Journal of Engineering and Development, Vol. 11, No. 3, December (2007) **ISSN 1813-7822**

Experimental Study of Flat Plate Construction with Special Embedded Shearhead

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Abstract

The objectives of this investigation are to study the efficiency of different shapes of steel plate embedded in flat plate slabs as shearhead reinforcement. The effects of the shear reinforcement (steel plate) on the cracking load, ultimate load and ductility are examined.

Fourteen test slabs were prepared in this study. The models simulate the region of negative bending moment around an internal column supporting a flat plate roof. Two specimens were cast without punching shear reinforcement and twelve specimens were cast with different shapes of steel plate as punching shear reinforcement. The test loads were applied incrementally till the ultimate carrying capacity was reached. Deformations, crack patterns and ultimate loads were recorded.

الخلاصة

الغرض من هذا البحث هو دراسة كفاءة اشكال مختلفة من الصفائح الحديدية كتسليح قص رأسي مغمور في السقوف المستوية. درس تأثير الصفائح الحديدية على حمل التشقق، الحمل الاقصى والمطيلية.

فحصت اربع عشر بلاطة في هذه الدراسة. وهذا الموديل يمثل منطقة العزم السالب حول العمود الوسطي الساند لهذه البلاطة. تم صب نموذجين بدون تسليح قص ثاقب و اثنا عشر نموذج صبت باشكال مختلفة من الصفائح الحديدية كتسليح للقص الثاقب. سلطت الاحمال بصورة متزايدة حتى بلوغ الحمل الاعظم (حمل الفشل). سجل مقدار التشوهات، انماط الشقوق و الحمل الاعظم.

1. Introduction

From an aesthetic and economic point of view, the flat plate structure has an advantage over other slab systems because of the significant saving in construction work and aesthetically pleasing appearance. In addition, the elimination of beams and girders reduces the overall floor depths of a multi-story building, thus creating additional floor space for a given building height. For this reason, flat plates are widely used for multi-storey structures such as office buildings.

A shearhead is a separately definable structure embedded in the concrete at the junction, and serves to spread the load of the floor on the respective column and thereby reduces the effect of the vertical forces; i.e., reduces the stress in the slab concrete by increasing the critical punching shear perimeter around the column.

Research into shearheads is based essentially on the premise that shear failure of the laterally extending slab occurs along a shear failure plane on a perimeter, around the head of the column. If this shear perimeter can be enlarged; i.e., wider space from the column axis, then the shear forces acting on the slab at a particular point on the perimeter will be reduced. And this may leads to control the design of flat plate, with less thickness and also less bending reinforcement in area adjacent to column and allows for the increase in the panel length.

Several types of shearheads are used in different countries such as:

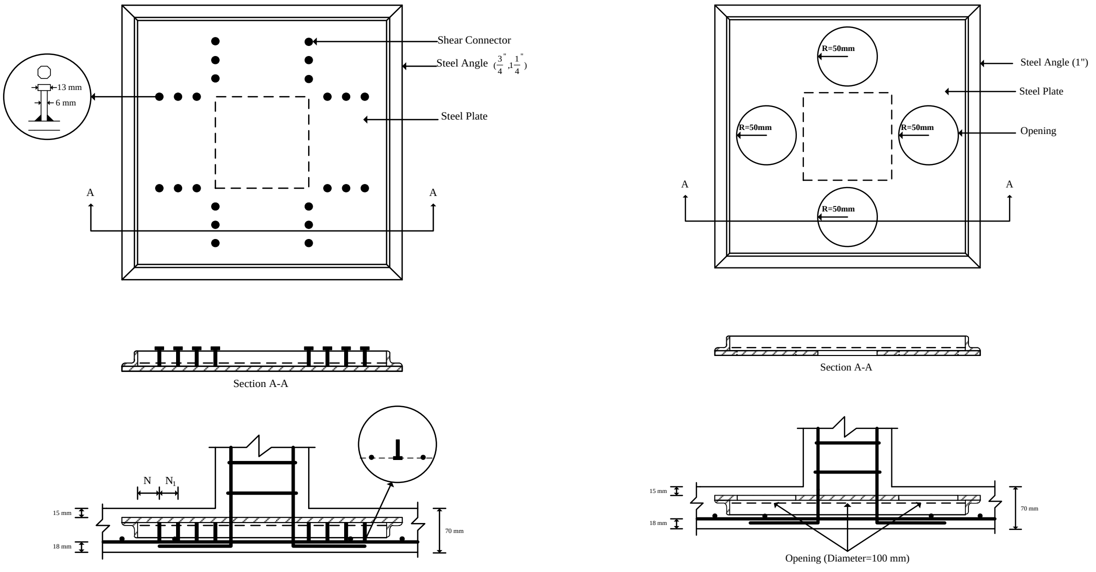
1. Two pairs or single crossed channel or wide flange steel sections.
2. Collars from steel channels (Giellinger shearheads).
3. Steel plate [1,2,3].

