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# HIGH STRENGTH CONCRETE BEAMS WITH AND WITHOUT STEEL FIBERS – SHEAR BEHAVIOR

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***Abstract:*** *This paper presents the behavior in shear of reinforced high strength concrete beams. The concrete grade is C80.The objective of the study is to analyze the influence of transversal reinforcement, stirrups and steel fibers, on the serviceability and ultimate limit states. Constant parameters of the study are the shear span to depth ratio, a/d and the area of longitudinal reinforcement.*
***Keywords:*** *high strength, concrete, beam, shear, fiber*

## 1. INTRODUCTION

The problem of shear behavior in reinforced concrete beams is an important one given the fragile failure modes it can lead to. Fragile shear failure is an even more pressing question when using high strength concrete, in which the resistance of the concrete matrix is close to that of the aggregate used. This leads to propagation of cracks through aggregate rather then around it [1]. Adding steel fibers to the concrete increases the ductility of reinforced concrete elements. The increase in ductility is due to the fact that fibers transmit tension between the faces of cracks thus delaying their opening. In order to study the effect of fibers on the shear behavior, a number of beams were cast and then tested, results from these tests, with regard to the serviceability limit state and the ultimate limit state, will be presented in this paper. As required by SR EN 1992-1-1:2004, the maximum width of a crack $w_{max}$ is 0.4mm for concrete elements which can be included in exposure classes XD and XC1 and 0.3mm for the rest of the exposure classes [2], the values of the load at which these values are reached will be compared for the beams in this paper.

## 2. TEST SPECIMENS

The beams in the study had a rectangular cross section of 125x250mm and a total length of 1400mm. The concrete grade used in casting the elements was C80. Longitudinal reinforcement in all beams consisted of 2Φ14 and 1Φ16 PC52 steel bars, with $f_{yk}$ = 345 N/mm$^2$. Transversal reinforcement consisted of Φ6 OB37 stirrups, with $f_{yk}$ = 255 N/mm$^2$, with and without steel fibers. In beams with steel fibers, the percentage of fibers is 2.5%, with no other difference in concrete composition from the beams without steel fibers. The steel fibers used were WLS-25/0.4/H, dimensions 25mm x 0.4mm, with bent ends and a tensile strength of 1000 – 1500 N/mm$^2$. Figure 1 shows the steel fibers used.


**Figure 1:** Cross sections of test beams

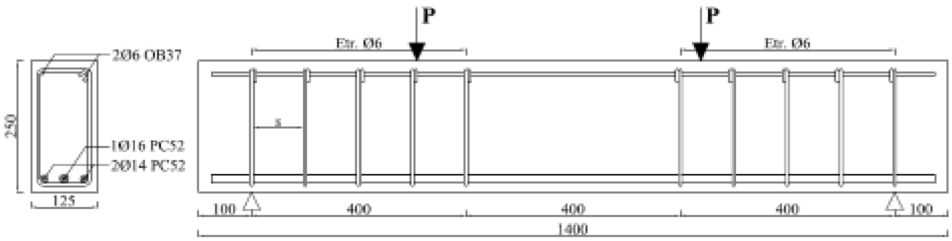


**Figure 2:** Cross sections of test beams

Table 1 shows the characteristics of the test beams.

**Table 1:** Beam properties

| Name of beams | s [mm] | a/d | Fibers |
|---|---|---|---|
| FT 6 1 – 2 | 300 | 1.5 | yes |
| FT 5 7 – 1b | 200 | | no |
| FT 5 7 – 2 | 150 | | no |
| FT 5 7 – 3 | 100 | | no |

s = distance between stirrups

## 3. TESTING PROCEDURE

The beams were tested as single span simply supported beams, loaded with two symmetrical concentrated loads at distance *a* from the supports, Figure 3. The effective span of the beams during testing was 1200 mm, allowing for a shear region located between the supports and the concentrated loads, with a shear span to depth ration of 1.50 for all beams discussed in this paper.

