TWO-WAY SHEAR BEHAVIOR OF CONCRETE SLABS REINFORCED WITH POLYPROPYLENE FIBERS

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ABSTRACT

Behaviors of the flat plate-column assembly of four reinforced slabs are investigated. Polypropylene synthetic fibers are added to the dense concrete that includes 63% of fine aggregate, the dimensions of the tested square slabs were 500 × 500 × 60 mm, reinforced by constant reinforcement ratio of 0.9%. The main parameter was the polypropylene volume fraction, where the percentages of fibers are used (0.5, 1.0, and 1.5%), compared to normal concrete slabs. The test results show that adding fibers to the dense concrete are control the slab deformation, moreover, adding 1.5% of fibers was increasing the ultimate resisting load by 39%, and increasing the energy absorption capacity by 149%.

INTRODUCTION

The flat plate-column connection is a structural system, where columns without capitals or drop panels support the slab. This type of connection is governed by its weak strength of two-way shear (punching shear), which shows high brittleness behavior that leads to sudden collapse. Many attempts have been conducting in order to increase the strength of slabs and/or increase the energy absorption capacity. Adding the various types of fibers were the most important solution had been attracted a wide attention. Improving the energy absorption capacity of the members using Fiber Reinforced Concrete (FRC) had been gaining a ground since 1980s [1], moreover, fibers are adding to the dense matrix in order to decrease the brittleness, and in turns, increasing the sense of the matrix is increasing the bond with fibers and increasing the post-cracking strength. Fibers used in Reinforced Concrete (RC) that randomly oriented making the concrete behave as composite materials [2], which improve the residual strength of the members [3]. The three directional orientations of the fibers provide significant resistance to the stresses in the three main directions, and transfer the stresses between the two types of stresses in slab-column connection (normal and shear stress).

Polypropylene (PP) is one of the synthetic fibers that used with normal concrete, in order to enhance the distribution the stress through the slabs. In addition, it is less sensitive to the unfavorable chemical reaction compared to the conventional bars [2], the low tensile strength of the PP (350 MPa) compared to reinforcement bars and other fibers are employing good interaction between the bond and yielding strength of the fibers. In the cracked section, the concrete matrix cannot resist the tensile strength and then the fibers hold this stresses up to fibers tensile and/or bond strength. Increasing the load, the fibers will transfer the stresses due to the bond stress, if the yield strength is more than the bond strength, additional cracking in the concrete will take place until reaching the fiber tensile strength and/or pull-out. Therefore, the bond between the fibers and the matrix plays important roles to enhance the posting behavior whereas the fiber strength has less effect on this process.

Based on these premises, and as a part of series of investigations on the effect of various types of fibers on the behavior of flat plate connection, authors are attempted to use the PP with a matrix of concrete that includes high percentages of the fine aggregate. The main judgment on the level of improvement based on the strength of the section and the toughness of the slabs. According to ACI, terminology [4] toughness is defined as "The ability of a material to absorb energy without rupturing"; in the current work, the toughness is calculated as the area under the load-deflection curve up to 50% of the peak load.

EXPERIMENTAL WORK

Slab's Design and Geometry

The tested slabs are designed to fail in punching shear, where the flexural capacity of the slabs are more than the punching resistance of the corresponding normal concrete slab obtained according to MC2010 [5] provisions. The punching shear stresses at d /2 of the concrete section without shear reinforcement ($\nu_{Rd,c}$) is a function of concrete strength and the rotation of the slab (ψ) that is affected by the maximum size of aggregate ($d_g < 16$ mm), where ($\nu_{Rd,c}$) calculated as follows;

$$\nu_{Rd,c} = k_\psi \sqrt{f_{ck}} \tag{1}$$

Where f_{ck} is the characterized compressive strength, and $k_\psi \leq 0.6$ is a function of ψ and d_g obtained as follows

$$k_\psi = \frac{16 + d_g}{24 + 1.5 d_g + 28.8\,\psi\, d} \tag{2}$$

The size effect is implicitly included in the ψ as follows;

$$\psi = \frac{1.5\ r_s\ f_y}{d\ E_s} \tag{3}$$

where r_s is the distance to the line counterflexure approximated as of 0.22 times the span length of the designed structure.