2. Experimental Investigation

2-1 Test Slabs

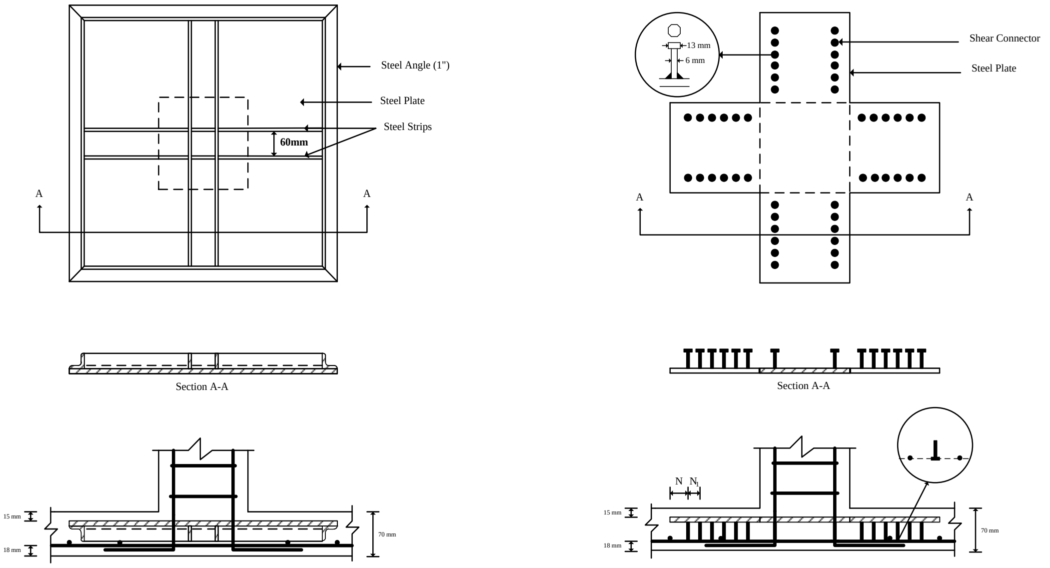
Fourteen slabs were cast at (1000X1000X70 mm) slab dimensions simply supported along the four sides and axially loaded through a central column (150X150X200 mm). The flexural reinforcement consisted of mild steel plain bars of (6 mm) diameter in the tension side with tensile yield strength 383MPa and spacing (105 mm) in each direction. A mesh consisting of 10 bars in each direction. The clear cover to reinforcement was 18 mm. The fourteen slabs were divided into groups; Group one contains seven specimens with steel plate as shown in **Fig.(1a)**, group two contains four specimens with three types of steel plate as shown in **Figs.(1b)**, **(1c)** and **(1d)**. Group three contains parametric study on slab in **Fig.(1d)** the details and specifications of these slabs are shown in **Table (1)**.

The concrete used for the preparation of these slabs consisted of locally available gravel, sand, ordinary Portland cement and water. The mix was designed to give cube compressive strength of (28MPa) tested according to BS 1881[4] by using hydraulic machine. The average modulus of elasticity was 23.7 GPa measured according to ASTM C469 [5]. The average modulus of rupture was 3.23 MPa measured according to ASTM C78-84[6].



