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Ductility analysis of standard and fiber-reinforced concrete beams

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Introduction

This thesis is dedicated to the study of the phenomenon of ductile breakage of beams subjected to bending. In particular the study concerned the influence of metal fibres on the degree of ductility of the structure. A test campaign was carried out, which made it possible, through an analysis of the results obtained, to assess the effect of the fibres on the failure of the compressed area of the beams.

Experimental campaign

The test campaign was divided into two main parts, the first part consisted in the characterisation of materials (concrete, steel, fibres), the results obtained were then used in the main test campaign to better evaluate the results obtained.
The main test campaign consisted of four 4-point-bending tests on reinforced concrete beams which the following characteristics:

Geometry	Materials	Fibres
Length: 3.25 [m]	Concrete C30/37	Dramix R RC-65/60-CN
Height: 0.38 [m]	Steel B500B	Length: 60 [mm]
Width: 0.18 [m]	Fibers: 25 kg/m³	Diameter: 0.90 [mm]

To better understand the phenomenon and to have a larger spectra of results to compare, it was decided to analyse 4 different beams, with the following characteristics:

Specimen's code	Presence of fibers	Flexural reinforcement	Shear reinforcement
MA-0.2-N	No	4 Ø 16	Ø 12/150
MA-0.2-F	Yes	4 Ø 16	Ø 12/150
MA-0.4-N	No	4 Ø 22	Ø 12/100
MA-0.4-F	Yes	4 Ø 22	Ø 12/100

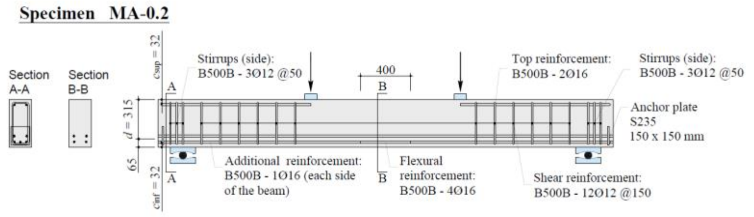

Figure 1 – Reinforcement scheme of specimen MA-0.2-N

Test setup

The test setup is shown in the following figure. The same setup is used for each 4-point-bending test described in the present work. The beams are supported by 380 x 40 mm steel plates, which are free to rotate. Similarly, under the hydraulic jacks, the same plates are disposed, to simulate a concentrate load and to know exactly the dimensions of the loading surface. Under those plates, to regularize the surface, a layer of mortar is placed.
The load frame shown in the drawing consists of two hydraulic jacks containing a load cell to measure the load applied to the beam. Each jack has a maximum load capacity of 300 kN. Both pistons are fixed in the upper part to a steel frame with sufficient stiffness so that their deformation does not affect the results obtained.

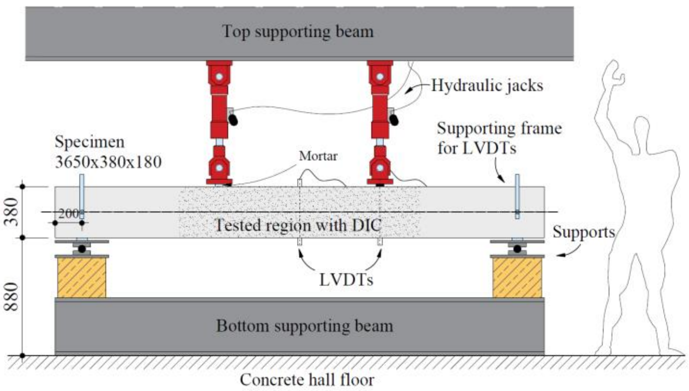

Figure 2 – Test setup for the 4-point-bending test

The test will be carried out in displacement control with a speed of 0.03 mm/s, the pistons have been programmed so as to exert the same force on the beam at each step, so as to have a totally symmetrical loading system. The test will be extended beyond reaching the breaking load, recording displacements and forces in the post-peak descending part of the force-displacement curve, until a post-failure resistance of about 50% of the ultimate load is reached.

