility decreases as the diameter of shearhead increases by about 20% when increase the shearhead diameter from 336mm to 550mm.
- In general there is an increase in stiffness due to the use of shearhead reinforcement.
- Curvature stiffness was increased as the diameter of shearhead increased.

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8. Conflicts of Interest

The authors declare no conflict of interest.

9. References

[1] McCormac, Jack C., and Russell H. Brown. Design of reinforced concrete. John Wiley & Sons, 9th Edition." (2014).

[2] Moreno, Carlos L., and Ana M. Sarmento. "Punching Shear Analysis of Slab‐column Connections." Edited by Helena Barros. Engineering Computations 30, no. 6 (August 16, 2013): 802–814. doi:10.1108/ec-jun-2012-0122.

[3] Nilson, A. H., Darwin, D. and Dolan, C. W. "Design of Concrete Structures, 14th edition." (2013). ISBN-13: 0073293490.

[4] Pilakoutas, Kypros, and Xiaopeng Li. "Alternative shear reinforcement for reinforced concrete flat slabs." Journal of Structural Engineering 129, no. 9 (2003): 1164-1172. doi: 10.1061/(ASCE)0733-9445(2003)129:9(1164).

[5] Al-Maiaahei A. N. "Experimental Study of Flat Plate Construction with Special Embedded Shearhead." (2006). M.Sc. Thesis. Al-Mustansiriya University. Baghdad. Iraq.

[6] ACI (American Concrete Institute). "ACI 318-08: Building code requirements for structural concrete." (2008).

[7] Piel, Wolfgang, and Gerhard Hanswille. "Composite Shear Head Systems for Improved Punching Shear Resistance of Flat Slabs." Composite Construction in Steel and Concrete V (February 3, 2006). doi:10.1061/40826(186)22.

[8] Fastabend, Michael, Norbert Sauerborn, Till Neubauer, and Norbert Doering. "Concepts of composite constructions for high punching loads-basic principles and application." Beton-Und Stahlbetonbau 103, no. 11 (2008): 735-740.

[9] Eder M, Elghazouli AY and Vollum RL, Strength and Ductility of Connections between Tubular Columns and Flat Slabs under Monotonic and Cyclic Loading Conditions, CIDECT Programme 4F, Final Report, Imperial College London, June 2010.

[10] Seible, Frieder, Amin Ghali, and Walter H. Dilger. "Preassembled shear reinforcing units for flat plates." In Journal Proceedings, vol. 77, no. 1, pp. 28-35. 1980.

[11] Abdu AL-Rahman, S., "Experimental Study of Embedded Steel Plate as Shearheads Reinforcement with Steel Fiber in Flat Plate-Column Connection", M.Sc. Thesis, Al- Mustansiriya University, 2010.

[12] Bompa, D.V., and A.Y. Elghazouli. "Structural Performance of RC Flat Slabs Connected to Steel Columns with Shear Heads." Engineering Structures 117 (June 2016): 161–183. doi:10.1016/j.engstruct.2016.03.022.

[13] Eder, M.A., R.L. Vollum, A.Y. Elghazouli, and T. Abdel-Fattah. "Modelling and Experimental Assessment of Punching Shear in Flat Slabs with Shearheads." Engineering Structures 32, no. 12 (December 2010): 3911–3924. doi:10.1016/j.engstruct.2010.09.004.

[14] Chana, P. S., and F. K. Birjandi. "Design guidance on structural steel shearheads in concrete." Project report for Reinforced Concrete Council and Department of the Environment, CRIC CLIENT REPORT CRIC95/001/F, Imperial College London (1996).

[15] ASTM C-150. 2015. "Standard specification for Portland cement." ASTM International,

[16] BS882. 1992."specification for aggregate from nurture source for concrete", (December 1992).

[17] Dixon, Donald E., Jack R. Prestrera, George RU Burg, Subcommittee A. Chairman, Edward A. Abdun-Nur, Stanley G. Barton, Leonard W. Bell et al. "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91)." (1991).

[18] Priestley, M. J. N., and M. J. Kowalsky. "Aspects of drift and ductility capacity of rectangular cantilever structural walls." Bulletin of the New Zealand National Society for Earthquake Engineering 31, no. 2 (1998): 73-85.