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EFFECT OF REINFORCED CONCRETE PANELS SHAPE AT PUNCHING SHEAR STRENGTH

Aamer Najim Abbas
Assist. Prof, College of Engineering, Al-Mustansiriya University, Iraq

Lina Abdulsalam Shihab
Lecturer, College of Engineering, Al-Mustansiriya University, Iraq

ABSTRACT

In this research, the structural behavior of similar depths flat plate panels specimens with different shapes has been studied. Three shapes of panels were used; square panel, triangular panel and trapezoidal panel. Each shape has two amounts of steel fibers (0.5% and 1%) in addition to reference specimen (free of steel fibers). The effects of panel shape and amount of steel fibers on failure pattern, ultimate capacity and cracking capacity have been adopted in this research. The test results concluded that irregular shape of panels have ultimate capacity and cracking capacity more than the square panels. Also, ultimate capacity and cracking capacity is affected increasingly by using steel fibers in concrete mixture. The steel fibers exchange the failure pattern from punching shear failure to flexural failure. The failure pattern also exchanged from punching shear failure to flexural failure in case of irregular panels shapes.

Key words: Punching Shear, Steel Fibers, Square Panel, Triangular Panel, Trapezoidal Panel.

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1. INTRODUCTION

Flat plate slab is considered one of the most important types of slabs because of it is ease of implementation and provided a large vertical spaces sufficient for the passing of service pipes and other different services due to dispense of beams, which positively affect the use of building by people.

The behavior of this type of slabs depends on several factors; the position of panel (interior at edge or at corner), the ratio of the length of the panel to it is width and the shape of panel.

Whatever the shape and geometry of the slab, remains the punching shear stresses the most important problem facing the design of this type of slab. The problem comes as a result of the concentration of stresses at column region, which lead to sudden and uncontrolled failure[1].

There are several ways for strengthening the slab-column connection area, as it is possible to use concrete with high compressive and tensile strength such as high strength concrete(2),(3), self-compacted concrete(4)(5) and reactive powder concrete(6),(7).

Also, increasing the thickness of slab around the column (drop panels) represents one of the common methods to strengthen the slab-column connection zone(8).

The reinforcing of punching shear zone by stirrups(9)(10), shearheads(11),(12) and stud rails(13) are also considered a well-known method in reinforcing the slab-column connection against punching shear stresses.

2. SPECIMENS GEOMETRY

Three shapes of flat plate panels were poured and examined under point load; square panel with dimensions [450mm (length) ×450 mm (width) ×50 mm (thickness)], trapezoidal panel with [450 mm (lower base) ×200 mm (upper base)×600 mm (height)×50 mm (thickness)] and triangular panel with [450 mm (base)× 600 mm (height)×50 mm (thickness)].

3. MATERIALS PROPERTIES

Below, details and specification of the materials used in the mixture of the slab adopted in this study:

1. Cement

Ordinary Portland cement (Type I) was used in this study. It was stored in a dry place in order to avoid damage of the samples. Below the physical and chemical properties of cement used in this study, see Table (1) and Table (2). The tests were carried out according to ASTM C-150(14).

Table (1) Physical Properties of Cement.

Physical Properties	Tested Results	ASTM C-150(14)
• Fineness(cm^2/gm)	288	250
• Soundness	0.17	< 0.8
• Setting time • Initial(min) • Final (min)	 66 3:26	 > 45 min < 10 min
• Compressive Strength (MPa) • 3 days • 7 days • 28 days	 24.1 36.2 52.0	 > 15 MPa > 23 MPa --------

Table (2) Chemical Properties of Cement.

Oxides	Results	ASTM C-150(14) Specifications
Calcium Oxide CaO	60.92	
Silica Oxide SiO_2	21.88	
Aluminum Oxide Al_2O_3	3.96	
Ferric Oxide Fe_2O_3	4.28	
Magnesium Oxide MgO	3.15	< 5
Sulfur Trioxide SO_3	2.46	< 2.8
Loss on Ignition L.O.I	2.09	< 4
Insoluble Residue I.R	0.60	< 1.5
Lime Saturation Factor L.S.F	0.86	0.66-1.02
C_3A	3.26	

2. Coarse Aggregate

Crushed gravel of maximum size of 14 mm is used in this study. The grading and physical properties of coarse aggregate are listed in Table (3) and Table (4).

