SHEAR TESTS ON SFR-UHPC BEAMS WITH OR WITHOUT WEB OPENING

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Abstract

This paper presents the experimentally obtained shear behaviour of SFR-UHPC (steel fibre-reinforced ultra-high performance concrete) I-shaped beams with or without web openings. Steel fibres added to the concrete replace the stirrups. A comparison between beams with diagonal rebar and without is made. The shear carrying capacity of UHPC beams is significantly increased compared to normal strength or even high strength concrete.

Keywords: Shear, steel fibres, UHPC, web opening

1. Introduction

During the last years the development of new materials increased considerably in the field of construction, among which evolutions in the use of steel fibres and high performance concrete.

In manufacturing prefabricated beams, the assembly of the reinforcement cage has a significant impact on the production, which makes replacement of stirrups by steel fibres of interest.

For a better usage of space between the floor and the roof in a prefabricated building some of the installation pipes need to pass through the beams by means of web openings, and for this a higher amount of reinforcement is needed in that section.

The aim of this study is to investigate the replacement of stirrups by steel fibres and the comparison between beams with or without web opening. In addition, partial replacement of shear links is investigated by comparing steel fibres with or without a single additional diagonal rebar. A mix between short straight fibres and long hooked fibres has been chosen to ensure the best contribution to the shear resistance of the beams, due to the fact that

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small fibres work better on micro-cracks while long fibres are starting to work after the cracks appeared [1].

2. Test program

2.1 Test set-up

Eight I-shaped beams made from SFR-UHPC (steel fibre reinforced ultra-high performance concrete) were tested in shear until failure. Each beam was tested two times, first with a shear span to depth ratio a/d=2.5 and secondly on the opposite shear span with a/d=2.3. Each element had a total length of 4 m, a cross-section of 140 mm width, 400 mm height and a web thickness of 60 mm (Fig. 1).

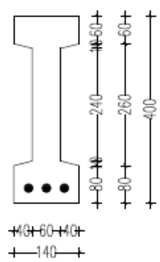

Fig. 1: Beam cross section (dimensions in mm)

Four different types of beams were used (Fig. 2):

- Type F: SFR-UHPC with longitudinal reinforcement;
- Type FD: as type F with diagonal rebar;
- Type FO: as type F with web opening;
- Type FOD: as type FO with diagonal rebar.

For each beam type 4 tests are conducted (2 times a/d=2.5 and 2 times a/d=2.3). The test setup is shown in Fig. 2. The supports allowed the horizontal movement of the tested beams. A hinge support was used at the support closed to the loading point, a roller support for the other side of the beam.

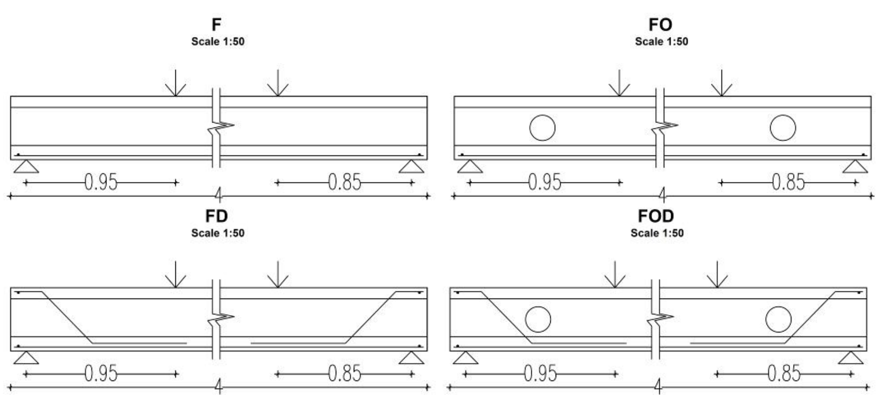

Fig. 2: Design scheme of the beams (dimension in m)

The load was applied on a load pad (ϕ260 mm) with a spherical hinge, and between the jack and the beam a load cell with an accuracy of 0.3 kN was positioned.

2.2 Materials

The UHPC mix is based on research at RWTH-Aachen University [2], and because all the materials were local, some adjustments were made to the recipe. The final concrete composition and some of the concrete proprieties are showed in **Tab. 1**.

