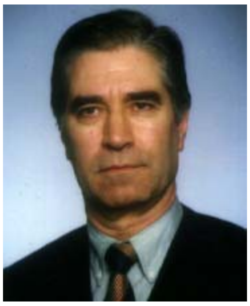
# EXPERIMENTAL ANALYSIS OF FIBER REINFORCED CONCRETE SLABS


**J. A. O. Barros**
Auxiliar Professor
School of Eng., UM
Guimarães, Portugal



**J. A. Figueiras**
Senior Professor
FEUP
Porto, Portugal



## SUMMARY

The influence of steel fibers on the behavior of concrete structures with fracture mode *I* is assessed by performing bending tests on slab strips reinforced with a conventional wire mesh reinforcement and different percentages of fibers. Tests performed with plain concrete slabs, steel fiber reinforced concrete slabs and wire mesh reinforced concrete slabs supported on soil are also described and the main results discussed.


## 1 - INTRODUCTION

The flexural strength, toughness and ductility of simply supported slab strips reinforced with wire mesh can be increased by fiber addition to the concrete mix [1-3]. In order to evaluate these improvements, an experimental and numerical [6] research program was developed to study the behavior of *SFRC* slab strips. In this paper the main experimental results are presented.

Industrial floors are the type of structures wherein the application of *SFRC* is advantageous [4]. During the service life, these structures are subjected to cyclic and impact loads, requiring an adequate fatigue flexural strength and energy absorption capacity. *SFRC* has also been economically competitive in industrial floors, when compared with conventional materials, since the time of mesh reinforcement arrangement is eliminated. Comparatively to plain concrete (*PC*) solution, *SFRC* pavement are 30-40% thinner. In order to assess the effectiveness of steel fibers as a substitute of the conventional reinforcement in slabs on soil foundation and to evaluate the benefits of fiber concrete over plain concrete in these applications, a set of experimental tests were carried out. This article describes the experimental tests and discusses the main results obtained.

## 2 - COMPOSITION AND CASTING

*Mixture proportions* - Table 1 presents the mixture proportions used in the experimental program.
*Mixing procedure* - A conventional equipment was used in the mixing procedure. The aggregates were washed and dried before mixing. The following mixing sequence was found to work efficiently for the mixtures designed: water, cement, coarse aggregates, sand and fibers. The mixing time was the necessary to warrant a uniform dispersion of fibers throughout the mixture.
*Casting procedure* - The slab strips and the slabs on soil were casted in a timber mould, faced with a zinc plate. An external vibration of the forms was applied in the slab strips, while in the slabs the compaction was performed with a vibrating ruler.
*Curing procedure* - Until demoulding (at approximately 7 days) the slabs and the corresponding cylinder and prismatic specimens were covered with wet cloths, remaining in the natural environment of the laboratory (65% RH and 20ºC) until the date of the test.

Table 1 - Mixture proportions

| | (kg/m$^3$) | |
|---|---|---|
| Component | Slab strips | Slabs on soil foundation |
| Cement (c) | 450 | 450 |
| Fine ($\leq$3 mm)<br>Aggregates (a)<br>Coarse ($\leq$15 mm) | 819<br><br>910 | 732<br><br>1055 |
| Water (w) | 157.5 | 171 |
| Additive (*Rheobuild 561*) | 4.5 | 2.25 |
| Dramix steel fibers *ZX60/.80* [5] | 0, 30, 45, 60 | 0, 30, 45 |
| Characteristics | | |
| w/c | 0.35 | 0.38 |
| c/a | 0.26 | 0.25 |
| Additive (% in weight of cement) | 1 | 0.5 |
| $W_f$ (% of fibers in weight of the mixture) | 0, 1.25, 1.85, 2.5 | 0, 1.25, 1.85 |