Table (3) Grading of Coarse Aggregate.

Sieve Size (mm)	**% of coarse Aggregate passing**	**BS882:1992 limit (% passing)[15]**
20	100	100
14	99.10	90-100
10	57.9	50-85
5	4.20	0-10
2.36	0	----

Table (4) Physical Properties of Coarse Aggregate.

Physical Properties	**Test Result**	**BS882:1992 limit (% passing)[15]**
Specific gravity	2.64	-----
Sulfate content	0.09 %	≤ 0.1
Absorption	0.63 %	-----

3. Fine Aggregate

Natural sand with maximum size (4.75mm) is used in this study. The grading and physical properties of sand are listed in Table (5) and Table (6).

Table (5) Grading of Fine Aggregate.

Sieve Size mm	Passing	BS882:1992 Limit zone "M" (%passing)[15]
10	100	100
4.75	93.4	89-100
2.36	85.4	65-100
1.18	75.6	45-100
0.6	41.7	25-80
0.3	9.1	5-48
0.15	0.04	0-15
Fineness Modulus=2.95		

Table (6) Physical Properties of Fine Aggregate.

Physical Properties	**Test Result**	**BS882:1992 Limit zone "M" (%passing)[15]**
Specific Gravity	2.6	------
Sulfate Content	0.32%	≤ 0.5%
Absorption	O.75%	------

4. Super-plasticizer

For the purpose of production of high strength conventional concrete with steel fiber, Glenium 51 is used as a high water reducing agent. Table (7) shows the typical properties of Glenium 51.

Table (7) Properties of Glenium 51.

Property	Result
Form Color Relative Density PH Viscosity Transport Labeling	Viscous Liquid Light Brawn 1.1@ 20℃ 6.6 128+/-30 cps@20℃ Not Classified as Dangerous Not Hazard Label Required

5. Steel Fibers

Hooked end steel fibers were used in this study.

The properties of steel fibers are listed in Table (8).

Table (8) Properties of Steel Fibers.

Tensile Strength (MPa)	Length (mm)	Diameter (mm)	L/d
1050/1150	30	0.5	60

6. Silica Fume

The chemical and physical properties of silica fume are shown in Table (9).

Table (9) Chemical and Physical Properties of Silica Fume.

Property	Results
1- Silicon Dioxide	85%
2- Particle Size	< 1 Mm
3- Bulk Density	
(as-Produced)	130-430 kg/m^3
(Densified)	480-720 kg/m^3
4- Specific Gravity	2.2
5- Specific Surface	15000-30000 m^3/kg

4. MECHANICAL PROPERTIES OF CONCRETE

Compressive strength was carried out on (100x100x100) mm^3 cubes according to BS 1881: part116 (16) and the modulus of rupture was carried out. Table (10) shows the mechanical properties of concrete.

Table (10) Mechanical Properties of Concrete

Property	Mix Designation		
Steel Fiber %	0	0.5	1
Cube Compressive Strength (Mpa)	50.5	53	55.6
Modulus of Rupture (MPa)	7.06	7.9	8.28

5. FLEXURAL STEEL REINFORCEMENT

BRC (Ø6) mm was used as flexural reinforcement, has yield strength (fy=471 MPa) and ultimate strength (fu=609 MPa).

6. MIX PROPORTIONS

The mix proportions are listed in Table (11), all the specimens have the same mix proportion except the percentage of steel fibers was (0%, 0.5% and 1%).

Table (11) Mix Proportion of Concrete

Mix No.	W/P	Water kg/m³	Cement kg/m³	Sand kg/m³	Gravel kg/m³	Super Plasticizer 1/100 kg of cement	Silica Fume %
1	0.36	160	418	760	1050	2	5%

7. LOAD-DEFLECTION BEHAVIOR

The load versus deflection curve has three main stages, each stage give attention about the behavior of specimen under effect of loading, see Figure (1) to Figure (9).