Tab. 1: Concrete composition and properties

Concrete composition [1 m^3]	
Cement	650 kg
Coarse aggregates(type andesite)	598 kg
Sand	354 kg
Silica Fume	184 kg
Quart powder	456 kg
Fibres	78 kg
Water	178 l
Superplastifiant	31 l

Concrete properties	
W/C	0,27
W/B	0,22
Slump-Flow(mm)	390

To determine the material properties Young's modulus (E_c), compressive strength (f_c), splitting tensile strength ($f_{ct,sp}$) and bending tensile strength ($f_{ct,fl}$), cubes of 100 mm x100 mm and prisms of 100 mm x100 mm x300 mm were produced. The mean value for the compressive strenght was 140 MPa, and for the mean value of axial tensile strenght 5.74 MPa (f_{ctm}=2,12ln(1+0.1($f_{ck+}\Delta_f$))) [3].

The fibres used are a mix of 1/3 from the total quantity of short fibres of 9 mm, straight (type WHS-9/0.175/S), and 2/3 long fibres of 25 mm, hooked (type WMS-25/0.4/H/430). The total amount of fibres for 1 m^3 of concrete was 78 kg.

Flexural reinforcement consisted in 3ϕ22 mm, and for shear reinforcement diagonal rebars of ϕ12 mm inclined at 45^0 were used. The tension yield stress strength (f_y) of the steel rebars equals 360 MPa.

2.3 Test matrix

Beams F_25, FD_25, FO_25, FOD_25 were tested with a span of 2,73 m and a ratio a/d=2.5 and beams F_23, FD_23, FO_23 and FOD_23 were tested in the opposite shear span, a span length of 2,53 m and a ratio a/d=2.3**Chyba! Nenalezen zdroj odkazů.**.

Each type of beam was casted twice, allowing to do each test 2 times to obtain an indication on test variability.

An overview of the test matrix is given in **Tab. 2**.

Tab. 2: Test matrix

Beam designation	a/d	Web openings (mm)	Diagonal rebar
F_25.1 and F_25.2	2.5	-	-
F_23.1 and F_23.2	2.3	-	-
FO_25.1 and FO_25.2	2.5	ϕ160	-
FO_23.1 and FO_23.2	2.3	ϕ160	-
FD_25.1 and FD_25.2	2.5	-	ϕ12
FD_23.1 and FD_23.2	2.3	-	ϕ12
FOD_25.1 and FOD_25.2	2.5	ϕ160	ϕ12
FOD_23.1 and FOD_23.2	2.3	ϕ160	ϕ12

3. Test results and discussion

All the tested beams failed in shear. When beams without diagonal reinforcement (F) reached the ultimate state, the failure was characterized by a single critical shear crack (Fig. 3. left). In case of beams with diagonal reinforcement (FD) the failure was characterized by more than one principal crack (Fig. 3. right).

For the beams with web openings the failure mode (Fig. 4) is very similar with previously beams and the failure was through the web opening.

The diagonal rebar (for beams FD and FOD) yielded before reaching shear failure.

Fig. 3: Failure of F_23.1 (left) and FD_23.1 (right)

Fig. 4: Failure of FO_23.1 (left) and FOD_23.1 (right)

The load-deflection diagrams can be seen in Fig. 5 and Fig. 6 for a/d=2.3 (similar results have been obtained for a/d=2.5). The difference between beams with or without diagonal rebar in terms of shear capacity is shown in Fig. 7 (for a/d=2.3).

Beams FD, FOD had an important increase in the ultimate strength due to 1 diagonal rebar, while beams F, FO developed an smaller improvement in ultimate shear strength. This indicates that the effect of adding a single diagonal rebar is more pronounced in the case of web-openings.