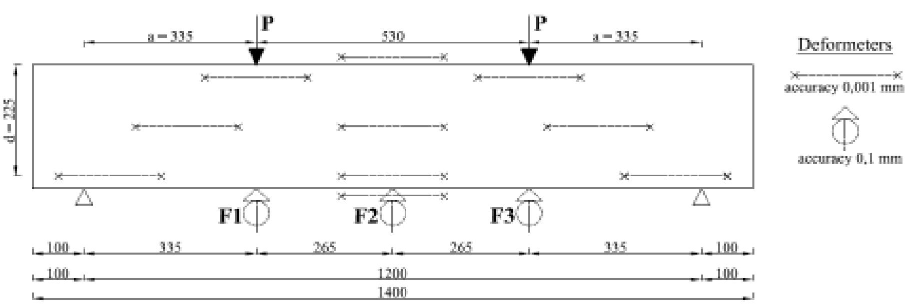


**Figure 3:** Test setup - diagram

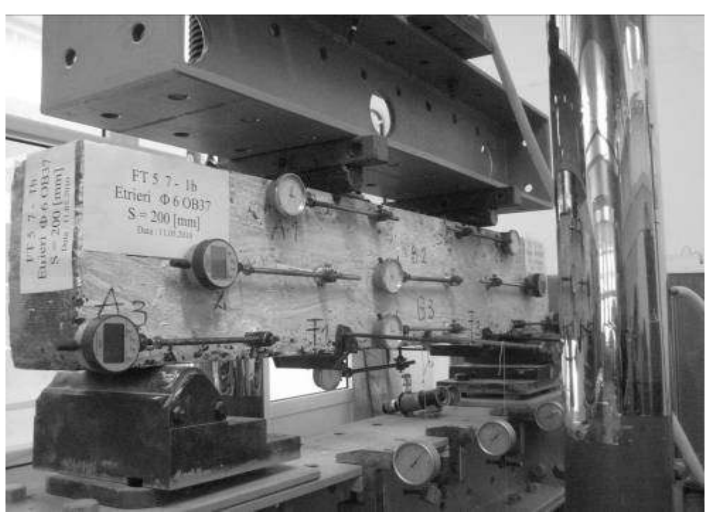


**Figure 4:** Test setup – position of measuring apparatus

During testing the load was increased in stages, allowing time between each loading stage to record values from deformeters with different accuracies, mounted as shown in Figure 3 and 4 and also for recording the position, height and width of cracks on the other side of the beam.
Deformeters, with a precision of 0.001mm, were fitted in order to measure sectional strains within the shear zone and also at the level of the geometric symmetry axis of the beams. Deformeters F1, F2 and F3 (with a precision of 0.1mm) measure deflection along the element.
Loading of the beams was monotonically increasing. The loading stages represent 1/10 of the calculated failure load. At each stage, the load was kept constant for 10 minutes in order to allow the stabilization of strains and cracks.

## 4. TEST RESULTS AND DISCUSION

The three beams without steel fibers first developed vertical cracks but failed in shear after the formation of inclined cracks in the area of the beam situated between the supports and the points of load application, as was expected. Table 2 shows the values of loads, $P_{cr}$, at which vertical cracks appeared, the values of loads, $P_{cr,i}$, at which inclined cracks appeared and also the load at which failure occurred, $P_u$, and the load at which $w_{max}$=0.4 mm, maximum allowed crack width, was reached. And Figure 5 shows a comparison of the load at which the maximum crack width, $w_{max}$, prescribed by SR EN 1992-1-1:2004, is reached, $P_{wmax,}$ and the load at failure for the tested beams, $P_u$.

**Table 2:** Experimental results for service and ultimate limit states

| Name | Fibers | s [mm] | $P_{cr}$ [kN] | $P_{cr,i}$ [kN] | $P_{wmax}$ [kN] | $P_u$ [kN] |
|---|---|---|---|---|---|---|
| FT 6 1 – 2 | yes | 300 | 32 | 70 | 145 | 165 |
| FT 5 7 – 1b | no | 200 | 30 | 55 | 100 | 142.5 |
| FT 5 7 – 2 | no | 150 | 30 | 76.5 | 111 | 157.5 |
| FT 5 7 – 3 | no | 100 | 34 | 102 | 119 | 180 |