First stage indicates the elastic behavior of the specimen, it is approximately linear, the panels appear stiff against loading. In this stage, the specimens free of cracks, the concrete and steel works together because the full bonding between them. This stage extends until appearance of first crack.

Second linear stage starts with different slop until yielding of steel bars. Several cracks begin to increase and extend toward the supports. The cracks width and length increase gradually. The stiffness of specimens begins to decrease because the reduction in bond between concrete and steel bars.

At the third stage, the specimens start to lose a large amount of its stiffness in addition to a significant increase in the cracks width. Clearly, the specimens begin to affect against the load through the acceleration of deflections readings.

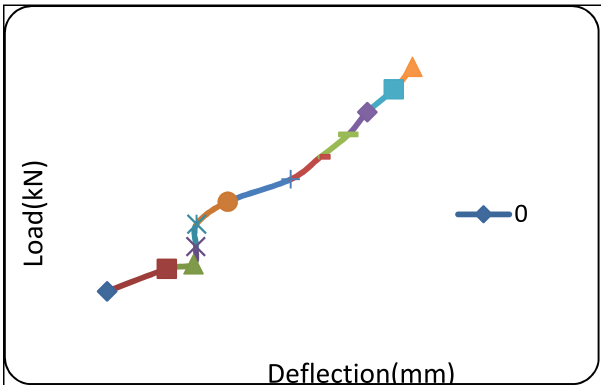

Figure (1) Load-deflection Curve of Panel (S1)

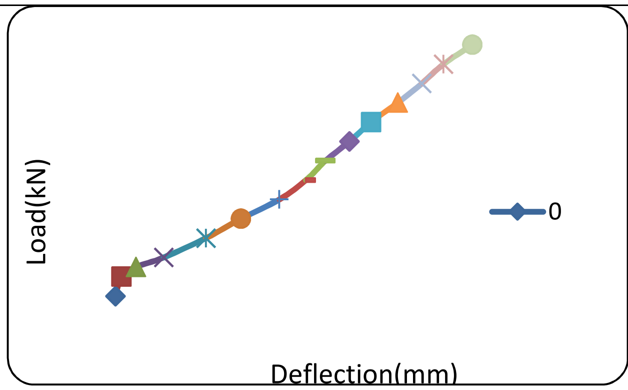

Figure (2) Load-deflection Curve of Panel (S2)

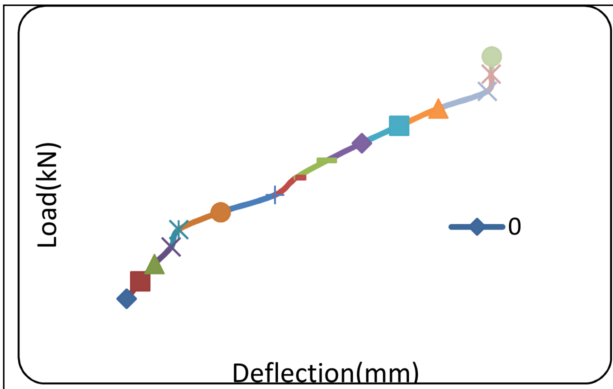

Figure (3) Load-deflection Curve of Panel (S3)

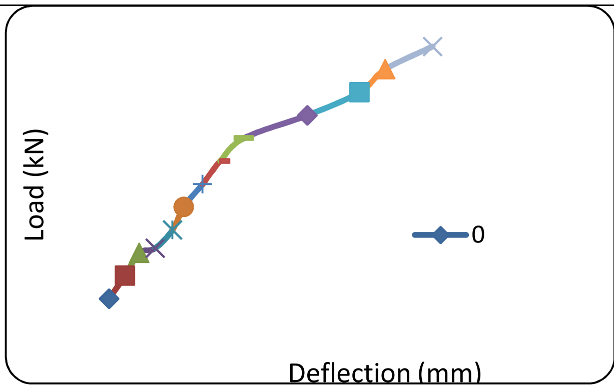

Figure (4) Load-deflection Curve of Panel (T1)

