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Experimental Investigation of One-Way Shear Behavior in Reinforced Concrete Flat Slabs Strengthened with Micro-Polypropylene Fibers

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Abstract: This research is presenting a strengthening technique for increasingone-way shear resistance in reinforced concrete flat slabs based on addingmicro polypropylene fibers during concrete mixing. Concentric loading is used in this research for studying the influence of different ratios of fiber on the behaviorof one-way solid slabs usingthree different compressive concrete strengthvalueswithconstant ratio of main steel reinforcement.

Results obtained showed significance increase in the punching load capacity for both one-way shear in flat slabs. In addition, results showed significant decrease in the deflection at mid-span of the slab for concrete strengths equal or less than 30 MPa.

Introduction:

The reinforced concrete one-way solid slab system is a widely used structural system. Its form-work is simple when no drop panels or column heads are required. However, the nature of the failure exhibited at the connection between the slab and columns is a major concern for structural designers due to the concentration of high punching shear stresses. Architects, contractors and owners avoid using flat slab system when column heads and dropped panels are required to resist punching shear stresses. Flat slab systems may prove to be more economical, saving of material and associated dead load and therefore more appealing than other flooring systems if the punching shear resistance of concrete can be enhanced

Shear failure at slab-column connections can have disastrous consequences, as has been clearly demonstrated by some flat plate structures that have failed during construction.

Shear failure at a slab-column connection can result in progressive failures of adjacent connections of the same floor, as the load is transferred elsewhere, causing the adjacent connections to become more heavily loaded. Also, the lower floors may fail progressively as they become unable to support the impact of material dropping from above. Hence, caution is clearly needed in shear strength calculations and attention should be given to the low ductility associated with shear strength in order to avoid brittle failure conditions if possible.

Existing design procedures for shear strength, as recommended in the ACI 318 are based primarily on the results of slab-column tests. The actual behavior of the failure region of the cracked slab is extremely complex, primarily because of the combined flexural and diagonal tension crackingand the three-dimensional nature of the problem. The design provisions used are of necessity derived from empirical simplifications of the real behavior.

The use of steel fibers in concrete improves the punching shear resistance allowing higher shear stresses to be transferred through the slab-column connection[1,2]. In recent years there has been increased interest in the use of fiber-reinforced polymers (FRP) for concrete structures. As one of the new promising technologies in construction, FRP material solves the durability problem due to corrosion of steel reinforcement; hence the use of FRP fibers to replace the steel fibers in the SFRC for resistance of punching shear stresses is a new trend.

L. Nguyen-Minh et al.[1] studied the behavior and capacity of steel fiber reinforced concrete flat slabs under punching shear force and investigated the effect of steel fibers amount on punching shear cracking behavior and resistance of the slabs by testing twelve small scale flat slabs of different dimensions.

L.F. Maya et al.[2] presented a mechanical model for predicting the punching strength and behavior of concrete slabs with steel fibers, the proposed approach was compared to 140 slab-column connection tests reported in the literature, their model exhibited good agreement with the test results and properly represented the influence of steel fibers on the punching strength of FRC slab-column connections.

Fernández and Muttoni[3] applied the critical shear crack theory to punching of reinforced concrete slabs with transverse reinforcement and concluded that the contribution of concrete to the punching shear strength of flat slabs is not constant and that the contribution of concrete to the punching shear strength is reduced for large rotations of the slab.

Cheng and Parra-Montesinos[4] conducted a series of tests on slabs under monotonically increased concentrated load. Four different types of FRCs (or fiber reinforced mortar) and two slab tensile reinforcement ratios were evaluated. The conclusions were that the addition of fibers led to an increase in slab punching shear strength and/or deformation capacity, this increase in punching shear strength due to the use of FRC may lead to a change in failure mode from punching shear failure to flexural yielding. Test results showed that FRC only in the connection region over two slab thicknesses from each column stub face was sufficient to increase punching shear resistance in the test specimens.

Research Significance and Material Properties:

This study investigates innovative way of strengthening one-way and two way solid slabs for punching shear resistance by using high performance micro polypropylene fiber.