a) Type One

b) Type Two



c) Type Three

d) Type Four

Figure (1) Type of tested steel plate

Table (1) Characteristics of the tested slabs

Group No.	Specimens	Type of plate Figure (1)	Dimensions of plate (mm)	No. of shear connectors in each direction	Spacing(mm)		Stiffeners
					N*	N_1**	
G1	R1	—	—	—	—	—	—
	S1	(a)	350×350×1	2	40.5	40.5	∟ 3/4
	S2	(a)	350×350×3	2	40.5	40.5	∟ 3/4
	S3	(a)	250×250×1	2	15.5	15.5	3/4∟
	S4	(a)	450×450×1	2	65.5	65.5	3/4∟
	S5	(a)	450×450×1	6	32.75	32.75	3/4∟
	S6	(a)	350×350×1	2	34.125	34.125	1 1/4∟
G2	R2	—	—	—	—	—	—
	PP5	(b)	450×450×5	—	—	—	1∟
	P52S	(c)	450×450×5	—	—	—	1∟
	P52R	(d)	450×450×5	12 (2 rows)	16	22.3	—
G3	P53R	(d)	450×450×5	18 (3 rows)	16	22.3	—
	P82R	(d)	450×450×8	12 (2 rows)	16	22.3	—
	P83R	(d)	450×450×8	18 (3 rows)	16	22.3	—

**N: The distance between edge of plate and first peripheral line of shear connectors as shown in Figure (1).*

***N_1: The distance between two shear connectors as shown in Figure (1)*

∟: *Steel angles with dimensions 3/4 or 1 1/4 or 1 inch.*

2-2 Loading Set Up and Measuring Devices

The tested slabs were mounted as shown in **Fig.(2)**. The simple support along each edge was provided by steel rods of (30mm) diameter resting on loading frame, made of structural steel C-Beam. All slabs were axially loaded through the central square column by hydraulic jack of (3000 kN) capacity. Deflections on the bottom surface of the slab were measured by dial gauge at the center of slabs its accuracy is (0.01 mm), as shown in **Fig.(3)**.

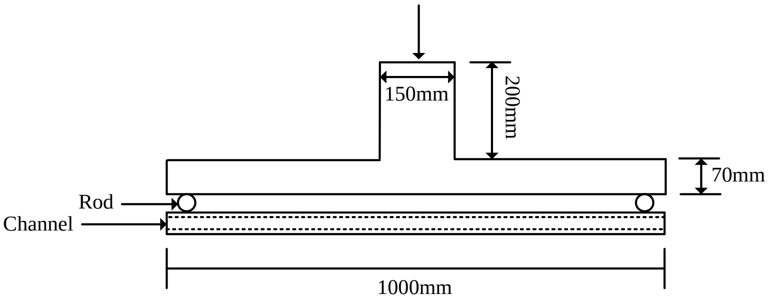


Figure (2) Positions of supports

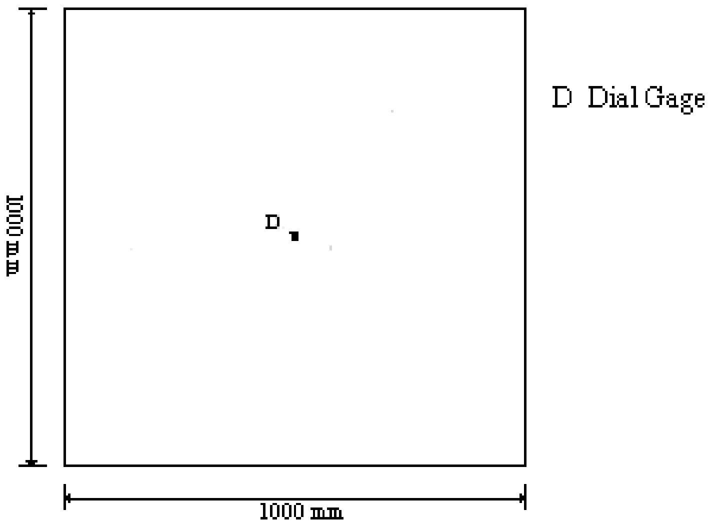


Figure (3) Position of dial gauge at bottom face

3. Experimental Results

3-1 Load-Deflection Relationship

The relationship between the applied load and the central deflection of the specimens are similar as shown in **Fig.(4)**. When a reinforced concrete slab is subjected to a gradual increase in load, the deflection increases linearly with the load in an elastic manner. After the cracks start developing, deflection in the slab increases at a faster rate. After cracks have developed in the slab, the load-deflection curve is approximately linear up to the yielding of flexural reinforcement after which the deflection continues to increase without an appreciable increment in load.