Same nominal punching shear resistance is adopted by ACI318 [6] but with different k, where 0.33 is assumed, while the specified compressive strength (f'_c) is represented.

Based on the approximation of the line of elastic moment contraflexure, a slab model of 1/6 of the prototype is chosen, the span is assumed to equal to 5450 mm, and therefore, four square slabs of 500 × 500 × 60 mm are cast and tested to investigate the influence of the PP fibers on the behavior of an RC slab column connection. The in-plane load is applied through a steel plate of size (c) 55 mm. all slabs are reinforced with one conventional reinforcement layer of 0.9 % ratio with a yield strength of 400 MPa. The single reinforcement layer is including two orthogonal sets of deformed bars of ϕ5.3 mm spaced 67 mm center-to-center. Figure 1 depicted the slab geometry and the reinforcement details, the two ends of each bar are bent 90º, one additional bar is added at the free ends of bars as shown in Figure 1. The concrete cover was 15 mm in all direction, which produce average effective depth $(d_1 + d_2)/2$ of 39.7 mm.

Test Setup and Investigation Parameters

In addition to the conventional reinforcements' bars, three slabs are reinforced by three volume percentages (0.5, 1.0, and 1.5 %) of PP fibers, coded as P0.5, P1.0, and P1.5. the three PP- FRC slabs are compared to the control slab of normal RC, coded as P0. Table 1 summarized the specimens' properties.

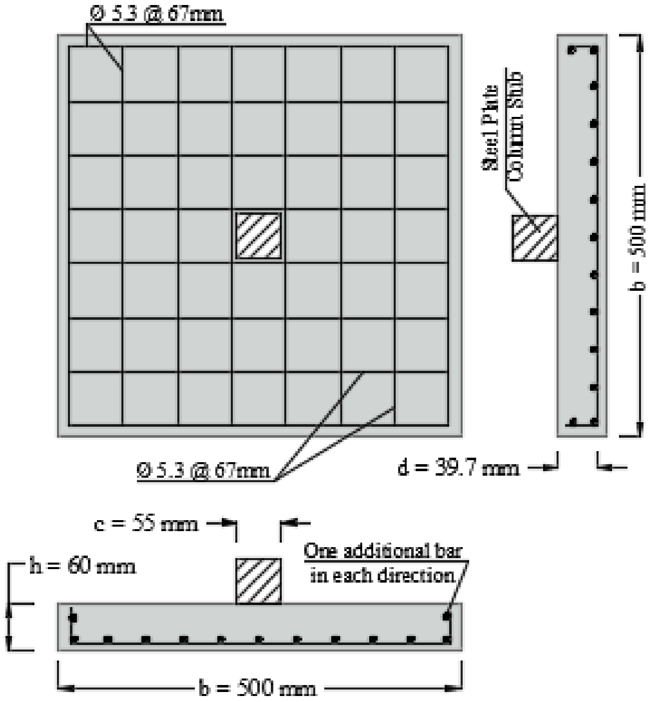


Figure1. Slab geometry and reinforcement bars' details.

Table 1. Summary of the specimens' properties

Spce. code	Fiber	age	density	b†	h†	d†	ρ	f_{sp}	f_{ck}
	%	day	Kg/m^3	mm	mm	mm	%	MPa	MPa
P0	0.0	47	2295	500	60	39.7	0.9	6.14	30.52
P0.5	0.5	27	2257					5.39	35.84
P1.0	1.0	27	2291					6.62	34.56
P1.5	1.5	30	2268					6.69	39.01

† Symbol is illustrated in Figure 1

Current work is part of a series undertaken to investigate the effect of various type of fibers on the behavior of slab column assembly. Therefore the test setup is followed the authors' recent work as shown in Figure 2 [7], where the slabs are supported on eight steel half balls, distributed so that the eight central angles are 45º, moreover, the radii of the mentioned supporting system (r_q) are 200 mm, which is assumed to locate on the line of contraflexure, moreover, the flexural strength of the current setup is obtained from equation that proposed by Guandalini et al., [8], substituting the terms proposed by Guandalini et al. [8], equation for the current work, yields P_{flex} is equal to 6.36 time the section moment capacity ("m" _"R") that obtained as normal.