Three different concrete mix are used in this research for a target of low compressive strength of 20 MPa, average compressive strength of 30 MPa and high compressive strength of 40MPa which will allow to simulate the concrete strength in different existing reinforced concrete flat slab systems. The steel reinforcement used in this research is Grade 60 with mean yield strength of 420 MPa.

High performance micro-polypropylene fibers meeting the requirements of ASTM C111.6 and having a tensile strength of minimum 300 N/m^2 were used (FOSROC - PPF) the properties of which is listed in Table 1.

Table 1. Mechanical properties of the micro-polypropylene fibers

Form	Virgin Polypropylene fibers
Specific gravity	0.91 g/cm³
Fiber thickness	18 and 30 microns
Young's Modulus	5500 - 7000 MPa
Tensile Strength	350 N/mm²
Melting Point	160°C
Alkali content	Nil
Sulfate content	Nil
Air Entrainment	Air content of concrete will not be significantly increased

Experimental set-up and results:

Tests were carried out in the structures laboratory of the civil engineering department at the University of Jordan.

To investigated the behavior of one-way shear in flat slabs 16 large flat slabs were tested to failure with constant ratio of steel for three different compressive concrete strength values (20, 30 and 40MPa) investigating the influence of different ratios of fiber on the behavior of the slabs.

Figure 1 shows thespecimen details. The slabs are rectangular shape (3 x 1.4x 0.15 m), as the column is (0.3 x 0.2 m). These dimensions are constant for all the samples. Each slab was tested as a simply supported on knife edges fixed on steel beams.

Three different ratios of fibers were used in tests based on the manufacturing minimum and maximum values recommendations.

Loading Procedure and Measurements:

The tests were performed with a deformation controlled hydraulic jack with a constant loading rate of 5kN per minute. During every test, the load was applied in steps of 25 kN at which between loading steps the load was kept constant for 10 minutes to allow measurements and inspection. Load was measured against mid-span deflection. After maximum load was achieved, the deformation was further increased to record the shear behavior of the slab.