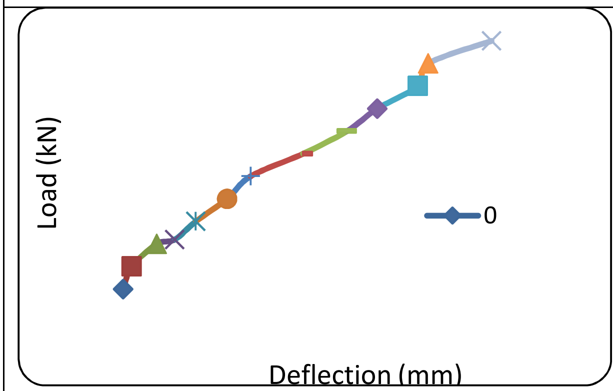

Figure (5) Load-deflection Curve of Panel (T2)

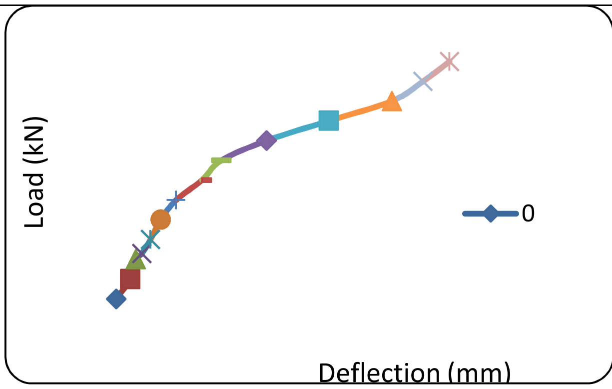

Figure (6) Load-deflection Curve of Panel (T3)

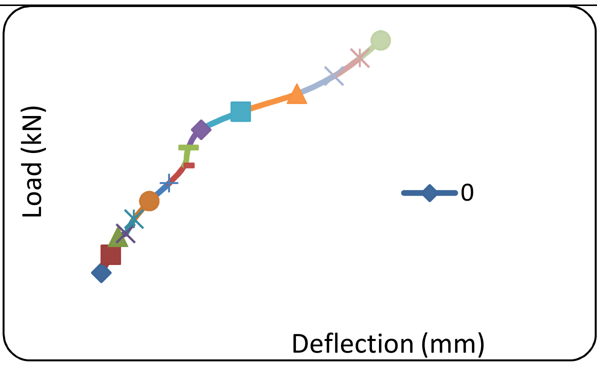

Figure (7) Load-deflection Curve of Panel (A1)

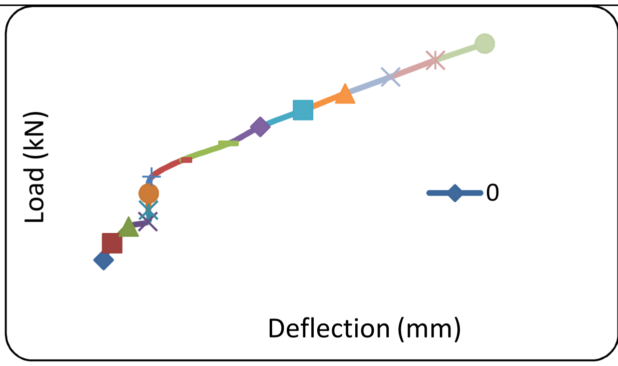

Figure (8) Load-deflection Curve of Panel (A2)

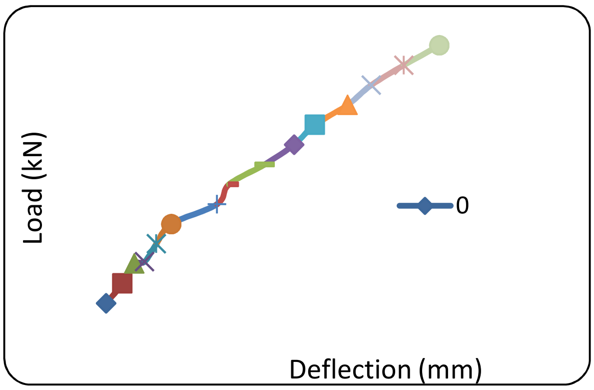

Figure (9) Load-deflection Curve of Panel (A3)

8. FAILURE MODE

The failure mode of tested specimens is affected by using amounts of steel fibers. In flat plate panels with trapezoidal and triangular shape, the flexural stresses in long direction of the panels increase with increasing the concentric column load and the unbalanced moment contributes to the arrival of the flexural strain in the panel section to it is maximum value (0.003) as a result the flat plate with triangle and trapezoidal shape have punching shear strength higher than the square slab. As indicated in Figure (10) to Figure (18), the rectangular and trapezoidal panels fail by flexural and the square slab fails by punching shear for reasons mentioned above.