The loads are applied at the center of the slabs through jack of the test machine to the column stub in the same rate for all slabs, which were 0.4 mm/min. In order to obtain the fictitious energy absorption, two displacements are recorded, one from the machine jack (δ_1) and the other from LVDT (δ_2) located at the center of the slabs. By visual inspection, the steel balls did not penetrate the slabs' surfaces; therefore, the recorded deflections (δ_2) are representing the net deflections.

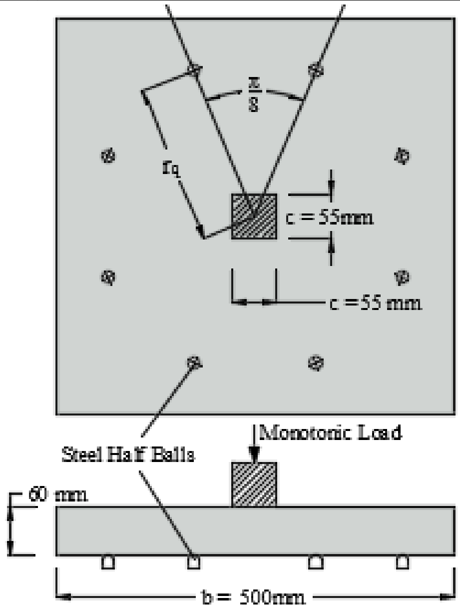


Figure 2. Test configuration

Mixing and Materials Properties

Same materials and mixing procedure of authors recently work [7] are conducted in the current work, where the slabs are cast in two batches, one for PP-FRC and the other for normal RC slab. The proportional materials details are listed in Table 2, in addition, the physical properties of PP are summarized in Table 3. In addition to the type of fibers, the main other differences between the previous work and the current work is that the water / (Cement + Silica fume) was 0.43 and in the current work is 0.58, thus increasing the water percentages are significantly reduced the compressive strength of the produced concrete, where f'_c is decreased about 39 %. This is because the high water percentage leads to less density after absorption and/or evaporation through hydration processes. This reduction in f'_c is decreases when the high fine aggregate percentage is increased (where the fine aggregate 63 % of the total aggregate percentage), it is worthy to mention here that the f'_c is obtained from 28-days cured standard cylinder test of 100 × 200 mm, and the f_{ck} listed in Table 1 is calculated as,

$$f_{ck} = f'_c - 1.6 \quad (4)$$

The mixed materials are poured into the mold, and then the normal concrete slab is internally vibrated, whereas the standard cylinders are rodded. However, both slabs and standard cylinders are externally vibrated for PP-FRC in order to minimize the balling of the fibers. The density of the produced concrete are summarized in Table 1, it is shown that the densities are not affected by inclusion the fibers.

Table 2. Concrete mixture amount per cubic meter

mix code	V_f [†] (%)	**C** kg	**G** kg	**S** kg	**S.fm** kg	**HWR** kg	**W** Lt
P0	0.0	465	680	1170	35	6.6	290
P0.5	0.5						
P1.0	1.0						
P1.5	1.5						

[†] V_f is the fiber volume fraction

C; Cement, **G**; Gravel, **S**; Sand, **S.fm**; Silica fume, **HWR**; High water reducer, **W**; Water

After curing in a water tank for 28-days, all slabs and cylinders were kept in laboratory condition until test day, where the slabs and its corresponding cylinders were tested on the same days, the ages of the slabs at the date of the test are showing in Table 1.

