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EXPERIMENTAL INVESTIGATION OF OVER-REINFORCED CONCRETE BEAMS OF THREE DIFFERENT TYPES OF CONCRETE AND AT TWO DIFFERENT SIZE SCALES

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Abstract
Experimental results from twelve beam experiments is presented. Three different materials at two size scales have been tested. The results are presented as load displacement curves and as moment rotation curves.
Key words: Compression failure, four point Bending, normal strength concrete, high strength, steel fibre.

1 Introduction

The goal is to investigate whether current modelling techniques, in combination with standard test data on strain softening of concrete under mode I and uniaxial compression are sufficient tools for correctly predicting the behaviour of over-reinforced concrete beams. The reason for choosing over-reinforced concrete beams is that they are relatively simple to test and that the softening part of the compression behaviour has a significant influence of the overall behaviour of the beams. Three different types of concrete at two different size scales have been tested.

2 Experiments

2.1 Materials

2.1.1 Steel

Two different types of steel were used. Ribbed steel bars and stranded wires. It was necessary to use stranded wires in the beams with high compressive strength in order to ensure a compressive failure.

Three uniaxial tensile tests have been performed for the ribbed steel bars. The initial modulus of elasticity was measured using a device attached directly on the specimens. The initial modulus of elasticity was determined as E_{rb} = 22200 GPa and the yield strength as 650 MPa.

Three uniaxial tensile tests have been performed for the stranded wires. The initial modulus of elasticity was measured using a device which measures directly on the specimens. The initial modulus of elasticity was determined as E_{sw} = 197000 GPa. The rest of the stress-strain relationship could not be measured due to difficulties with the grips.

2.1.2 Concrete

A normal strength concrete (NSC), a very brittle high strength concrete (HSC) and a similar concrete, but with an added large amount of steel fibres (FRHSC) have been tested. The composition of the three materials can be seen in table 1.

Table 1. Composition of the three types of concrete.

Units are kg/m3	NSC	HSC	FRHSC
Cement	212	0	0
Densit Binder	0	971	971
Silica Fume	9.96	0	0
Pozzolith 80 N	1.57	0	0
Water	155	146	158
Steel Fibres	0	0	503
Sand (0 mm- 0.25 mm)	0	176	176
Sand (0.25 mm - 1 mm)	0	357	357
Sand (1 mm - 4 mm)	0	716	716
Sand (0 mm - 2 mm)	945	0	0
Sand (2 mm - 4 mm)	1001	0	0

Different reference parameters have been determined using different measurement techniques and boundary conditions. The compressive strength, the tensile strength and the fracture energy are shown in table 2. For a more detailed description of the determination and stress strain curves in compression reference is made to Ulfkjaer, Van Mier and Stang (1997).

Table 2. Compressive strength, uniaxial tensile strength and the specific bending fracture energy of the three types of concrete. The results are given in the format Mean/Coefficient of variation in percent.

Type of concrete	Compressive strength [Mpa]	Tensile strength [Mpa]	Specific Bending Fracture Energy [N/m]
NSC	22.75/2.0	1.89/17.7	85/14
HSC	117.74/9.0	4.83/9.71	125/35.9
FRHSC	114.41/4.0	7.14/02.9	3780/10.6

2.2 Test setup

The beams are tested in four point bending at two different size scales, the largest beam geometry is exactly twice the scale of the small. The two scales are given the names 'small' and 'large' (i.g. a beam called NSC large b, will be the second repetition of a normal strength concrete beam at the largest size scale).

2.2.1 Small specimens

Nine beams with the dimensions length 3800 mm, span: 3600 mm, depth 200 mm and thickness 100 mm three repetition of each type of concrete were cast and tested. For simplicity the same reinforcement arrangement was used for all nine beams. Due to the very high compressive strength of the high strength concrete it was necessary to use 8 stranded wires in order to obtain an over reinforced fracture mode. The stranded wires are placed in three layers, with three bars in the two lowest layer and two bars in the upper layer. The layers are (centre of gravity of the layer) 23.6 mm, 48.8 mm and 74. mm from the bottom of the beam. The cover in the vertical direction (to centre of gravity) is 23.6 mm and the distance between the wires are 26.4 mm in the two lowest layers, and 52.8 mm in the upper layer.