Figure (10) Failure Pattern of Panel (S1)

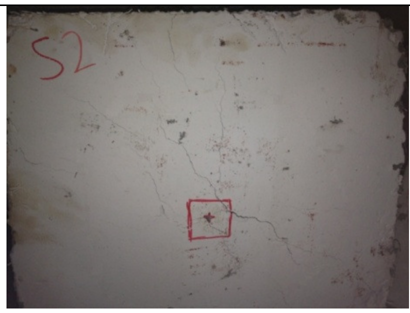

Figure (11) Failure Pattern of Panel (S2)

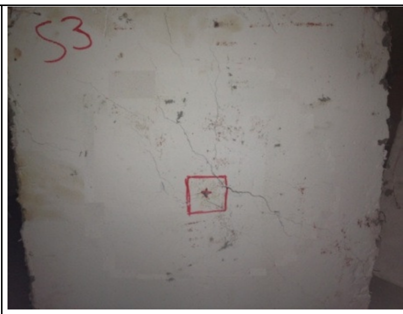

Figure (12) Failure Pattern of Panel (S3)

Figure (13) Failure Pattern of Panel (A1)

Figure (14) Failure Pattern of Panel (A2)

Figure (15) Failure Pattern of Panel (A3)

Figure (16) Failure Pattern of Panel (T1)

Figure (17) Failure Pattern of Panel (T2)

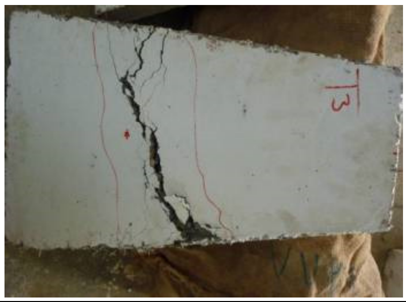

Figure (18) Failure Pattern of Panel (T3)

9. EFFECT OF STEEL FIBERS ON ULTIMATE CAPACITY

The ultimate capacity of tested specimens is affected by using steel fibers to the concrete mix. The amount of improvement of square specimens (S2) and (S3) is (17.39) % and (30.43) % respectively in comparison with reference specimen (S1). Also, triangle specimens (A2) and (A3) is affected by adding amount of steel fibers about (5.1)% and (10.14) % respectively over reference specimen (A1). The same manner applied on trapezoidal specimens (T2) and (T3) which have amount of improvement about (4.23) % and (8.47)% increasing over reference specimen (T1), see Table (12).

The clear improvement of the ultimate strength when adding the steel fibers to the concrete mix is belong to; the steel fibers work as a three dimensional reinforcement, increasing the modulus of elasticity, increasing the toughness and decreasing the residual strength post first crack.

Table (12) Ultimate Capacity of Tested Panels

Specimens No.	Ultimate Capacity (kN)	% of Improvement
S1	57.5	-
S2	67.5	17.39
S3	75	30.43
A1	69	-
A2	72.5	5.1
A3	76	10.14
T1	59	-
T2	61.5	4.23
T3	64	8.47

10. EFFECT OF PANELS SHAPE ON CRACKING CAPACITY

The cracking capacity of tested specimens is that stage of loading in which the applied and cracking moments are equals. The cracking capacity of the section is tipping point between the elastic and plastic behavior of specimen. Factors that affect the value of the cracking moment is the amount of applied load, cross sectional area and the span between supports.

In this study, there is a noticeable improvement in the delayed appearance of the first crack of triangular and trapezoidal panels when compared to the square panel, see Table (13). The main reason for this increase is due to the short span of triangular and trapezoidal panels is less than the span of the square panel.

