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NUMERICAL SIMULATION OF ULTIMATE LOAD TESTS ON FIBRE REINFORCED CONCRETE BEAMS

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Summary. *This contribution deals with the numerical simulation of ultimate load tests on continuous beams made of fibre reinforced concrete. The employed material model is based on the theory of plasticity taking into account the softening material behaviour of fibre reinforced concrete in tension.*

1 INTRODUCTION

Ultimate load tests on continuous concrete beams were conducted at the Institute for Concrete Structures and Construction Materials of the University of Innsbruck. In the first test series only longitudinal reinforcing bars were placed in the beams in order to obtain reference data for the subsequent test series, in which steel fibres were added to the concrete.

This contribution deals with the numerical simulation of the described tests. The nonlinear material behaviour of concrete is described by an elastic-plastic material model. To take into account the properties of the fibre reinforced concrete special attention is paid to the consideration of the softening material behaviour in tension. To this end, tests on notched beam specimens were performed in order to determine the specific fracture energy of fibre reinforced concrete.

The computed results are compared with the experimental results on the basis of (i) the ultimate loads, (ii) the longitudinal strain at midspan in terms of the applied loads and (iii) the crack patterns. It will be shown that the numerical model allows a realistic prediction of the structural behaviour and the crack patterns of fibre reinforced concrete beams.

2 TEST DESCRIPTION

The test setup is shown in Figure 1. The length of the beams is 5.40 m with two spans of 2.5 m each, the height and the width of the cross section are given as 0.35 m and 0.20 m, respectively [1]. The beams were loaded by two point loads, each acting at midspan, which were increased until failure of the beams occured. For all test series the

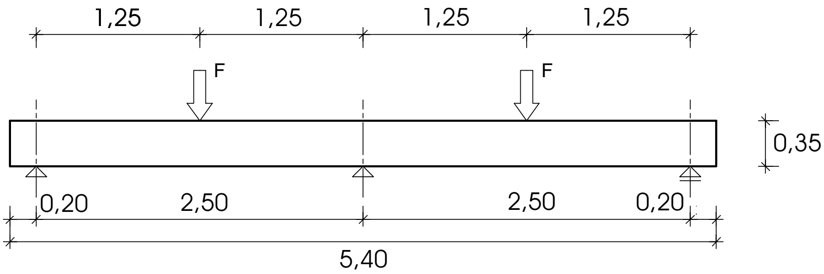

Figure 1: Test setup

longitudinal reinforcement of the beams consists of 4 bars of 14 mm diameter, extending over the complete length of the beams – two of them placed at the top and two at the bottom of the beam – and of two bars of 20 mm diameter at the bottom of each span. The material parameters for the longitudinal reinforcement are given in Table 1.

Young's modulus	N/mm^2	200 000
Yield strength	N/mm^2	574
Tensile strength	N/mm^2	652
Strain at failure		7.8%

Table 1: Material parameters of the longitudinal reinforcement

The material parameters for the concrete are provided in Table 2. For test series B1 they refer to plain concrete, whereas for test series B3 and B4 they refer to fibre reinforced concrete with fibre contents of $30\,kg/m^3$ and $50\,kg/m^3$, respectively. The employed steel fibres are made of cold drawn wires with hooked ends. The fibre length and the fibre diameter are chosen as 60 mm and 0.75 mm, respectively. The yield strength of the fibres is within the range of 1050 - 1210 N/mm^2. In order to determine the specific fracture energy of the fibre reinforced concrete three point bending tests were performed on notched specimens with dimensions $0.10 \times 0.10 \times 0.90$ m with a span of 0.80 m. From these tests the specific fracture energy is obtained for plain concrete as $G_f = 145\,Nm/m^2$, for concrete with fibre content of $30\,kg/m^3$ as $G_f = 4905\,Nm/m^2$ and for concrete with fibre content of $50\,kg/m^3$ as $G_f = 30\,000\,Nm/m^2$.