**3 - SLAB STRIPS**

**3.1 - Description of tests**

Figure 1 shows a schematic representation of the measuring devices and load arrangement applied in a typical test. In reference [6] the equipment applied in the tests is described. Two slab strips reinforced with 0, 30, 45 and 60 kg/m$^3$ of steel fibers and including a wire mesh were tested. The reinforcement of each slab strip consists of a mesh with wires of 2.7 mm in diameter and an area of longitudinal reinforcement of 40 mm$^2$ in the slab width (see Figure 1). This reinforcement is placed in the slab strip tensile face with a concrete cover of 3 mm. The yield stress and the ultimate strength, determined for the steel of the wire mesh, was 560 MPa and 800 MPa, respectively. According to *CEB-FIP* model code 1990 [7] and taking into account the average compression strength recorded in specimens' tests, it will be necessary about 41 mm$^2$ of longitudinal reinforcement area, in order to control cracking [8]. Therefore, the wire mesh used is a proper amount of reinforcement to illustrate the benefits of fiber reinforcement.

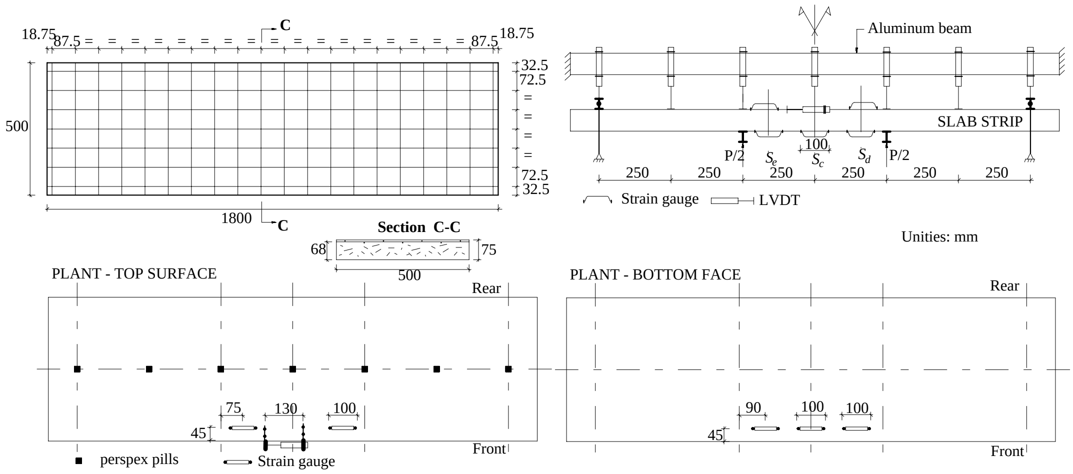



Figure 1 : Slab strip geometry, support and load arrangement, and details of instrumentation

### 3.2 - Properties measured in specimens

For each slab strip, at least two prismatic specimens of dimensions 600x150x150 mm and two cylinders of 150 mm diameter and 300 mm height were tested, in order to assess the bending and compression behavior, respectively. The average compression strength, $f_{cm}$, and the average net bending stress at maximum load, $f_{fnet}$, [8,9] are presented in Table 2.

Table 2 - Average compression strength and net bending stress of slab strip specimens

| Content of fibers (kg/m$^3$) | $f_{cm}$ (MPa) [days] | $f_{fnet}$ (MPa) [days] |
|---|---|---|
| 0 | 65.8 [217] | 6.41 [298] |
| 30 | 61.5 [204] | 6.38 [284] |
| 45 | 59.9 [176] | 7.53 [223] |
| 60 | 59.1 [124] | 8.64 [208] |

### 3.3 - Results

Figure 2 shows the relationship between the load and the displacement at mid span. The value of the failure load of each slab strip tested is specified in Table 3, as well the percentage of load increment with fiber content.