Acquisition system

Several measuring systems are installed during the test:

I Measures of the applied force:

The load cells integrated in the hydraulic jacks, which have a maximum capacity of 300 kN, were used to measure the applied force. These load cells were tested in anticipation of the test campaign and were adjusted to increase the accuracy of the measurements for the type of material and the type of test performed.

II Measures of displacement and crack opening:

For data acquisition it was decided to opt for DIC (Digital Image Correlation) system consisting of two cameras which a resolution of 2 x 29 MPix, and able to record vertical and horizontal movements of the tested region, as well as the position and opening of the cracks with a measured surface of 0.4m x 1.2m.

III Control measures of displacement

Control measures shall be carried out in such a way that the quality of the data recorded with the DIC can be measured. These control measurements shall be carried out by installing 2 LVDTs placed respectively under the south jack and in the centre of the beam. Figure 3.14 shows the position of LVDT and the geometry of the beam.

Results

The results obtained were then analysed to estimate the influence of fibres on the ductility of the beams. Several factors were then computed to compare standard concrete and fibre-reinforced concrete failure type:

I Displacement capacity after breakage – Ductility factor:

A first parameter for the evaluation of ductility is the ductility index, which represents the ratio between the deflection at the ultimate limit state, i.e. before beam failure, and the deflection at which the tension reinforcement reaches the yield limit, using the following equation:

$$\mu_D = \Delta_u / \Delta_y$$

The advantage of this approach is that the factor is dimensionless, so it is possible to compare different members, such as in our case. The results obtained are the following

II Ductility capacity – post failure slope of force-displacement curve:

A further indicator of the ductility of the system is the relationship between the slope of the post-peak force-displacement curve and the elastic rigidity, represented by the slope of the same curve before reaching the yield strength of the reinforcement. This value in fact represents the post-breakage deformation capacity, highlighting the response of the system after that the maximum load has been reached.

$$\mu_m = m_{post} / m_{pre}$$

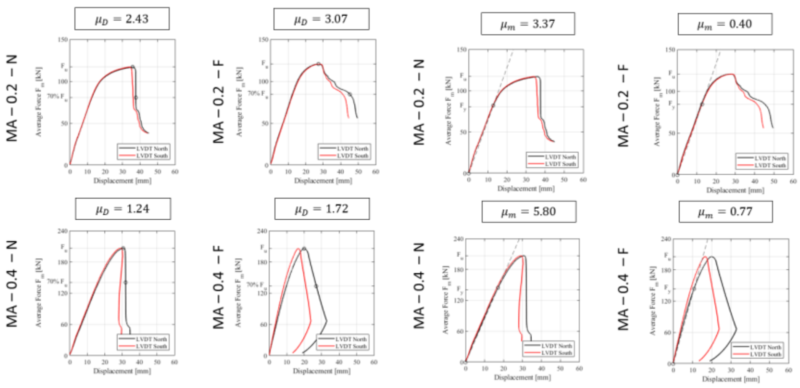

Figure 3 – (Left) Results obtained from ductility factor computation
(Right) Results obtained from post failure slope computation

Conclusions

The test campaign carried out during this thesis work made it possible to analyse the opportunity of increasing the ductility of concrete structures subject to bending using fibre-reinforced concrete. In particular, it was decided to analyse two pairs of beams each with the same reinforcement rate and comparing the type of failure for one element without fibres and one with steel fibres.
The results obtained have shown that for an element subject to bending, for which there is no reinforcement in the compressed area, the addition of fibres causes a very interesting increase in ductility. This characteristic is mainly due to the fact that for elements without reinforcement in the compressed zone, the type of failure is governed by the ductility of the compressed zone. In conclusion, it is evident that the presence of fibres, even in a low quantity (25 kg/m³), has a very positive effect on the ductility of the system and the post-failure displacement capacity.