Table 3. Physical properties of polypropylene (PP)

Density	l_f	D_f	l_f/D_f	Tensile strength	Elastic modulus
kg/m^3	mm	mm	mm/mm	MPa	GPa
910	12	0.03	400	350	1.4

EXPERIMENTAL RESULTS AND DISCUSSION

Punching Shear Strength

The tested slabs are designed to fail due to punching shear, where the flexural capacity of the slabs P_{flex} are more than punching shear capacity. The test results are summarized in Table 4, it is shown that inclusion PP are significantly enhanced the ultimate load resistance, where the resistance load is increased by 23, 34, and 39% when using 0.5, 1.0, and 1.5% of PP, respectively. The cracking loads (P_{cr}) are ranging between 22 to 28% of the ultimate load, this is same cracking load obtained by most researchers, and it is not surprising because the bridging effect of the fibers starts after the initiation of the crack. However, according to authors' these percentages are less for PP when it is used in Engineering Cementitious Composite materials. This is means that the effects of the fibers are increases with increasing the fineness of the matrix.

Table 4. Summary of the test results

Spce. code	**P_{cr}**	**δ_{cr}**	**P_u**	**δ_{1u}**	**δ_{2u}**	**P_{flex}**	$\frac{P_{cr}}{P_u}$	$\frac{P_u}{P_{flex}}$	**$V_{R,MC2010}$**	**$V_{R,ACI318}$**
	kN	mm	kN	mm	mm	mm			kN	kN
P0	14.1	1.1	58.9	4.0	3.0	51.2	0.24	1.15	38.2	28.1
P0.5	18.3	0.94	72.7	4.5	3.6	51.6	0.25	1.41	41.3	30.4
P1.0	22.4	1.0	78.9	4.5	3.5	51.5	0.28	1.53	40.6	29.8
P1.5	17.8	1.0	81.7	5.0	4.0	51.8	0.22	1.58	43.1	31.6

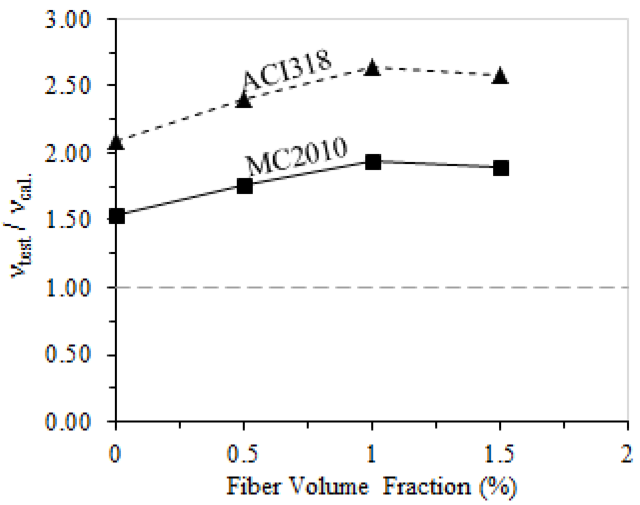


Figure 3. Comparison between tested shear stress and stresses proposed by MC2010 [5] and ACI318 [6]

The obtained ultimate shear stress (ν_{test}) at d/2 from the column stub face are compared to the proposed stresses by MC2010 [5] and ACI318 [6] (Figure 3), the comparison shows that the ACI318 is conservative by approximately 36% than MC2010, this is not surprising because the k_{ψ} in Equation 1 is equal to 0.45 for the current work, while k is equal to 0.33 in ACI318 [6]. It is worthy to mention here that the calculated stresses are excluded the safety factors for the materials and the structure because the loadings are continued up to failure.

Load –Deflection Relationship

Figure 4 shows the load-deflection relationship, the loads are applied until the slabs were failed, while the depicted curves are introduced up to 50 % of the peak loads, in order to include the effect of the membrane action. the deflections in the figure are measured from the bottom center of the slab, the depicted curves generally, PP fibers are reduced the deformation of the slabs compared with normal concrete slab, this is clearly seen from the high rate of load compared to the deflection ($\Delta P/\Delta\delta$), moreover, P0.5 and P1.5 slabs show short plateau beyond the ultimate resistance, whereas slab P0 a P1 shows sudden failure after the peak load.

