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STEEL FIBER-REINFORCED SELF-COMPACTING CONCRETE SUBJECTED TO CONCENTRATED LOADS

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To model the behavior of precast segmental tunnel linings under thrust jack loading, cylindrical concrete columns, subjected to concentrated loads, are investigated. Specifically, uniaxial compressive tests have been performed on specimens made with self-compacting concrete and reinforced with two different amounts of steel fibers (0, 30 kg/m^3, respectively). In addition, to measure concrete properties, three point bending tests have been carried out in accordance with code rules. As a result, not only the fracture toughness of concrete in compression is improved, but also the ultimate and the maximum splitting loads are remarkably increased by the presence of long fibers. Accordingly, a new formulation of the classical Leonhardt's approach is eventually proposed. Finally, based on the results of the present research, it seems reasonable to replace reinforced concrete with SFRSCC in structures subjected to high concentrated loads.

Keywords: Uniaxial compression test, Cylindrical specimens, Confinement, Axial loads, Splitting loads.

1 INTRODUCTION

Fiber-reinforced concrete has been widely employed in recent decades, especially in the field of precast members. Some investigations have shown that the use of steel fiber-reinforced concrete (SFRC) can improve strength and structural ductility (Ganesan and Murthy 1990). Moreover, the combination of steel fibers and self-compacting concrete (SCC) can solve problems associated with the workability of traditional fiber-reinforced concrete (FRC) (Khayat and Roussel 2000, Dhonde *et al.* 2007), and their combination can reduce the amount of ordinary reinforcement. In particular, higher strength and larger ultimate strain have been obtained (Aoude *et al.* 2009).

Although some researchers investigate the role of fibers in compression, they mainly focus on the behavior of specimens under uniaxial (Foster 2001, Fantilli *et al.* 2007, Paultre *et al.* 2010) and multi-axial loads (Fantilli *et al.* 2011a, Fantilli *et al.* 2011b). In fact, there is no literature on the behavior of steel fiber-reinforced self-compacting concrete (SFRCC) under concentrated loads. Thus, with the aim of quantifying effectiveness of fibers, new experiments are performed on SFRSCC cylinders subjected to concentrated uniaxial compression loads, is herein described.

2 EXPERIMENTAL PROGRAM

Uniaxial compression tests have been carried out on the specimens made with self-compacting concrete and reinforced with long steel fibers (SFL) and short steel fibers (SFS). Figure 1 shows the arrangement of the tests, whereas Table 1 reports the concrete mix design. Two types of fibers have been used: SFL (length L = 60mm, diameter ϕ = 0.75mm) and SFS (length L = 35mm, diameter ϕ = 0.55mm). A total of 3 batches of concrete were cast: the first (named C55) is a plain concrete; the second (named SFL30) is composed by the same concrete mixture, but reinforced with 30 kg/m^3 of SFL; the third (named SFS30) is made with the same concrete and 30 kg/m^3 of SFS.

Table 1. Mix proportions of SFRSCC.

Components	**C55**	**SFL30**	**SFS30**
Water(kg/m^3)	190	190	190
Superplasticizer(kg/m^3)	15.5	15.5	15.5
Cement(42.5)(kg/m^3)	400	400	400
Fine aggregate(kg/m^3)	915	915	915
Coarse aggregate(kg/m^3)	740	740	740
Fly ash(kg/m^3)	50	50	50
Slag powder(S95) (kg/m^3)	100	100	100
Fiber amount(kg/m^3)	0	30	30
Fiber reinforcement (kg/m^3)	-	30 SFS	30 SFL

Within each batch, nine cylindrical specimens, having a diameter Φ = 310 mm and a height H = 960mm, were prepared. As shown in Figure 1, the specimens were subjected to a concentrated load, P. Specifically, such load is applied on the area A_L, lower than, or equal to, the cross-sectional area A of the specimen. The loading area ratio (i.e., A_L/A) is the most significant parameter which affects the mechanical response of the cylinders (Niyogi 1975).