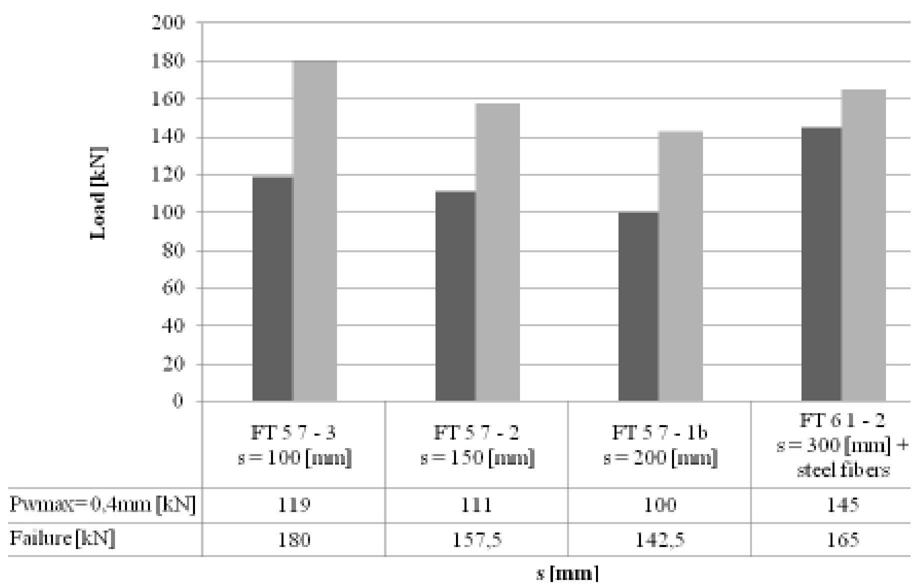


**Figure 5:** Comparison between loads causing maximum allowable width of cracks and failure loads for tested beams

Of note is the fact that the maximum value for crack width, $w_{max}$, in all beams, was observed in diagonal cracks, although these cracks appeared after the flexural cracks they developed rapidly, leading to the failure of the beam. The evolution of flexural cracks was slowed after the appearance of diagonal cracks. Figure 6 shows the beams after testing.
In the case of beam FT 6 1 – 2, even though the shear span to depth ratio and the longitudinal reinforcement was the same as for the other beams, the transversal reinforcement in the form of steel fibers caused the beam to fail due to flexural moment and shear.

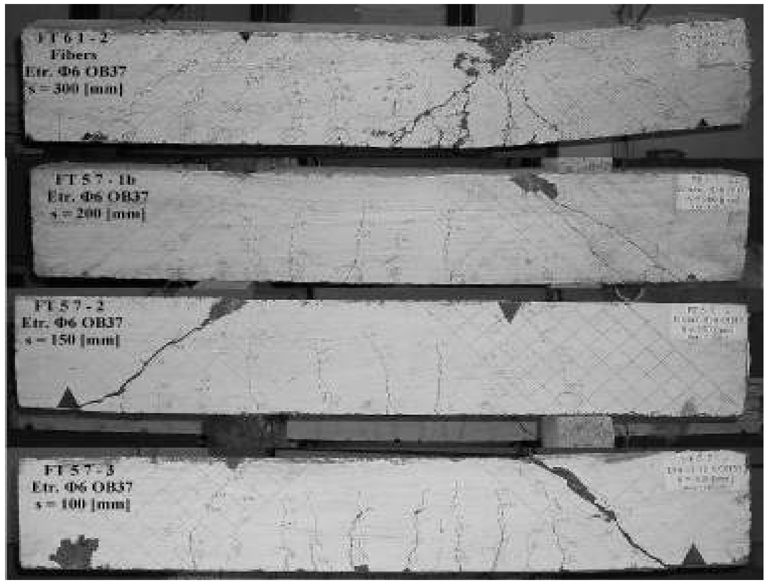


**Figure 6:** Beams after testing,
from top to bottom: FT 6 1-2, FT 5 7-1b, FT 5 7-2, FT 5 7-3

Failure occurred in the compression zone, in which one of the concentrated loads was applied, at the tip of an inclined crack, that appeared at a load value $P_i/P_u = 0.74$ ($P_i$ - load value at which the inclined crack appeared). As can be seen in Figure 6, the initial vertical cracks that appeared converged toward the concentrated load as the load increased, becoming inclined.