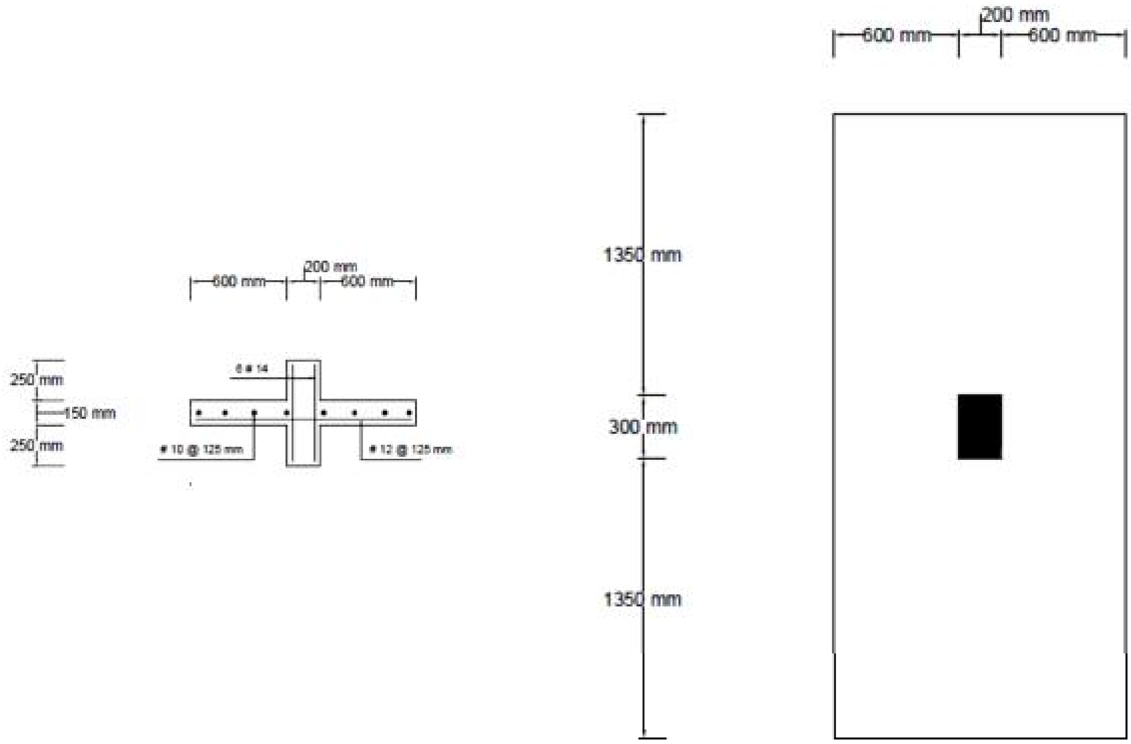

Figure 1. Specimen details

Figure 2.Concrete and Fiber Mixing and Test Setup

Loading Procedure and Measurements:

The tests were performed with a deformation controlled hydraulic jack with an ultimate capacity of 650 kN applying a compressive load with a constant loading rate of 5 kN per minute. During every experiment, the load was applied in steps of 25 kN at which between loading steps the load was kept constant for 10 minutes to allow measurements and observations. Load was measured against mid-span deflection

After maximum load was achieved, the deformation was further increased to record the punching behavior of the slab.

The deflection and the ultimate load for each step were recordedin every experiment; and results of load-deflection relationship were plotted.

Results and Conclusions

The concrete cylinders were tested for tensile strength as shown in Figure. 3, the tensile strength of concrete showed an increase of about 10% to 12% as tabulated in Table 2. In each test the midspan deflection at each step and the ultimate load were recorded, results were plotted in Figures 4, 5 and 6.

Figure. 3. Tensile (splitting) test

Table 2. Tensile Strength of Concrete with Micro-Polypropylene Fibers

Concrete Nominal Compressive Strength $f_c^{'}$ (MPa)	Concrete Experimental Tensile Strength $f_c^{'}$ (MPa)	Micro-Polypropylene Fiber Content %	Concrete Experimental Tensile Strength $f_r^{'}$ (MPa)
20	20.6	6	3.05
	19.8	7.5	3.32
	20.2	9	3.61
30	29.25	6	3.75
	29.8	7.5	3.88
	30.6	9	3.96
40	40.2	6	4.35
	39.7	7.5	4.42
	40.5	9	4.51

In each test the midspandeflection at each step and the ultimate load were recorded, results were plotted in Figures 3, 4 and 5