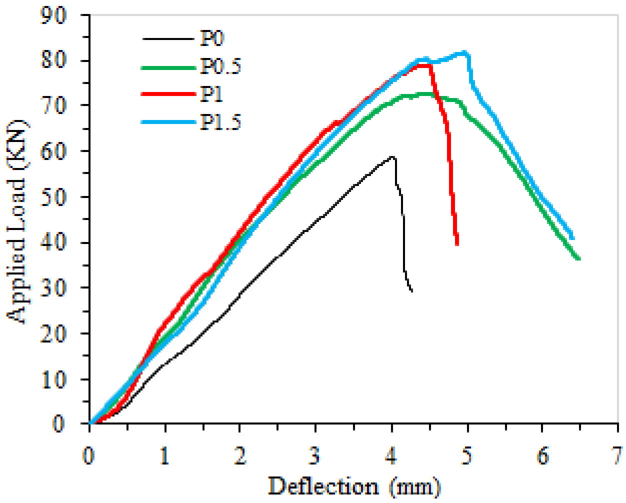


Figure 4. Load-Deflection curves for tested slabs

Table 5 summarized the Energy Absorption Capacity (EAC) of the tested slabs, the result shows that the PP-FRC slabs are increased with increasing the dosages of fiber, where the EAC increased 140, 79, and 149% for PP volume fraction of 0.5, 1.0, and 1.5%, respectively. As it is mentioned previously, the deflection is collected from the LVDT attached beneath the slab, the Fictitious Energy Absorbed Capacity (FEAC) is the differences between the deflection recorded from LVDT and the jack deflection, this FEAC is also increasing with increasing the fibers content, i.e. the effect is more pronounced for ductile specimens, which is agree with Bernard's [**9**] finding.

Table 5. Energy Absorption Capacity and Failure Mode

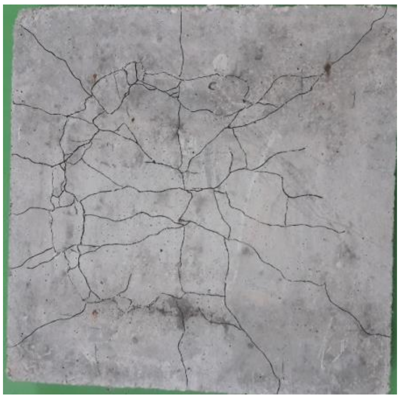
Spce. Code	P_u	EAC	FEAC	Cone shape	l_{cr}†	Failure type
	kN	kN.mm	kN.mm		mm	
P0	58.9	126	11.4	Uncomp. Rectangular	138	F
P0.5	72.7	303	15.9	Uncomp. Circle	146	F
P1.0	78.9	225	18.5	Uncomp. Rectangular	131	F
P1.5	81.7	314	23.4	Uncomp. Circle	155	F

† The distance from the column face to the punching shear crack in term of effective depth d, for the rectangular shape the distance are measured from the shorter side

Cracks Pattern

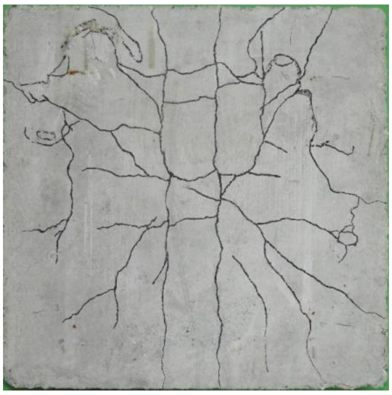
Exception the weak bond between the reinforcement and the matrix, there are three failure types are identified in the testing of slab-column joint [10]. When there are no forces induced from external membrane, as in isolated slabs such as in the current work configuration, these failures depends on the flexural capacity of the section P_{flex}, where brittle punching shear can be defined if $P_{u,test}/P_{flex} < 0.95$, while flexural shear failure are defined when the $P_{u,test}/P_{flex}$ relation is fluctuated in between 0.95 and 1.15, for that relation more than 1.15 the failure is defined as pure flexural, i.e. due to yield line formation. Table 5, shows that all the tested slabs are failed in the pure flexural, where $P_{u,test}/P_{flex}$ were greater than 1.15, this is approved by the crack patterns introduced in Figure 5. Although the specimens are failed due to flexure low resistance, two types of cracks can be identified from Figure 5, radial cracks, and punching shear cracks, the latter shows in different shape where in P0 and P1.0 the punching shear cone appear in uncompleted rectangular shape with average distance of approximately 1.7d and 1.65d from the column face, respectively. However, uncompleted circular punching shapes are identified in P0.5 and P1.5, with distance 1.8d and 1.95d from the column face, respectively. That means that inclusion the fiber not much affected the failure shape and the distance from the column face, this because the effect of high fine aggregate content is more effective than the PP-fibers, where the both normal and shear stress are perfectly transferring from the column to the supports.

