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# Behavior of Reinforced Concrete Slabs Using Different Amounts of Steel Fibers

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**Abstract**
In this research, the effect of steel fibers on the punching shear characteristics of concrete slabs has been studied. Three specimens were poured and tested, one of them poured without steel fibers, and the others two specimens were poured with two different percentages of steel fibers (0.5% and 1%) of total volume. The effect of adding steel fibers has been discovered through studying its impact on the load-deflection behavior, ultimate capacity, cracking capacity, failure mode, ductility and energy absorption of tested specimens.It is concluded that the loading capacity, deflection, ductility and energy absorption increased with increasing steel fibers ratio. Also, the stresses at slab-column connection have been reduced.

**Introduction**
A flat plate floor system is a two-way concrete slab supported directly on columns with reinforcement in two orthogonal directions[(1)]. The reinforced concrete flat slab system is a widely used structural system. Its formwork is very simple as no beams or drop panels are used. However, the catastrophic nature of the failure exhibited at the connection between the slab and the column has concerned engineers. This area becomes the most critical area as far as the strength of flat slabs is concerned due to the concentration of high bending moments and shear forces. The failure load may be considerably lower than the unrestrained flexural capacity of the slab[(2)].

Recently, particularly with the development of modern flat-plate floor system for high-rise residential buildings, the researchers have begun to think about the development of new methods to resist the concentration of stresses at slab column connection. One of the structural solution using the drop panels[(3),(4)] or column capitals[(5)] to reduce the stresses in this region as a result of the distribution of the loads over a wider area. Others reinforced this region with stirrups[(6),(7),(8),(9) and (10)] or with shearheads[(11),(12),(13),(14),(15),(16) and (17)].

In the recent decades, the tendency to increase the strength of slab column connection is improving the mechanical properties of concrete such as compressive strength and tensile strength through using different types of admixtures such as super-plasticizer, steel fibers and silica fume to produce reactive powder concrete[(18)] and self compacting concrete[(19),(20)] with good compressive strength.

**Experimental Work**

1. **Specimens details**

All the slabs have same dimensions (450x450x50) mm for (length x width x thickness) respectively, and have same reinforcement (ϕ6@75mm). The variable which adopted in this study is the ratio of steel fibers, two steel fiber ratios were used in this study (0.5% and 1%) of total volume. The steel column dimensions are (50X50) mm loaded at the center of slab. See Figure (1).

 

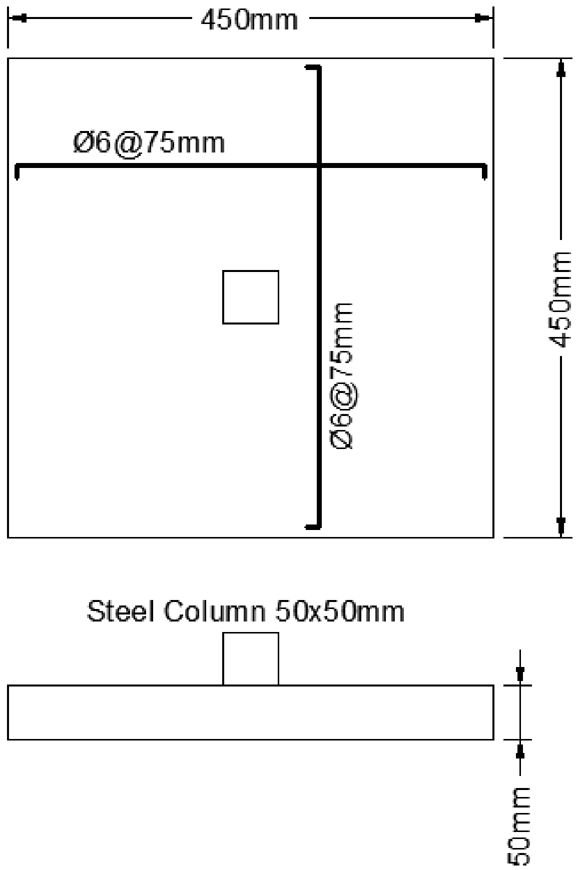


**Figure (1) Specimens Details**

## 2. Materials

### a. Cement

The type of cement used in this study is ordinary Portland cement (Type I), the Tables (1) and Table (2) contains the chemical and physical properties of cement.