Three loading ratios (i.e., A_L/A = 1, 0.64, and 0.36) have been used in the present experimental project. As three specimens were tested for each type of concrete and each loading ratio, a sum of 27 uniaxial compressive tests were performed in the displacement-controlled mode (see Table 2).

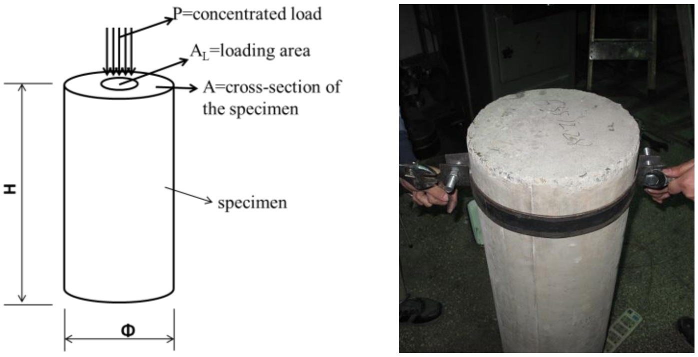

Figure 1. Geometry of the specimen.

Table 2. Details of cylindrical specimens.

Specimen	**Type of concrete**	**Specimen diameter Φ (mm)**	**Loading area diameter Φ_L (mm)**	**Loading ratio A_L/A**	**P_{max} (kN)**
C55-1-1	C55	310	310	1	2697.7
C55-1-2		310	310		2758.0
C55-1-3		310	310		2405.9
C55-2-1		310	250	0.64	2173.3
C55-2-2		310	250		2313.9
C55-2-3		310	250		2400.3
C55-3-1		310	190	0.36	1424.3
C55-3-2		310	190		1339.2
C55-3-3		310	190		1609.7
SFL30-1-1	SFL	310	310	1	2741.91
SFL30-1-2		310	310		3172.81
SFL30-1-3		310	310		3490.83
SFL30-2-1		310	250	0.64	2092.44
SFL30-2-2		310	250		2430.46
SFL30-2-3		310	250		2441.80
SFL30-3-1		310	190	0.36	1888.17
SFL30-3-2		310	190		2105.94
SFL30-3-3		310	190		1582.88
SFS30-1-1	SFS	310	310	1	3202.53
SFS30-1-2		310	310		2355.09
SFS30-1-3		310	310		2968.01
SFS30-2-1		310	250	0.64	2172.87
SFS30-2-2		310	250		2274.46
SFS30-2-3		310	250		2249.54
SFS30-3-1		310	190	0.36	1596.21
SFS30-3-2		310	190		1621.96
SFS30-3-3		310	190		1528.31

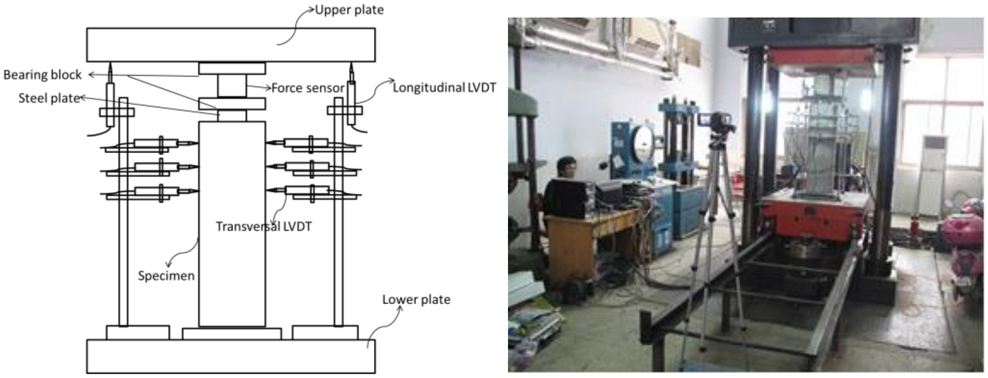

Figure 2. Concentrated compression test.