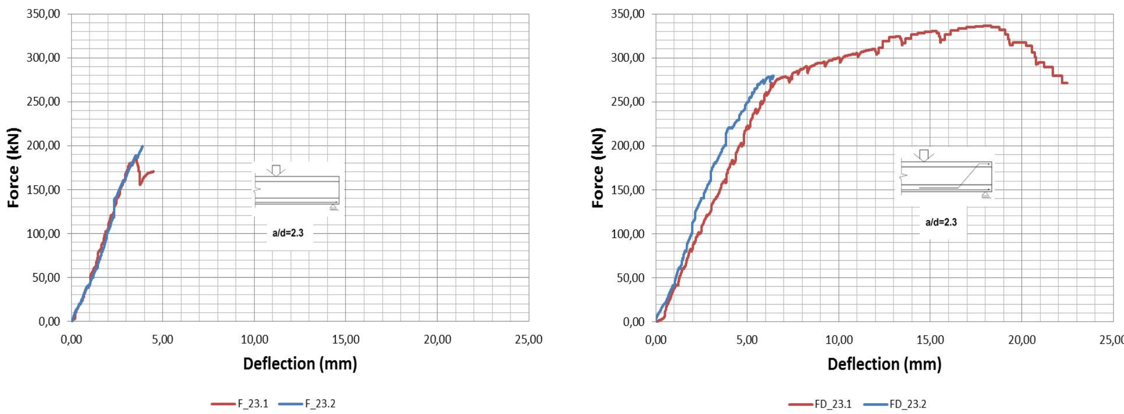

Fig. 5: Deflection under loading point for F and FD beams with a/d=2.3

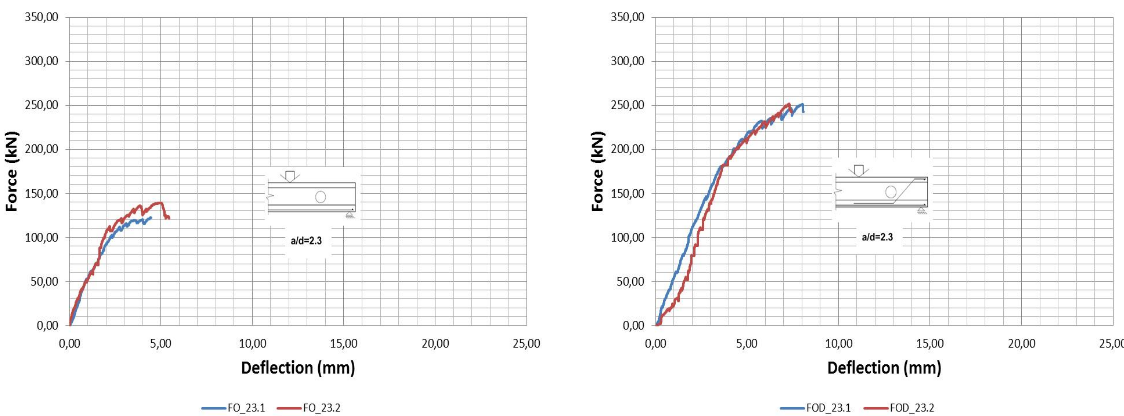

Fig. 6: Deflection under loading point for FO and FOD beams for a/d=2.3

4. Conclusions

It can be observed that the FD beams collapse at a 59% higher load with respect to the F beams, and FOD beams had an increase of 91% compared to FO beams. As all beams have the same amount of fibres, the higher failure load relates to the additional diagonal rebar.

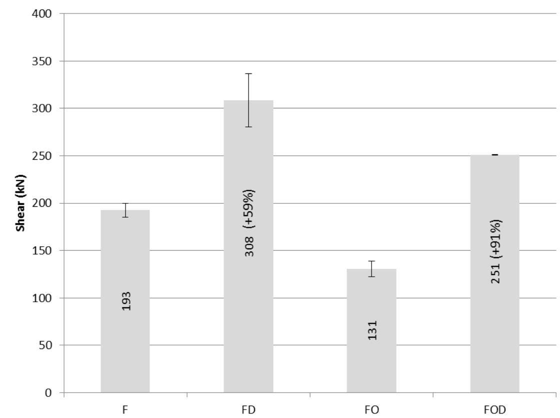

Fig. 7: Comparison between the V_{exp} of the beams for a/d=2.3

When a diagonal rebar was placed the failure is characterized by more than one critical shear crack.

The shear resistance of FO beams (with opening) was about 65% of the solid beams F, while FOD beams (with opening and a single diagonal rebar) resistance was about 80% of solid beams FD (with single diagonal rebar). The use of the fibres and diagonal reinforcement can be enough for strength and ductility requirements to avoid shear failure.

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