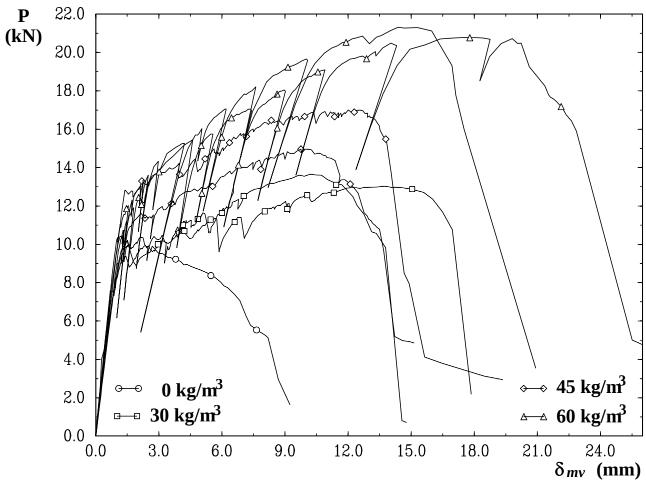



Figure 2 : Relationship between load and displacement at mid span

Table 3 - Maximal ( $P_{\max}$ ), average ($\overline{P}_{\max}$) and percentage increase on the failure load

| Content of fibers (kg/m$^3$) | $P_{\max}$ (kN) | $\overline{P}_{\max}$ (kN) | $\dfrac{\overline{P}_{\max,W_f\neq 0}-\overline{P}_{\max,W_f=0}}{\overline{P}_{\max,W_f=0}}100$ |
|---|---|---|---|
| 0 | 10.2 | 10.2 | - |
| 30 | 13.7<br>13.0 | 13.4 | 31 |
| 45 | 17.0<br>15.0 | 16.0 | 57 |
| 60 | 20.8<br>21.3 | 21.1 | 106 |

### 3.4 - Discussion

For wire mesh slab strips reinforced with 30, 45 and 60 kg/m$^3$ of fibers, it was measured an average crack spacing of 100, 80 and 40 mm between point loads (central span), while for the slab strip reinforced with wire mesh only, a unique crack was developed [6]. The collapse of the slab strips always occurred by the failure of the longitudinal wires, at the section where the longitudinal and transverse wires were welded. Figure 2 shows that, the energy absorption capacity and the failure load increase significantly with the increment of fiber content.

## 4 - CONCRETE SLABS ON SOIL

### 4.1 - Description of tests

The experimental program consists of two series of tests. Each series includes two slabs reinforced with hooked-ends steel fibers (30 and 45 kg/m$^3$), one slab reinforced with wire mesh placed in the tensile face ($A_{sx}$=$A_{sy}$= 94 mm$^2$/m, corresponding to a 20 kg/m$^3$ of steel with a yield stress and a ultimate strength of 560 MPa and 700 MPa, respectively), and one plain concrete slab.

Figure 3 shows the schematic representation of the structure supporting the set up [8]. In Figure 4 it is shown the disposition of the displacement transducers (*LVDTs*) used in the tests. In reference [8] the equipment and the procedures applied in the tests are described.

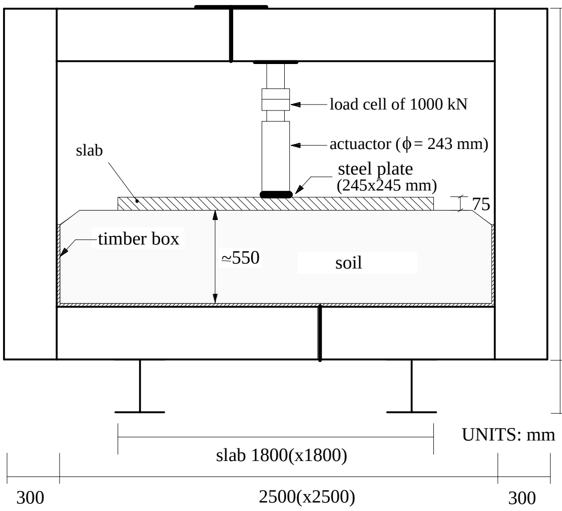



Figure 3 : Schematic representation of the supporting structure utilized in tests