At same load, the deflection in the slab with embedded steel plate and their components (shear connectors and stiffeners) is smaller than the deflection in the slab without steel plate because the steel plate increased flexural rigidity of the slab. As a result the deflection is decreased.

The effect of increasing shear connectors, thickness of steel plate and dimensions of steel plate is clear in increasing the ultimate deflection.

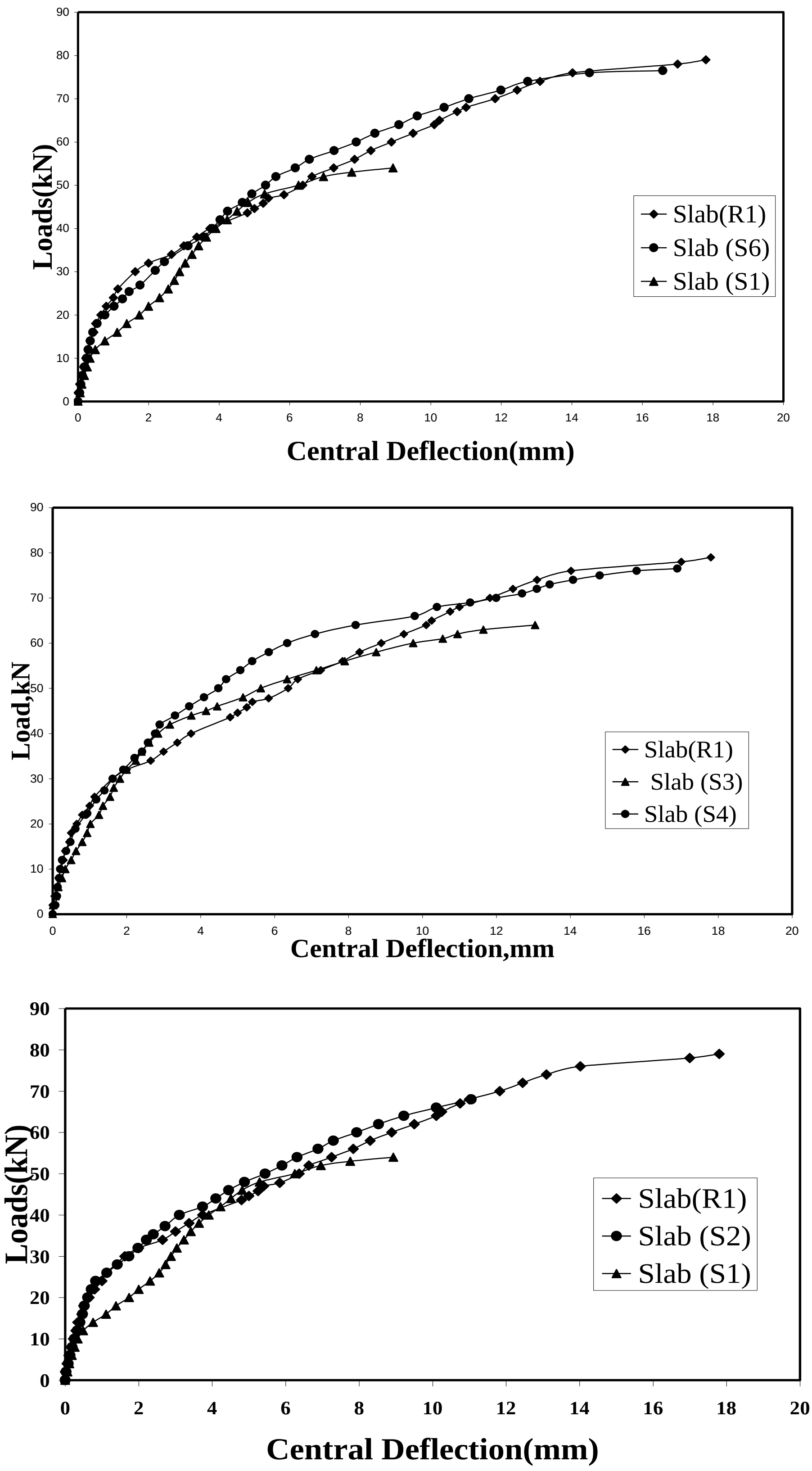
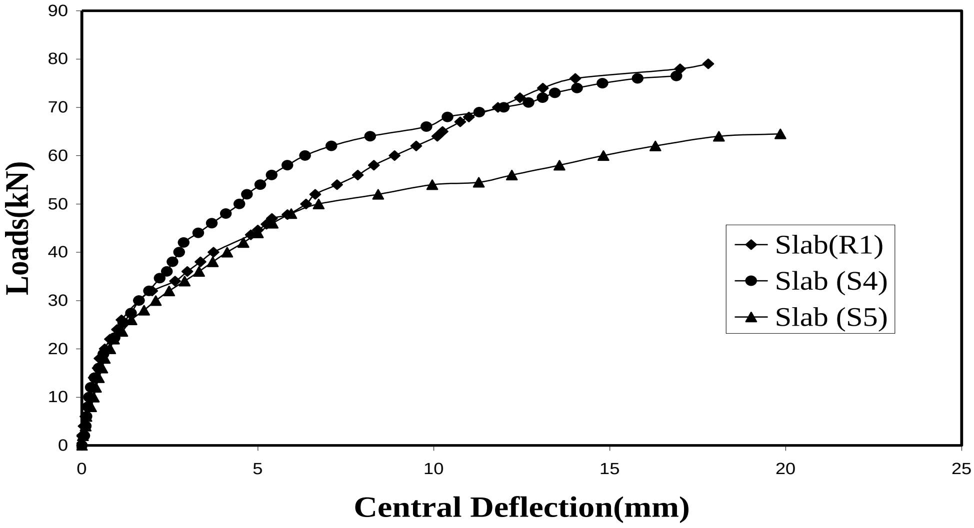
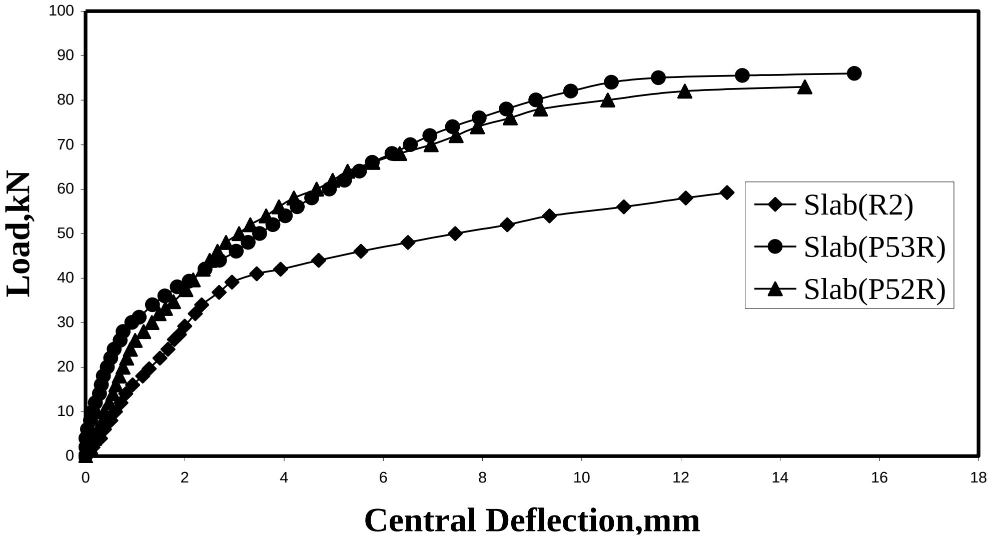