As Figure 2 shows, the load was applied through a displacement-controlled testing machine with a capacity of 10000 kN, controlled automatically by a computer system. Linear variable differential transducers (LVDTs) were applied, both longitudinally and transversally along the cylinders, in order to measure vertical and radial displacements, respectively. Finally, three point bending tests were carried out to determine the material properties of the fiber reinforced concretes (RILEM TC 162-TDF 2003).

3 EXPERIMENTAL RESULTS

Table 2 reports the maximum value of the applied vertical load ($P_{\max}$), whereas the complete load-vertical displacement curves are illustrated in Figure 3. Compared to plain concrete (i.e., C55), the presence of the fibers (in the concretes SFL30 and SFS30) increases both the strength and the ductility of the post-peak response under concentrated loads. However, the longer the fibers, the greater are the maximum vertical load $P_{\max}$, because of the efficient confinement provided by longer fiber. In particular, at the loading ratio of 0.36, $P_{\max}$ of SFL30 is 20.8% higher than that of C55. Such increment is only 5.5% in the case of SFS30. For larger loading areas (i.e., at the loading ratio of 0.64), the peak load increases, with respect to C55, of 14.8% and 4.4% in the case of SFL30 and SFS30, respectively.

3.1 Prediction of $P_{\max}$ and of the Maximum Splitting Load

By applying the least squares method to the values of $P_{\max}$ listed in Table 3, the coefficients a and b of the following prediction formula can be evaluated

$$P_{\max} = a\left(\frac{A_L}{A}\right)^b \tag{1}$$

As illustrated in Table 3, the values of such coefficients depend on the presence, and on the type, of the fibers. According to Figure 3 and Table 2, the addition of long fibers significantly increases the maximum values of concentrated loads, with respect to those measured in plain concrete. On the contrary, the influence of the fiber-reinforcement is not evident in presence of short fibers. In fact, the SFS30 and C55 specimens define more or less the same values of the coefficient *a* and *b*. In all the cases, the exponent *b* can be assumed to be $\cong 0.5$.

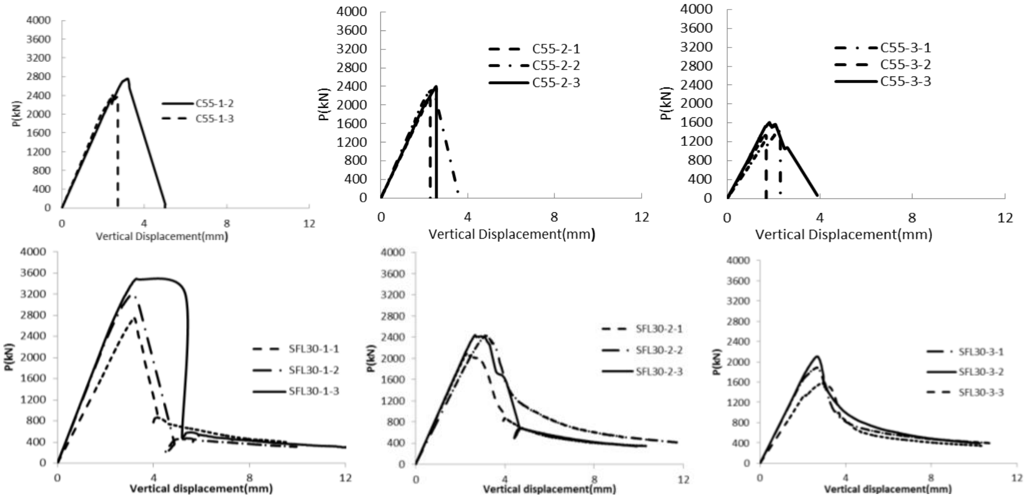

Figure 3. Load-vertical displacement curves measured in the tests.