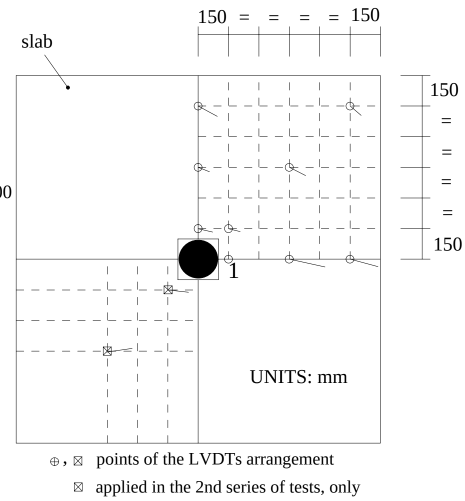



Figure 4 : Disposition of the *LVDTs*

The soil was initially compacted with a mechanical device employed currently in practice. After each test, the soil under the loaded area was removed, replaced and recompacted. Five days before to perform the test, the soil was covered with a polyethylene sheet, over that it was spread a cement mortar with 5 mm of thickness, where the slab was settled. In this way, a more uniform contact between slab and soil was warranted, the friction soil-slab was reduced and the real conditions of the execution of industrial floors are simulated.

**4.2 - Properties measured in specimens**

*Concrete* - From the uniaxial compression tests on the cylinder slab specimens it was obtained an average compression strength of 44.4, 48.4 and 54.0 MPa for the *PC* and concrete reinforced with 30 and 45 kg/m$^3$ of fibers, respectively. The net bending stress, the fracture energy [10] and the toughness factor [11] were evaluated from the three-point bending notched beam tests. The net bending stress has increased marginally with the increment of fiber content, being measured values ranged from 4.6 to 6.6 MPa. The average fracture energy of *PC* and concrete reinforced with 30 and 45 kg/m$^3$ of fibers was 0.208, 3.156 and 8.061 N/mm, respectively. The toughness factor of *PC* and concrete reinforced with 30 and 45 kg/m$^3$ of fibers was 0.46, 2.8 and 4.4 MPa, respectively.

*Soil* - In order to simulate realistic support conditions for the slabs on elastic foundation it was used a 550 mm thickness layer of silty sand well graded, non plastic with a soil reaction modulus of 125 $MN/m^3$ [8].

**4.3 - Experimental results**

In Figure 5 the load-displacement relationship at *LVDT* number 1 (see Figure 4) is presented for all tests performed. The test of the slab reinforced with 45 $Kg/m^3$ of fibers of the second series of tests (*SL2s45*) was accidentally stopped at 248 kN. Table 4 specifies the ultimate load and describes the failure mode of the slabs tested.