**Table (1) Chemical Composition of Cement**

| Chemical composition | Percentage by weight |
|---|---|
| CaO | 60.92 |
| $SiO_2$ | 21.88 |
| $Al_2O3$ | 3.96 |
| $Fe_2O_3$ | 4.28 |
| MgO | 3.15 |
| $SO_3$ | 2.46 |
| L.O.I | 2.09 |
| I.R | 0.6 |
| L.S.F | 0.86 |
| C3A | 3.26 |

**Table (2) Physical Properties of Cement**

| Physical properties | Test result |
|---|---|
| Fineness ($kg/m^2$) | 2790 |
| Soundness | 0.17 |
| Initial setting time (min) | 66 |
| Final setting time (hrs:min) | 3:26 |
| Compressive strength (3 days) (MPa) | 24.1 |
| Compressive strength (7 days) (MPa) | 36.2 |

### b. Coarse Aggregate

The maximum size of coarse aggregate used in this study is (14) mm. The sieve analysis of coarse aggregate is listed in Table (3).

**Table (3) Grading of Coarse Aggregate**

| No. | Sieve size (mm) | Present work of coarse aggregate (% passing) | BS882:1992 limit (% passing)(21) |
|---|---|---|---|
| 1 | 20 | 100 | 100 |
| 2 | 14 | 99.10 | 90-100 |
| 3 | 10 | 57.90 | 50-85 |
| 4 | 5 | 4.2 | 0-10 |
| 5 | 2.36 | 0 | 0 |

**c. Fine Aggregate**

The maximum size of fine aggregate used in this study is (5) mm. The sieve analysis of fine aggregate is listed in Table (4).

**Table (4) Grading of Fine Aggregate**

| No. | Sieve size (mm) | Present work of fine aggregate (% passing) | BS882:1992 Limit zone "M" (%passing)(21) |
|---|---|---|---|
| 1 | 5 | 93.40 | 89-100 |
| 2 | 2.36 | 85.40 | 65-100 |
| 3 | 1.18 | 75.60 | 45-100 |
| 4 | 0.6 | 41.70 | 25-80 |
| 5 | 0.3 | 9.10 | 5-48 |
| 6 | 0.15 | 0.04 | 0-15 |

**d. Steel fibers**

The properties of steel fibers are listed in Table (5).

**Table (5) Properties of Steel Fibers**

| Tensile Strength | Length (mm) | Diameter (mm) | Steel Fibers Addition (%) | L/d |
|---|---|---|---|---|
| 1050/1150 | 30 | 0.5 | (0, 0.5, 1) | 60 |

**e. Super-plasticizer**

The super-plasticizer is used in this research as a high water reducing agent to produce high strength concrete. Table (6) shows the properties of super-plasticizer.

**Table (6) Grading of Fine Aggregate**

| Property | Test Results |
|---|---|
| Form | Viscous Liquid |
| Color | Light Brawn |
| Relative Density | 1.1@20OC |
| PH | 6.6 |
| Viscosity | 128+/-30cps@20OC |
| Transport | Not Classified as Dangerous |
| Labeling | No Hazard Label Required |

**3. Mechanical Properties of Concrete**

Two types of test were adopted on hardened concrete; compressive strength and modulus of rupture. Table (5) below illustrates the test mechanical properties of concrete.

**Table (7) Mechanical Properties of Concrete**

| Property | Mix Designation | | |
|---|---|---|---|
| Steel Fiber % | 0 | 0.5 | 1 |
| Cube Compressive Strength (MPa) | 50.50 | 53.0 | 55.6 |
| Modulus of Rupture (MPa) | 7.06 | 7.9 | 8.28 |

**4. Tensile Strength of Steel Bars**

The steel reinforcement used in this study consists of BRC has yield strength (fy) equal to 471 MPa and ultimate strength (fu) equal to 606 MPa.