Table (13) Effect of the Shape of Panels on Cracking Capacity

Specimen No.	First Cracking Load (kN)	% of Improvement
S1	6	-
A1	10	66.6
T1	11	83.3
S2	8	-
A2	11	37.5
T2	12	50
S3	10	-
A3	13	30
T3	14	40

11. EFFECT OF STEEL FIBERS ON CRACKING CAPACITY

The use of steel fibers in the concrete mix contributes greatly the stability of the concrete mix components before the appearance of first crack. So, the first cracking load affected by adding of steel fibers to the specimens in different ratios.

The improvement ratio of fibrous square panels reached to (33.3) % and (66.6)% of specimens (S2) and (S3) respectively as compared with reference panel (S1). The same trend in triangular specimens (A2) and (A3) which have the ratio of increasing about (10) % and (30) % respectively above reference specimen (A1). Similarly, the value of improvement of cracking capacity increased about (9.1) % and (27.3) % of trapezoidal specimens (T2) and (T3) respectively in comparison with reference specimen (T1), see Table (14).

The reason for the late appearance of cracks in the fortified slabs with steel fibers is due to good bond characteristics between fibers and concrete mix components which delay the appearance of micro cracks at the core of tested specimens.

Table (14) Cracking Load of Tested Specimens.

Specimen No.	First Crack (kN)	% of Improvement
S1	6	-
S2	8	33.3
S3	10	66.6
A1	10	-
A2	11	10
A3	13	30
T1	11	-
T2	12	9.1
T3	14	27.3

12. EFFECT OF PANEL SHAPE ON CARRYING CAPACITY OF TESTED PANELS

Table (15) shows that there is an increase in the carrying capacity of triangular panels over square panels, this improvement may be due to the transmission of stresses in short direction of the panel and there is no obvious effect of punching shear stresses. Unlike the trapezoidal panels, it is observed that there is a decrease of the carrying capacity of the panels as a result of combination the punching shear stresses and the transverse stresses along the short direction of the panels.

Table (15) Effect of Panels Shape on Ultimate Capacity

Specimen No.	**Ultimate Capacity (kN)**	**%of Improvement**
S1	57.6	-
A1	69	20
T1	59	2.6
S2	67.5	-
A2	72.5	7.4
T2	61.5	-8.9
S3	75	-
A3	76	1.3
T3	64	-14.6

13. INFLUENCE OF STEEL FIBERS ON THE DEFLECTION CAPACITY

The influence of steel fibers on deflection capacity has been studied by calculated the ratio between the maximum deflection at failure of improved specimens by steel fibers (Δ) to the maximum deflection of the specimen free of steel fibers (Δf).

As indicated in Table (16), the deflection capacity of square panels reached to (125)% and (175)% for panels with (0.5)% and (1)% steel fibers respectively in comparison with reference panel ((0)% steel fibers). The deflection capacity of triangle specimens (A2) and (A3) is (128)% and (157) % respectively in comparison with reference specimen (A1). Also, the deflection capacity of trapezoidal specimens affected by increasing the amount of steel fibers, which it is increased about (25) % and (50) % for specimens (T2) and (T3) respectively over reference specimen (T1).

The increasing in deflection capacity may give an indication on good improvement in ductility of specimens with steel fibers in comparison with specimens free of steel fibers.

Table (16) Deflection Capacity of Tested Specimens

Specimen No.	Deflection (mm)	Deflection Capacity (Δ/Δf)*100
S1	4	-
S2	5	125%
S3	7	175%
A1	7	-
A2	9	128%
A3	11	157%
T1	4	-
T2	5	125%
T3	6	150%

14. CONCLUSIONS

The following conclusion can be gained from this study:

1. The using of steel fibers in concrete mixture improved the ultimate carrying capacity of tested panels.
2. The cracking capacity is affected positively by adding steel fibers on concrete mixture.
3. The deflection capacity improved in fibrous concrete panels.
4. There is a good enhancement in cracking capacity of tested panels in case of trapezoidal and triangular panels in comparison with square panels.
5. The punching shear strength improved in triangular and trapezoidal panels in comparison with square panels.
6. The mode of failure exchanged from punching shear failure to flexural failure in case of triangular and trapezoidal panels.
7. The efficiency of steel fibers is clear in exchanging the type of failure from punching shear to flexural.

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