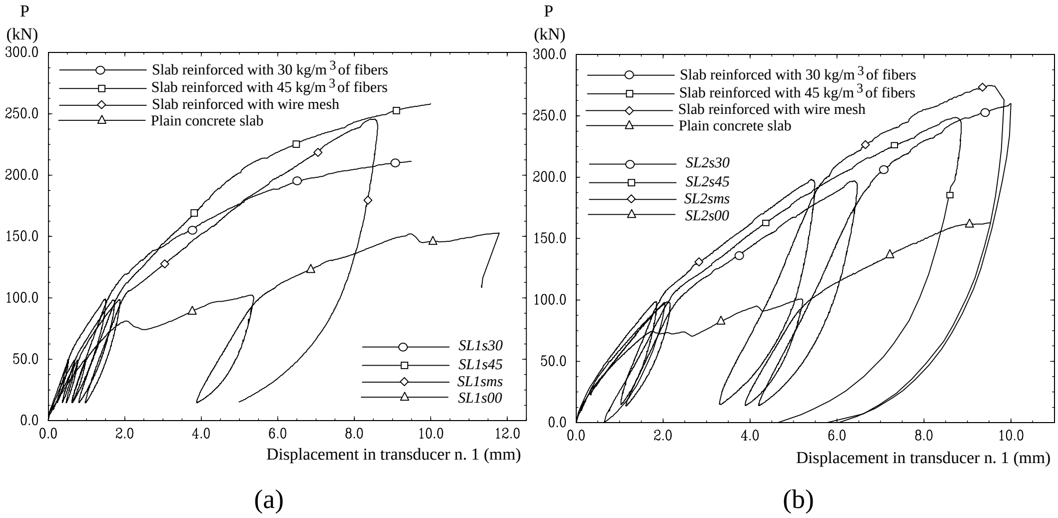



Figure 5 : Load-displacement relationship at *LVDT* number 1 (see Figure 5) for the first (a) and second (b) series of tests

Table 4 - Ultimate load and failure mode of the slabs

| Slab reference | Ultimate load (kN) | Comments of failure mode |
|---|---|---|
| *SL1s00*<br>*SL2s00* | 153<br>163 | The cracks crossed the slab thickness desegregating itself in parts. Punching failure. |
| *SL1s30*<br>*SL2s30* | 211<br>260 | The cracks did not reach the slab top surface. Large deformations in the soil-slab system. |
| *SL1s45* | 257 | The cracks did not reach the slab top surface. Large deformations in the soil-slab system. |
| *SL2s45* | 248 | The cracks did not reach the slab top surface. Test stopped at 248 kN. |
| *SL1sms* | 245 | The cracks did not reach the slab top surface. Large deformations in the soil-slab system. |
| *SL2sms* | 274 | After rupture of some wires of the reinforcing mesh, the cracks crossed the slab thickness. |

**4.4 - Discussion of the results**

From Figure 5 and Table 4 it can be concluded that the addition of steel fibers to concrete significantly increases the load carrying capacity and the ductility. Analyzing the Figure 4 it can be observed that the behavior of the *PC* slabs is substantially different from the reinforced slabs. After cracking, at approximately 70 kN, the *PC* slabs lost the major part of its stiffness, due to the reduced energy absorption capacity of the plain concrete, and failed by punching. The steel fiber and the wire mesh reinforced concrete slabs cracked at about 100 kN. After this load the stiffness decreasing of the *SFRC* slabs was smooth, due to the concrete energy absorption capacity proportioned by fiber reinforcement. Between cracking and failure loads several cracks were developed and a rather ductile failure mode was observed in *SFRC* slabs [8]. In slabs reinforced with wire mesh, the stiffness decreasing after cracking was similar to the *SFRC* slabs, however, a more concentrated crack pattern was observed and near failure some wires crossing the cracks started to break. A more brittle failure mode was observed in these conventionally reinforced slabs comparatively to the failure mode of *SFRC* slabs.

The minimum area of reinforcement ($A_{s,min}$) required within the tensioned concrete zone will be [7] $A_{s,min}=0.4\times f_{ctm}/f_{sym}\times h/2\times 100=86$ mm$^2$/m, where $f_{ctm}$= 3.2 MPa is the average concrete tensile strength, obtained from the results determined in the uniaxial compression tests, $f_{sym}$=560 MPa is the yield stress of the steel and $h$ is the slab thickness. The $A_{s,min}$ is slightly less than the reinforcement area used in the slabs with wire mesh ($A_{s,eff}$= 94 mm$^2$/m). Taking into account that in industrial floors it is necessary to reinforce the top and bottom slab surfaces, it can be concluded that a slab reinforced with 30 to 45 Kg/m$^3$ of fibers exhibits a behavior similar to a slab reinforced with twice the minimum area of flexural reinforcement.