2.2.2 Large specimens

Three beams with the dimensions length 7500 mm, span: 7200 mm, depth 400 mm, and thickness 200 mm of normal strength concrete were tested. Originally it was planned to scale the small beams by a factor of two including the reinforcement. It was however, not practically possible to arrange 32 stranded wires in the mould. Instead, 9 ribbed bars were used. The ribbed bars are placed in three layers, with three bars in each layer, 40 mm, 80 mm and 120 mm from the bottom of the beam. The cover in the vertical direction (to centre of gravity) is 41 mm and the distance between the bars is 59 mm.

2.3 Test Set-up

The beams were subjected to four point bending in a servo-controlled materials testing system.

At both supports horizontal displacements and rotations were allowed, and at one support rotation around the beam axis were also allowed. At the load point rotations were allowed around two axes. This should reduce the influence of axial normal forces and torsion. At both end a stop was placed at the top of the beam to prevent the beam from sliding off the supports.

The stroke was measured using a built-in LVDT (Linear Variable Differential Transformers). The vertical displacements were measured at nine points using LVDTs. The horizontal displacements of the beam were measured at both beam ends using two LVDTs.

Between the loads a set of measuring frames were fixed to the beam. The frames were attached to the beams in three points and with three LVDTs attached to each frame. The LVDTs were thus measuring the horizontal displacement between two frames in three points. By assuming that plane sections remain plane it is possible to calculate the mean strain field in each measuring field.

2.3 Test procedure

The rate of loading was chosen such that the peak load would be reached within 5-10 minutes. A typical experiment would take about 30 minutes. All signals, together with time, *t*, were recorded using a data logger and a personal computer. The tests were controlled by a feedback signal that

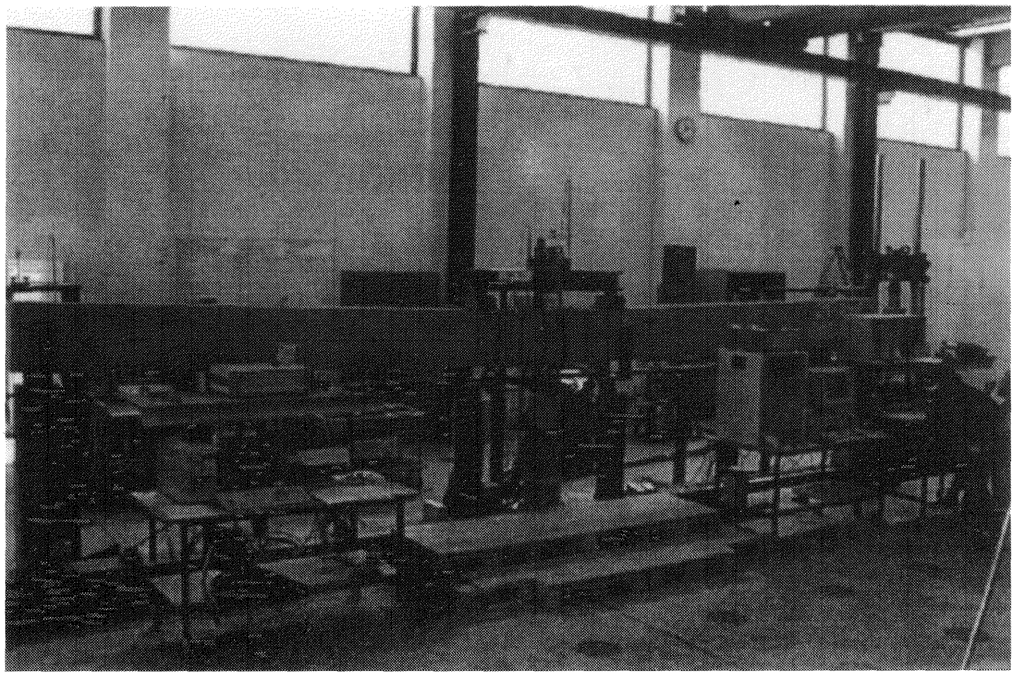

Fig. 1. Photo of the large beam. The data acquisition equipment (to the left) and the servo control (to the right) can be seen.

included contributions from both the stroke and the COD. In figure 1 is shown a photo of the test set-up for one of the larger beams.