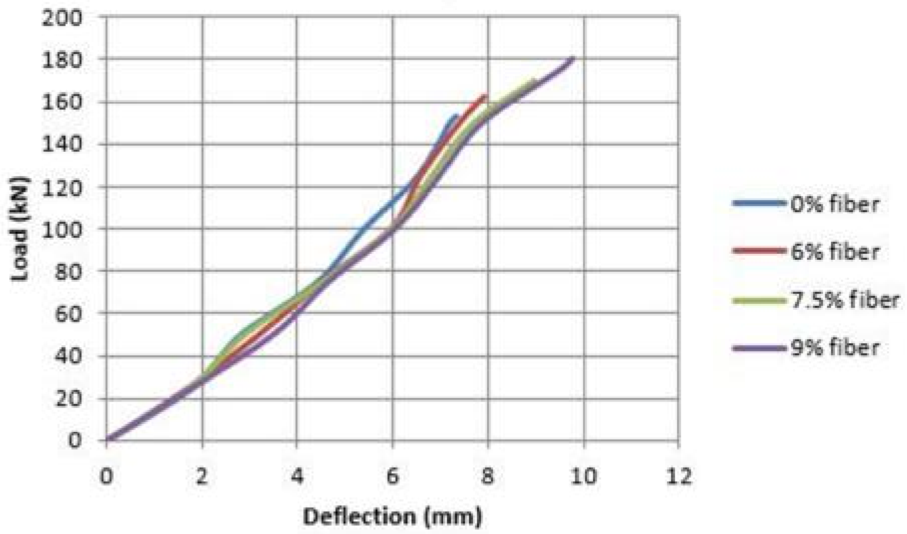

Figure 3. Load VS Deflection for f_c' = 20 MPa

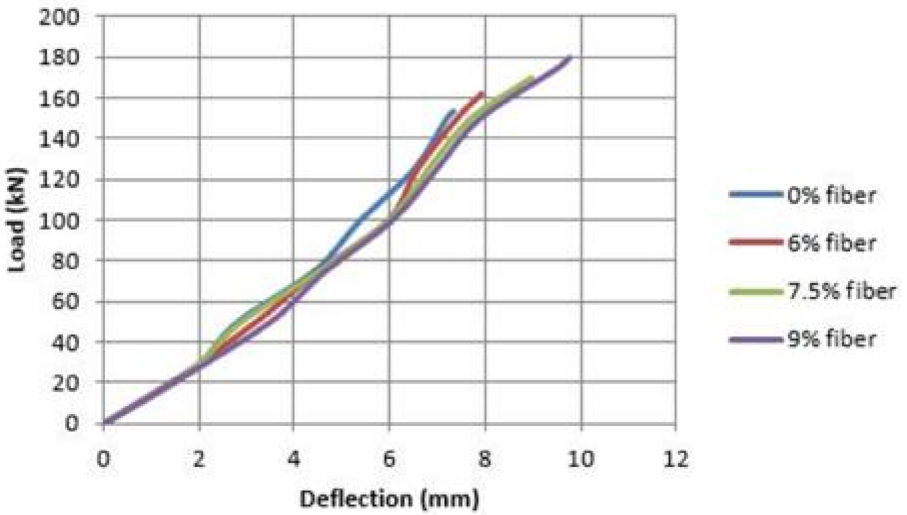

Figure 4. Load VS Deflection for f_c' = 30 MPa

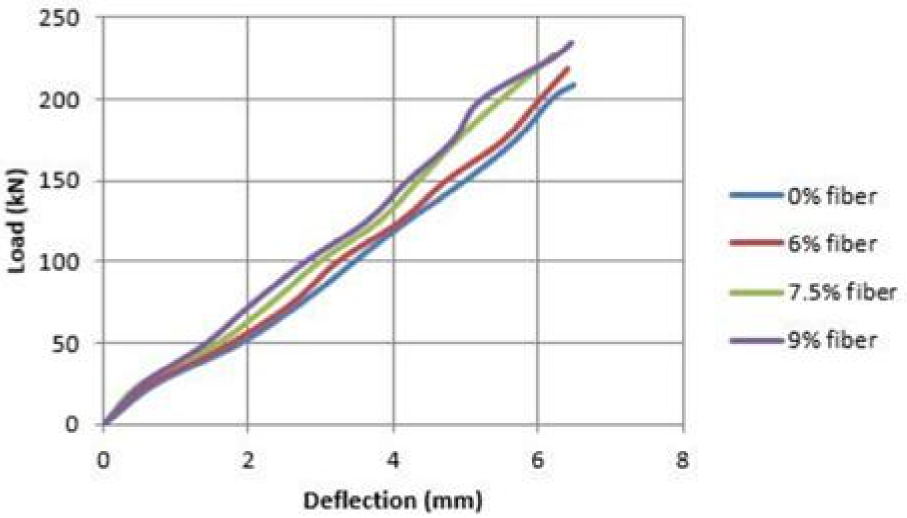

Figure 5. Load VS Deflection for f_c' = 40 MPa

Figure 6. Failure pattern of specimens

This result suggest that the one-way shear resistance and deflection at failure of flat slabs using concrete with $f_c^{'} \leq 30$ MPa is enhanced when using the micro-polypropylene fibers with different ratios, but the flat slab made using concrete with $f_c^{'} \geq 30$ MPawill only the micro-polypropylene fibers will only enhance the shear resistance but will not increase the deflection at failure.

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