Figure (4) Load-central deflection curves for tested slabs





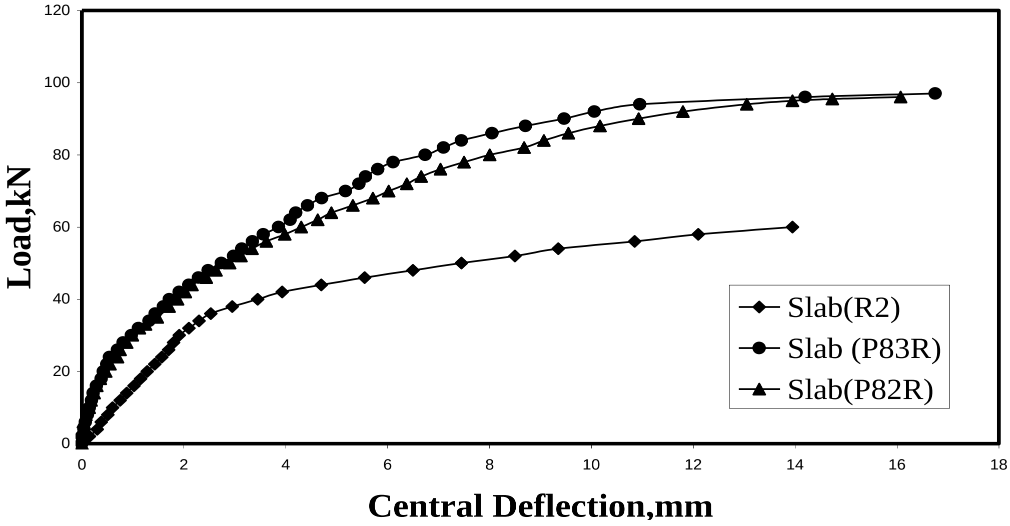
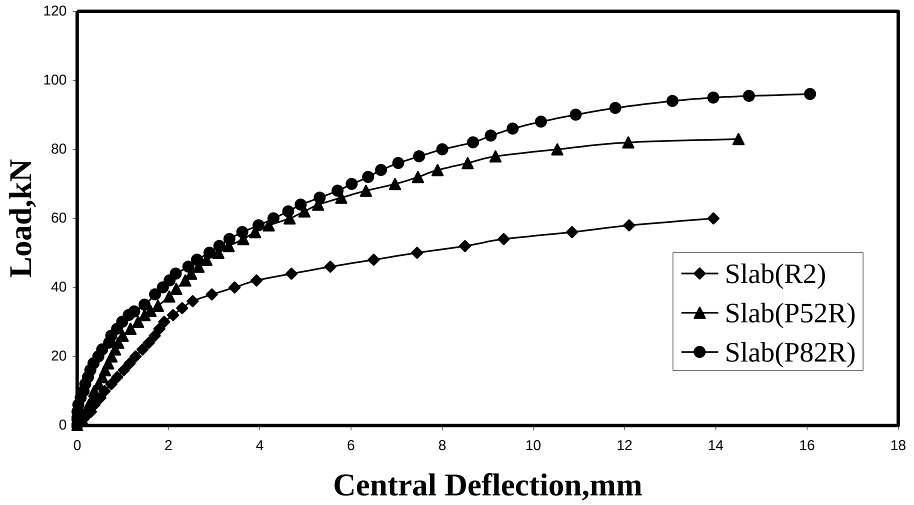
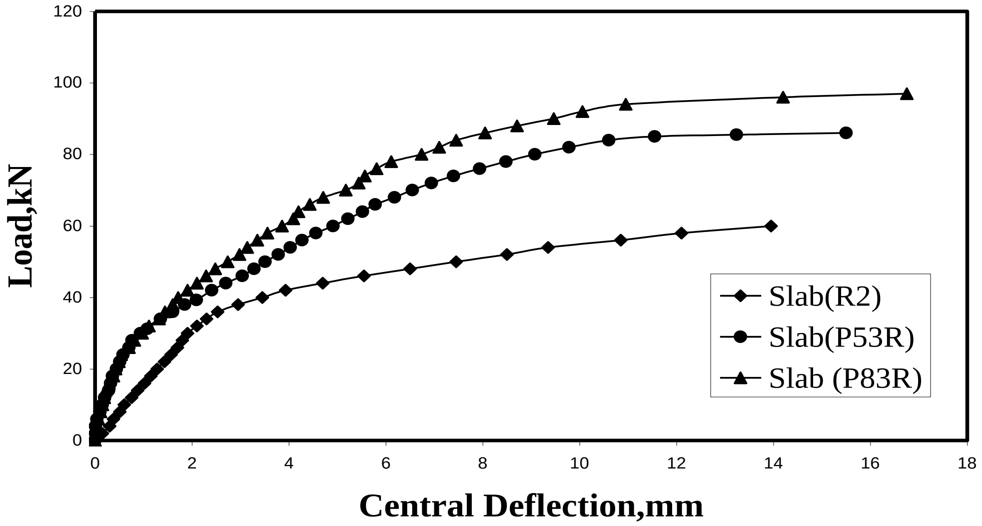