3 Results

3.1 Load displacement and moment rotation curves

The results are presented as Load-displacements curves and as Moment - rotation curves, were the displacement is the midpoint deflection and the rotation is the rotation at the supports. The dead weight of the beams, are included by calculating a force which gives the same cross sectional moment in the loading points, and by adding the equivalent displacement.
The rotation at the supports are calculated by adding the two deformations and by dividing by the distance between the two transducers. In figure 2 - figure 7 the results from the small beam sizes are shown and in figure 8 and figure 9 the curves for the large beams of normal concrete are presented. The peak load, the deformation at peak load, the moment at peak and the rotation at peak are shown in table 3.

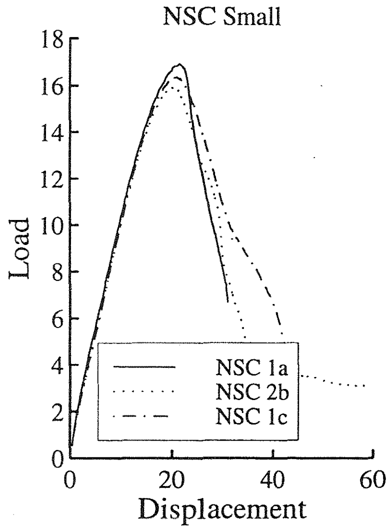

Fig. 2. Load displacement curves for NSC for the small beams.

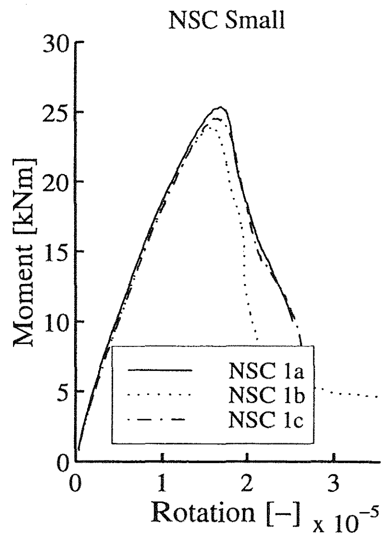

Fig. 3. Moment rotation curves for NSC for the small beams.

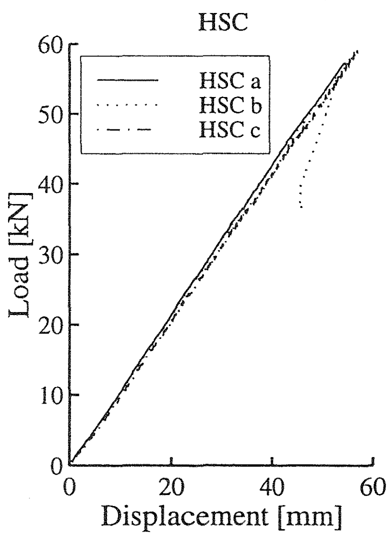

Fig. 4. Load displacement curves for HSC.

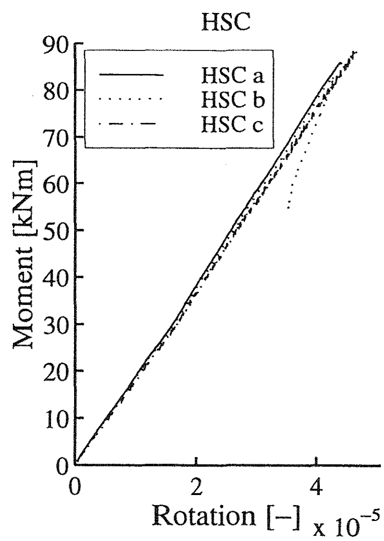

Fig. 5. Moment rotation curves for HSC.

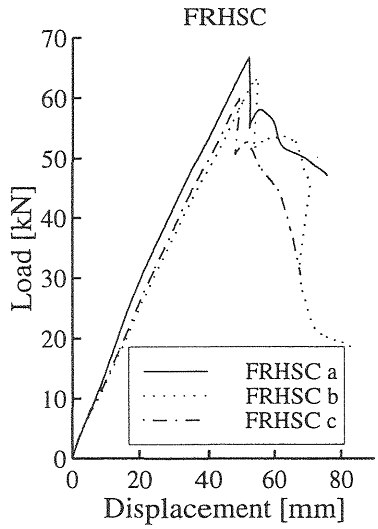

Fig. 6. Load displacement curves for FRHSC.