**5. Mix Proportions**

The components and amount of materials used in high strength concrete in this research are listed in Table (8).

**Table (8) Mix proportions**

| Mix Designation | Water (kg/m$^3$) | Cement (kg/m$^3$) | Sand (kg/m$^3$) | Gravel (kg/m$^3$) | Super-plasticizer 1/100 kg of cement | % of Steel Fibers by Weight of Mix |
|---|---|---|---|---|---|---|
| C40 | 160 | 418 | 760 | 1050 | 2 | 0 |
| | | | | | | 0.5 |
| | | | | | | 1 |

**Failure mechanism:**

The failure mode of tested specimens is shown in Figures (2, 3 and 4). At the early stages of loading application, the specimens seem not to be affected by load until the appearance of the first crack directly under column stub in tension face of panels. Then, the cracks extend to the outer edges of the panels, the crack width increases through loading. In reference specimen (S1), the cracks appear near column stub at the compression face until failure by developing of cracks progressed rapidly and announced an imminent failure and as a result of crushing of the concrete processed the failure by punching shear.

In fortified slabs with steel fibers, the cracks at the lower face extend toward the supports and appear increasing in width and number until failure by flexure.


**Figure (2) Failure Mode of Panel (S1)**


**Figure (3) Failure Mode of Panel (S2)**

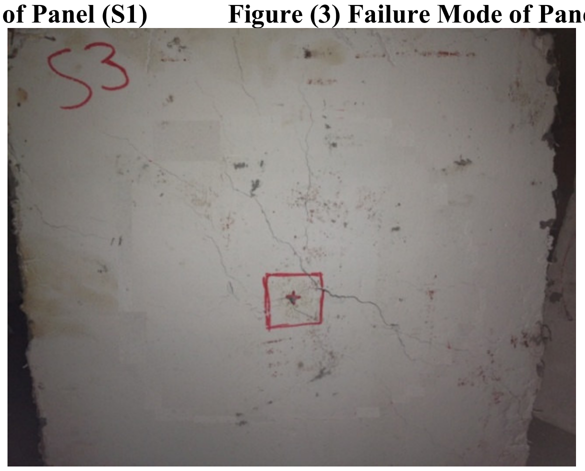


**Figure (4) Failure Mode of Panel (S3)**

**Load Characteristic**

By studying the Table (9), it is evident that there is a clear effect on the appearance of cracks when increasing the amount of steel fibers. As it was observed, there is an increase of cracking load about (33.3%) and (66.6%) when adding (0.5%) and (1%) steel fibers respectively compared to the specimens free of steel fibers.

The yielding of steel bars clearly influenced by increasing the proportions of steel fibers. As noted in slab (S2) and (S3), the percentage of increasing the yield load is about 16.6% and 41.6% respectively in comparison with reference slab (S1).

The efficiency of adding the steel fibers is clear also in increasing the ultimate capacity of panels. The percentage of improvement reached to (17.4%) and (30.4%) in comparison with reference specimen when using (0.5%) and (1%) steel fibers respectively.

The development of cracking, yielding and ultimate load in the fibrous specimens is attributed to good absorption of tensile stresses in the panels through its working as a buffer against development of cracks.

**Table (9) Loading Characteristics of Tested Specimens**

| Specimens No. | Cracking Load(kN) | Percentage of improvement % | Yielding load (kN) | Percentage of improvement % | Ultimate load(kN) | Percentage of improvement % |
|---|---|---|---|---|---|---|
| S1 | 6 | - | 24 | - | 57.5 | - |
| S2 | 8 | 33.3 | 28 | 16.6 | 67.5 | 17.4 |
| S3 | 10 | 66.6 | 34 | 41.6 | 75 | 30.4 |

**Load- deflection behavior:**

Figure (5) shows the experimental load- deflection curves at mid- span for concrete panels with varied ratios of steel fibers. Corresponding important values of deflections are presented in Table (10).