The behavior of beam FT 6 1 – 2 can be attributed to the steel fibers used as transversal reinforcement. By transmitting tension between crack faces they did not allow the formation of a single, clearly defined, diagonal crack between the support and the point of load application, as was the case in the beams without steel fibers. Figure 7 shows the behavior of the four beams during testing, in terms of load and deformation at midspan.

The presence of steel fibers improves the behavior of high strength concrete elements. The load value for which the maximum width of the inclined crack is reached ($w_{max}$=0.4 mm), $P_{wmax}$, is approximately 18% higher then corresponding values in beams having the minimum distance between stirrups, s=100 mm.

In regard to the deformability of the elements, the presence of steel fibers substantially increases shear ductility, as can be observed in Figure 7. A more ductile behavior can be seen, in the beam with steel fibers than in the beams without steel fibers. Ultimate deformations represent *l*/40 for the beam with steel fibers compared to *l*/77 for the beam with the minimum stirrup spacing (s = 100 mm) and without steel fibers.

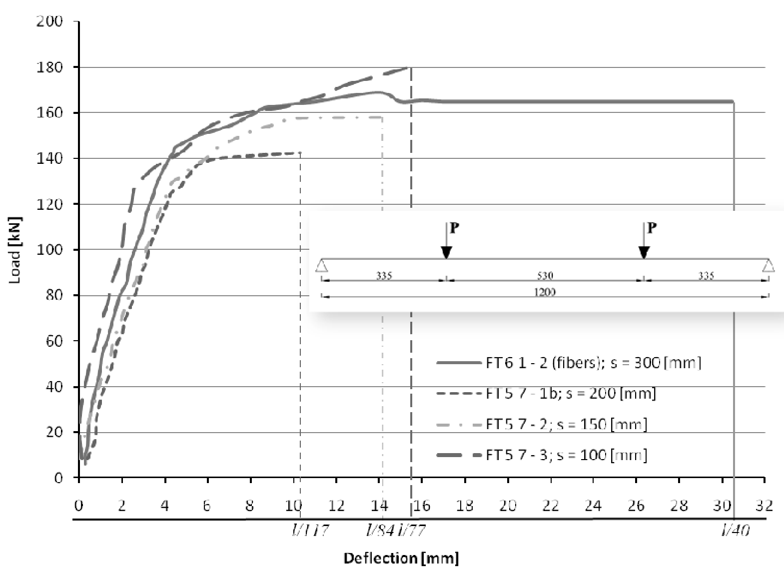


**Figure 7:** Load – Deflection graph for tested beams

## 5. CONCLUSIONS

The use of steel fibers in reinforced concrete elements greatly increases their ductility; they limit the opening of cracks by transmitting tension between their faces and ensuring a more uniform distribution of internal forces within the element.
In terms of shear behavior, the elements tested show a great increase in performance; beam FT 6 1 – 2, which had Φ6 OB37 stirrups spaced 300mm apart, behaved better than beam FT 5 7 – 3 which had Φ6 OB37 stirrups spaced 100 mm apart. Thus, the presence of steel fibers improves the behavior of high strength concrete elements. The load value for which the maximum width of the inclined crack is reached ($w_{max}$=0.4 mm), $P_{wmax}$, is approximately 18% higher then corresponding values in beams having the minimum distance between stirrups, s = 100 mm. In regard to the deformability of the elements, the presence of steel fibers substantially increases shear ductility, as can be observed in Figure 7. A more ductile behavior can be seen, in the beam with steel fibers than in the beams without steel fibers. Ultimate deformations represent *l*/40 for the beam with steel fibers compared to *l*/77 for the beam with the minimum stirrup spacing (s = 100 mm) and without steel fibers.
As such the use of steel fibers as reinforcement seems a highly attractive method of improving the behavior of reinforced high strength concrete beams, which are known to exhibit fragile failure, when subjected to shear.

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