Table 3. Coefficient *a* and *b* obtained through the best fit of the experimental data.

Type of concrete	*a* (kN)	*b*
C55	2741	0.5855
SFL	3041	0.5078
SFS	2838	0.5670

As the maximum splitting load $T_{\max}$ is used to evaluate the capability to resist concentrated loads, the following Leonhardt's relationship (Collins and Mitchell 1997)

$$T_{\max} = 0.25\,P_{\max}\,(1 - \frac{\Phi_L}{\Phi}) \tag{2}$$

can be modified to take into account the presence of fibers. To be more precise, by substituting Eq.(1) into Eq.(2), a new way to compute the maximum splitting load is here introduced:

$$T_{\max} = 0.25\,a\left(C^{0.5} - C\right) \tag{3}$$

where C = loading ratio = A_L/A .

4 CONCLUSIONS

Based on the experimental data, measured in plain and fiber reinforced self-compacting concrete under concentrated loads, the following conclusions can be drawn:

(1) Both the ultimate and the maximum splitting loads increase in the case of fiber-reinforced concrete, especially when long steel fibers are added to the traditional cementitious concrete.

(2) A simplified approach is proposed to predict the peak load for SFRSCC, and, accordingly, a modification of the classical Leonhardt's formula is also introduced to estimate the maximum splitting load.

(3) From a practical point of view, it seems reasonable to replace simple reinforced concrete with SFRSCC in structures subjected to high concentrated loads.

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References

Aoude, H., Cook, W. D., and Mitchell, D., Behavior of Columns Constructed with Fibers and Self-Consolidating Concrete, *ACI Structural Journal*, 106 (3), Jan. 2009.

Collins, M. P., and Mitchell, D. *Prestressed Concrete Structures*, Response Publications,1997.

Dhonde, H. B., Mo, Y. L., Hsu, T. T. C., and Vogel, J., Fresh and Hardened Properties of Self-consolidating Fiber Reinforced Concrete, *ACI Materials Journal*, 104(5), 491-500, Oct. 2007.

Fantilli, A.P., Mihashi, H., and Vallini, P., Post-Peak Behavior of Cement-Based Materials in Compression, *ACI Materials Journal*, 104(5), 501-510, Jan. 2007.

Fantilli, A. P., Mihashi, H., Vallini, P., and Chiaia, B. M., Equivalent Confinement in HPFRCC Columns Measured by Triaxial Test, *ACI Materials Journal*, 108(2), 159-167, Jan. 2011.

Fantilli, A. P., Vallini, P., and Chiaia, B., Ductility of Fiber-reinforced Self-consolidating Concrete under Multi-axial Compression, Cement and Concrete Composites, 33(4), 520-527, Apr. 2011.

Foster, S. J., On Behavior of High-Strength Concrete Columns: Cover Spalling, Steel Fibers, and Ductility, *ACI Structural Journal*, 98(4), 583-589, Jan. 2001.

Ganesan, N., and Ramana Murthy, J. V., Strength and Behavior of Confined Steel Fiber Reinforced Concrete Columns, *ACI Materials Journal*, 87(3), 221-227, Jan. 1990.

Khayat, K. H., and Roussel, Y., Testing and Performance of Fiber-reinforced, Self-consolidating Concrete, *Materials and structures*, 33(6), 391-397, July, 2000.

Niyogi, S. K., Bearing Strength of Reinforced Concrete Blocks, *Journal of the Structural Division*, 101(5), 1125-1137, May 1975.

Paultre, P., Eid, R., Langlois, Y., and Lévesque, Y., Behavior of Steel Fiber-Reinforced High-Strength Concrete Columns under Uniaxial Compression, *Journal of Structural Engineering*, 136(10), 1225-1235, Oct. 2010.

RILEM TC 162-TDF, Test and Design Methods for Steel Fiber Reinforced Concrete: σ-ε Design Method, *Materials and structures*, 36, 560-567, Oct. 2003.