As shown in this figure, all specimens exhibited the linear load- deflection behavior until cracking of specimens, in this elastic stage the specimens back to original manner if removing the applied load. After the applied moment exceeds the cracking moment, the flexural stiffness of the slabs was slightly decreased and the second linear stage was started up to yielding of steel bars. The final stage of load-deflection curve was started after yielding of steel bars, this stage characterized by fast loss of stiffness and non- linear relationship between load and deflection. The mid- span displacement of cracking, yielding and failure stages increased with an increasing the percentage of steel fibers, this improvement means that the specimens give a good attention period before failure.

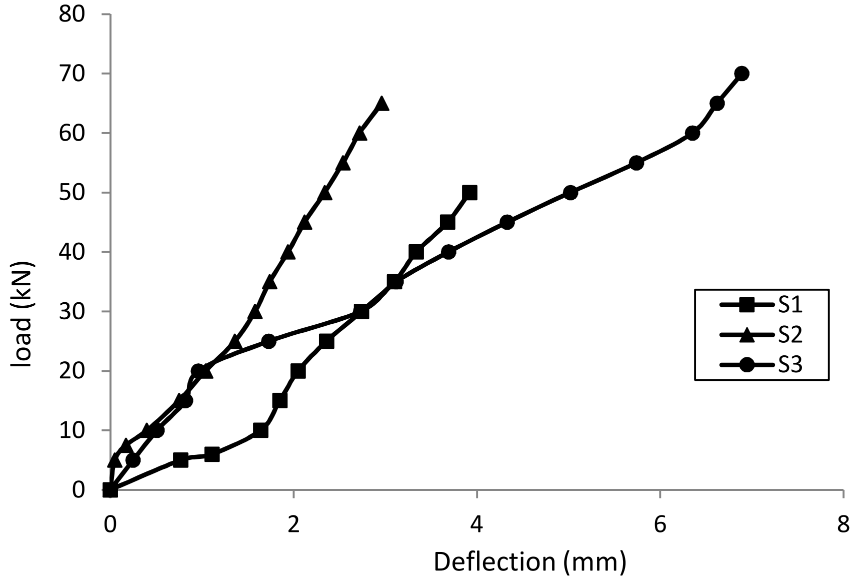


**Figure (5) Load-deflection Curve of Tested Panels**

**Table (10) Deflection Characteristics of Tested Specimens**

| Specimens No. | Cracking deflection (mm) | Yielding deflection (mm) | Ultimate deflection (mm) |
|---|---|---|---|
| S1 | 1.2 | 1.7 | 4.5 |
| S2 | 1.3 | 2.2 | 6.2 |
| S3 | 1.6 | 3 | 7.8 |

**Toughness and ductility**

The most important benefits of steel fibers in concrete mix are that the specimens fail with high deformation, which is positively affects the toughness of specimens (amount of energy a material can absorb before fracture). The specimens that contain a high proportion of steel fibers characterized higher toughness than the specimens with low proportion, see Table (11). This extra energy revealed an improvement in ductility (measure of how much deformation or strain a material can with stand before breaking.

**Table (11) Toughness and Ductility Indexes of Tested Panels**

| Specimens No. | Ductility Index | Toughness Index |
|---|---|---|
| S1 | 4.5 | 86.385 |
| S2 | 4.77 | 92.237 |
| S3 | 4.87 | 242.35 |

**Conclusions**

Through testing and discuss the results, the following conclusions have been reached:

1. The using of steel fibers in concrete mix changed the failure pattern from punching to flexural failure.
2. The adopting of steel fibers in strengthening the slab against punching shear stresses gives a good improvement. The improvement includes increasing in cracking load, yielding load and ultimate load.
3. The using of steel fibers make the specimens shows a large deformation during load application.
4. The inclusion of steel fibers on concrete mix reduces to some extent the stresses at slab column connection

zone.
5. The fibrous concrete panels have ductility and energy absorption more than the panel free of steel fibers.

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