Figure (4) Continued





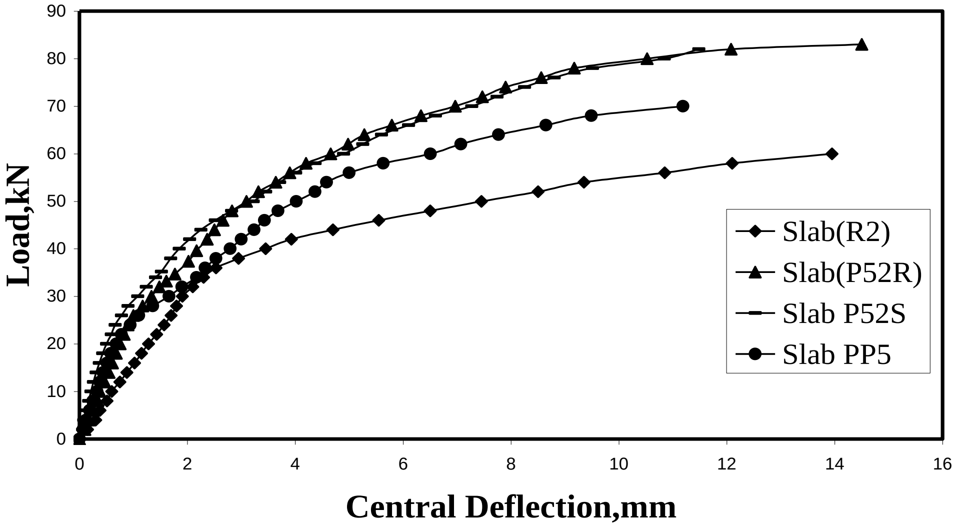


Figure (4) Continued

3-2 Ductility of Tested Slab

Considering that the central deflection at ultimate load is a measure of ductility. It is found that the slabs in group one (type one in **Fig.(1)**) and slabs(PP5) (type two in **Fig.(1)**) have ductility less than the reference specimen (R1) (lost a percentage of their ductility about (15-65)% because the steel plates used in this group have small rigidity and as a result have large initial displacement up to yield), and the slabs (type (3) and (4)) have large rigidity and as a result the ductility increased with respect to reference specimen, as shown in **Table (2)**.

In general, in the slab with larger amount of shear reinforcement, the shear reinforcement (steel plate) increase appreciably the ductility index of the slabs compared to similar specimens without shear reinforcement.

The test results show that the increase in number of shear connectors and thickness of steel plate is clear on increasing the ductility index with respect to reference slab.

Table (2) Ductility of the tested slabs

Specimens	Δ_u **(deflection at failure)**	**% Increase in Ultimate Deflection**	Δ_y **(deflection at yield)**	**Ductility Index***	**% Increase in Ductility Index Relative to reference**
R1	17.8	—	2.13	8.35	—
S1	18.15	1.96	2.56	7.08	-15.2
S2	18.35	3.08	3.11	5.9	-29.34
S3	13.65	-23.31	3	4.55	-45.5
S4	16.825	-5.5	3.95	4.25	-49.1
S5	19.85	11.5	5.95	3.33	-60.11
S6	16.58	-6.8	5.61	2.95	-64.67
R2	12.93	—	2.53	5.11	—
PP5	11.55	-10.67	3.68	3.13	-38.74
P52S	12	-7.19	1.85	6.48	26.81
P52R	14.5	12.14	2.83	5.12	0.19
P53R	15.5	19.87	1.95	7.94	55.38
P82R	17.9	38.43	2.15	8.32	62.81
P83R	19.12	47.87	2.28	8.38	64

**Ductility index represent the ratio of ultimate deflection to deflection at yield* [7].

3-3 Load Characteristics

In general, the first flexural crack initiated at (15-46) % of the ultimate load, as shown in **Table (3)**, and at this stage of loading the tensile stress in concrete reached the modulus of rupture value and cracking started in the zone of maximum tensile stress. Slabs with punching shear reinforcement (steel plate) had first cracking load more than the reference specimens except several specimens in group one (G1) (S1, S3, S4) because these specimens had small steel area and minimum number of shear connectors and small length of angle legs. The test results show that the increase in number of shear connectors, size of angle legs, thickness of steel plate increased first cracking load as shown in **Table (3)**.