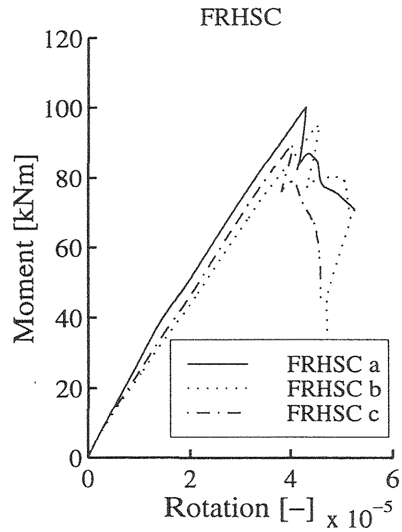

Fig. 7. Moment rotation curves for FRHSC.

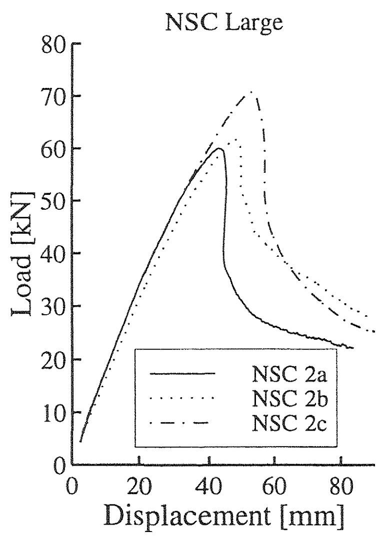

Fig. 8. Load displacement curves for NSC for the large beams.

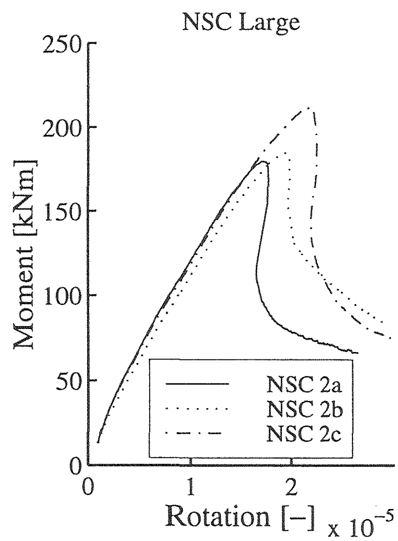

Fig. 9. Moment rotation curves for NSC for the large beams.

Table 3. Peak characteristics for beam tests.

Type	U_{peak} [mm]	P_{peak} [kN]	α_{peak} [mm-1]	M_{peak} [kNm]
NSC Size 1 No. 1	21.55	16.92	1.687e-5	25.39
NSC Size 1 No. 2	20.49	15.94	1.582e-5	23.90
NSC Size 1 No. 3	20.96	16.37	1.648e-5	24.56
FRHSCa	52.07	66.90	4.306e-5	100.3
FRHSCb	54.15	63.45	4.536e-5	95.17
FRHSCc	48.97	59.93	4.029e-5	89.90
HSCa	57.25	54.49	4.387e-5	81.72
HSCb	52.88	55.48	4.294e-5	83.21
HSCc	57.04	59.18	4.636e-5	88.77
NSC Size 2 No. 1	42.89	60.00	1.734e-5	90.01
NSC Size 2 No. 2	47.61	61.68	1.931e-5	92.5
NSC Size 2 No. 3	52.88	70.65	2.179e-5	106.0

4 Conclusions

The results from twelve beam tests have been presented. It is seen that the behaviour is highly dependent on the material type and also a size effect is seen. For the high strength concrete and the ultra high strength concrete the influence of the descending branch of the stress strain relationship is of highly importance.

5 Acknowledgement

The beam experiments reported here were performed by M.Sc. Lone Høgholm Pedersen, M.Sc. Kim Bundgaard and M.Sc. Torben Mørch during their masters project.

6 References

Pedersen, L.H., Bundgaard, K. and Mørch, T. (1996), **Compression Failure of Concrete Beams**, Aalborg University, Masters Thesis, pp. 1-162.

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