## 5 - CONCLUSIONS

*Slab strips*
In order to verify the benefits of fiber, slab strips reinforced with different content of hooked-ends steel fibers were tested. The slab strips were also reinforced with conventional wire mesh. For the fiber contents employed ($\leq$60 kg/m$^3$) the cracking load was marginally increased. However, a significant increase in the load carrying capacity and ductility, and a smaller crack spacing was observed with the increment of fiber content. The average failure load of slab strips reinforced with 60 kg/m$^3$ of fibers was 2.1 times the average failure load of concrete slab strips reinforced with wire mesh only. The average crack spacing was reduced from 100 mm in the slabs reinforced with 30 kg/m$^3$ to 40 mm in those reinforced with 60 kg/m$^3$. A brittle failure mode with an unique crack was observed in slab strips reinforced with wire mesh only.

*Slabs on soil foundation*
The load carrying capacity of the slabs on soil foundation is considerably increased when steel fiber reinforcement is added to the concrete mix. Comparatively, the slabs reinforced with 30 and 45 Kg/m$^3$ of fibers, and the slabs reinforced with wire mesh in tensile surface ($A_{sx}$=$A_{sy}$= 94 mm$^2$/m), developed an average ultimate load 49%, 60% and 64%, respectively, higher than the average ultimate load of plain concrete slabs. It must be also taken into account that the *SFRC* slabs have identical resistance under positive and negative moments, which is equivalent to slabs conventionally reinforced in both faces.

The cracking behavior is also improved by fiber reinforcement, developing a large number of thin cracks. Therefore, the material durability is enhanced and the number of expansion joints needed is smaller. The ultimate behavior of the *SFRC* slabs was much more ductile than that exhibited by the plain concrete slabs.

## 6 - ACKNOWLEDGEMENTS

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## 7 - REFERENCES

[1] ACI Committee 544**,** *State-of-the-Art Report on Fiber Reinforced*, Concrete International: Design & Construction, May 1982, 22 p.

[2] Balaguru, P.N. and Shah, S.P., *Fiber Reinforced Cement Composites*, McGraw-Hill International Editions, Civil Engineering Series, 1992, 530 p.

[3] Clarke, R. and Sharma, A., “Flexural behavior of fibro-ferrocrete one-way slabs”, Fiber Reinforced Concrete Properties and Apllications, *ACI*, *SP-105*, 1987, p. 493-516.

[4] Tatnall, P.C. and Kuitenbrouwer, L., “Steel fiber reinforced concrete in industrial floors”, *Concrete International*, December 1992, p. 43-47.

[5] *Dramix Fibres Hors Fils d'Acier pour Reinforcement de Béton et de Mortier*, Specification, BEKAERT N.V., 1991, 6 p.

[6] Barros, J.A.O.; Figueiras, J.A., “Experimental and numerical analysis of steel fiber reinforced slabs”, *I Conferencia Internacional sobre los materiales compuestos aplicados en arquitectura y construcción*, 1996, p. 29-39.

[7] CEB-FIP Model Code, *Design Code*, Bulletin d'information, CEB, Lausanne, Switzerland, 1990.

[8] Barros, J.A.O, *Comportamento do Betão Reforçado com Fibras Análise Experimental e Simulação Numérica*, PhD Thesis (in Portuguese), Faculty of Eng., University of Porto, Portugal, 1995.

[9] Hillerborg, A., *Additional Concrete Fracture Energy Tests Performed by 6 Laboratories According to a Draft RILEM Recommendation*, Report to RILEM TC50-FMC, report TVBM-3017, 1984.

[10] RILEM, Draft Recommendation, 50-FMC Committee Fracture Mechanics of Concrete, “Determination of the fracture energy of mortar and concrete by means of three-point bending tests on notched beams”, *Materials and Structures*, V. 85, Nº 85, 1985, p. 285-290.

[11] *Method of Tests for Steel Fiber Reinforced Concrete*, Standard JSCE-SF4 for Flexural Strength and Flexural Toughness of SFRC, Concrete Library of JSCE, Nº 3, 1984, p. 58-66.