Table (3) Load and failure characteristics in tested slabs

Group No.	Specimen	Cracking Load (kN)	% Increase in Cracking Load	Ultimate Load (kN)	% Increase in Ultimate Load	$P_{cr.}/P_{ult}$	Type of Failure
G1	R1	18	—	79.5	—	22.6	Punching
	S1	12	-33.3	57.5	-27.67	20.86	Punching
	S2	22	22.2	71.5	-10	30.76	Punching
	S3	30	66.6	64.5	-18.56	46.51	Punching
	S4	12	-33.3	76.5	-3.77	15.68	Punching
	S5	22	22.2	64.5	-18.86	34.1	Punching
	S6	18	—	76.5	-3.77	23.52	Punching
G2	R2	16	—	63.5	—	25.19	Punching
	PP5	20	25	71	11.8	28.16	Punching
	P52S	26	62.5	83	30.7	31.32	Punching
	P52R	26	62.5	84.5	33.07	30.76	Punching
G3	P53R	28	75	85.5	34.64	32.76	Punching
	P82R	29	81.25	97	52.75	29.86	Punching
	P83R	31	93.75	98	54.33	31.63	Punching

The observed failure load of the tested slabs is shown in **Table (3)**. Test results show that the slabs in group one (G1) (type one in **Fig.(1)**) give a decrease in strength over that of the reference specimen R1 (slab without punching shear reinforcement). This may be due to the high concentration of stresses in the corners of the plate so minimization of these stresses was necessary, the rigidity of these specimens is not enough to resist the punching shear loads, and the number and distribution of shear connectors used in these specimens, were not sufficient to give the interaction between concrete and steel plate. Other types of steel plates in this study gave increasing in ultimate load over that of reference specimen reached to (54.33 %).

The test results show that the increase in number of shear connectors did not affect the ultimate load capacity for the tested slabs because the shear crack did not pass through the shear connectors, which started at the edges of steel plate with angle ($\leq 45^o$) inclination of cracks out of steel plate. Also, the increase in size of angle legs, thickness of steel plate and dimensions of steel plate cause increase in the ultimate load capacity in all tested slabs.

3-4 Failure Modes

In all of the slabs, relatively wide cracks were found on the compression surface around the edge of the column. Also, diagonal cracks started at the corners of the steel plate and extended to the corners of tested slab in compression face, as shown in **Fig.(5)**.

At the end of loading stages, all the slabs failed in punching shear, and failure shape took the shape of the steel plate, as shown in **Fig.(6)**.

Figure (5) Compression surface of tested slabs after failure

Figure (6) Failure modes

3-5 Critical Section Perimeters

In general, the steel plates and their components increase critical section perimeter in all tested slabs except slab (S3). This behavior(in slab S3) may be attributed to the effect of the size of the plate, which is so small that the angle of punching shear cracks is larger than 45° (as usual) with the horizon then a type of semi- vertical failure appears. It seems to be a splitting failure.

4. Conclusions

1. The initial cracking load increased by using steel plate as shear reinforcement in slab-column connection.
2. The slab-column connection without shear reinforcement had little ductility but the slab with punching shear reinforcement (steel plate) had ductility larger than the slab without punching shear reinforcement.
3. The ultimate load increased by using steel plates which have cross shape and large rigidity with respect to reference specimens, and the slabs which have small rigidity gave a decrease in ultimate load capacity with respect to reference specimens.
4. Failure shape took the shape of the steel plate embedded in the slabs.
5. At service load, the deflection in the slab with embedded steel plate and their components (shear connectors and stiffeners) is smaller than the deflection in the slab without steel plate because the steel plate increases the flexural rigidity of the slab.
6. The increase in size of angle legs, thickness of steel plate and dimensions of steel plate will increase the ultimate load capacity in all tested slabs.
7. The test results show that the increase in number of shear connectors and thickness of steel plate is clear on increasing the ductility index with respect to reference slab.
8. The effect of increasing shear connectors, thickness of steel plate and dimensions of steel plate is clear in increasing the ultimate deflection.

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