Specimen P0.5
P_u = 72.74 kN
f_{ck}= 35.84 MPa



Specimen P1.0
P_u = 78.88 kN
f_{ck}= 34.56 MPa

Specimen P1.5
P_u = 81.65 kN
f_{ck}= 39.01 MPa



Specimen P0
P_u = 58.87 kN
f_{ck}= 30.52 MPa

Figure 5. Crack patterns for the tested specimens

SUMMARY AND CONCLUSIONS

This research is a part of a series investigation on the effect of fibers on the behavior of flat plate-column connection; four slabs include 0, 0.5, 1.0, and 1.5% by volume of PP. the slab designed to fail in punching, where the flexural capacity of the slabs that calculate basing on yield line theory is more than the punching behavior calculate from MC2010 [5] and ACI318 [6] provisions, The improvement judgment is based on the load resistance, and the energy absorption capacity compared to the normal concrete slab. Important conclusion can be driven from the current work as follow,

a. Inclusion the PP fibers in the concrete matrix increased the load resistance gradually as the fiber content increases, the enhancement can reach 39% of slab content 1.5% of fiber volume fraction.
b. Adding PP fibers are increases the energy absorption capacity of the flat plate-column connection by about 149% compared to the normal concrete slab. The fictitious energy absorption capacities are decreases with increasing the toughness of the slabs.
c. Increasing the fineness of the matrix increase the interaction between the fibers and the matrix.
d. There is no significant effect of the fibers on the shape and size of the failure.
e. The nominal punching shear resistance proposed by MC2010 [5] and ACI318 [6] are underestimated the resistance of the slabs with low slab thickness.
f. Proposed nominal punching shear resistance according to ACI318 [6] is more conservative approximately 36 % than that proposed by MC2010 [5].

REFERENCES

[1] V.C. Li, Engineered *Cementitious Composites (ECC) – Material, Structural, and Durability Performan*ce, in Concrete Construction Engineering Handbook. New York: CRC Press, 2007.

[2] P.K. Mehta, P.J.M. Monteiro, *Concrete: Microstructure, Properties, and Materials*. USA: McGraw-Hill Professional, 2005.

[3] A. Noushini, B. Samali, K. Vessalas, Ductility and damping characteristics of PVA-FRC beam elements, *Advances in Structural Engineering*, 18 (11) (2015), 1763-1787.

[4] ACICT-13, *ACI Concrete Terminology*. American Concrete Institute, 2013.

[5] MC2010. (2012). *Model Code 2010 final draft*, 1. International Federation for Structural Concrete (CEB-FIB bulletin 65), 2010.

[6] ACI318-14, *Building Code Requirements for Structural Concrete (ACI 318M-14) and Commentary (ACI 318RM-14)*, American Concrete Institute, Farmington Hills, 2014.

[7] A.A. Abo Altemen, F.H. Arnaot, A.A. Abbass, M. Ozakca, Punching shear behavior of small SFRC flat plate, *ICOCEE Cappadocia 2017-2nd International Conference on Civil and Environmental Engineering*, Nevsehir, TURKEY, 2017: s 891-901.

[8] S. Guandalini, O.L. Burdet, A. Muttoni, Punching tests of slabs with low reinforcement ratios, *ACI Structural Journal*, 106 (1) (2009), 87-95.

[9] E. S. Bernard, Influence of test machine control method on apparent performance of ASTM C1550 fiber reinforced concrete panels, *Advances in Civil Engineering Materials*, 2 (1), (2013) 163-177.

[10] J.S. Kuang and C.T. Morley, Punching shear behavior of restrained reinforced concrete slabs, *ACI Structural Journal*, 89 (1992) 13-19.