Test series		B1	B3	B4
Young's modulus	N/mm^2	34 880	32 170	33 810
Compressive strength	N/mm^2	46.5	35.4	41.9
Bending tensile strength	N/mm^2	4.43	5.20	5.54
Fibre content	kg/m^3	—	30	50

Table 2: Material parameters of concrete

3 NUMERICAL MODEL

An elastic-plastic material model for concrete, formulated for plane stress conditions, is employed for the numerical analyses. It is characterized by a composite yield surface, consisting of two yield functions to limit the tensile stress and to describe the nonlinear material behaviour in the compressive regime. Hardening and softening behaviour is described in terms of two hardening variables, which represent equivalent plastic strains in tension and compression, respectively. Suitable softening laws are employed to describe tensile and compressive failure. The softening material behaviour of plain concrete in tension is represented by an exponential law, whereas the respective softening law for fibre reinforced concrete is chosen according to [2]. Immediately after reaching the tensile strength it consists of an exponential softening law, which after full activation of the fibres is followed by a linear softening law. Hence, the exponential part represents the material behaviour of plain concrete in tension, whereas the linear part accounts for the contribution of the fibres to the residual tensile strength after full activation of the fibres. Cracking is represented in a smeared manner by distributing the crack opening over the width of the respective finite element. Objectivity of the numerical results with respect to the employed mesh size is obtained by employing the specific fracture energy for tensile failure of concrete and an equivalent length. The latter is simply taken as the root of the area of the respective finite element.

4 COMPARISON OF EXPERIMENTAL AND COMPUTED RESULTS

In a first step the three point bending tests on fibre reinforced concrete specimens are analysed. The comparison of measured and computed load-displacement diagrams is shown in Figure 2.

It follows from Figure 2 that the employed softening relationship is suitable for concrete with a relatively low fibre content, whereas for higher fibre contents the increased load carrying capacity after reaching the tensile strength is neglected.

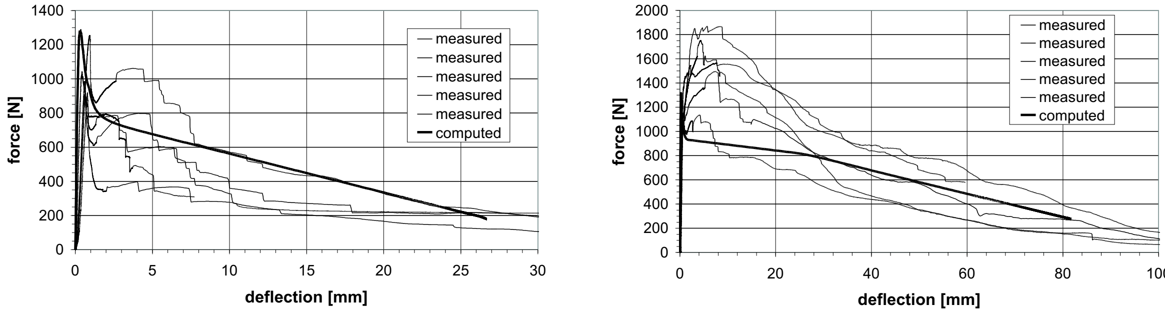

Figure 2: Measured and computed load displacement diagrams for the three point bending specimens made of concrete with fibre contents of 30 kg/m^3 (left) and 50 kg/m^3 (right)

In the second step the ultimate load tests on continuous beams are simulated numerically. The comparison of measured and computed longitudinal strain at midspan (measured 38 mm above the bottom surface) in terms of the applied load is shown in Fig. 3. Expectedly, the ultimate load is increasing with increasing fibre content. For all three test series good correspondence between test results and numerical results is achieved.

Finally, Figure 4 contains a comparison of the observed crack pattern with the computed one for test series B3, shortly before the ultimate load is attained.

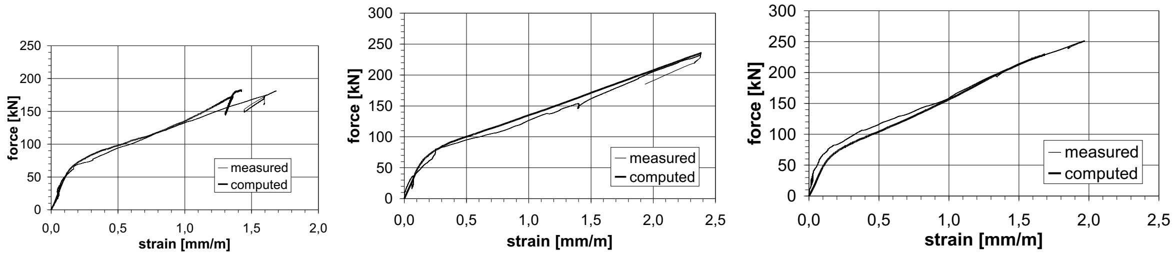

Figure 3: Longitudinal strain in terms of the applied load for the continuous beams: test series B1 (left), test series B3 (middle), test series B4 (right)

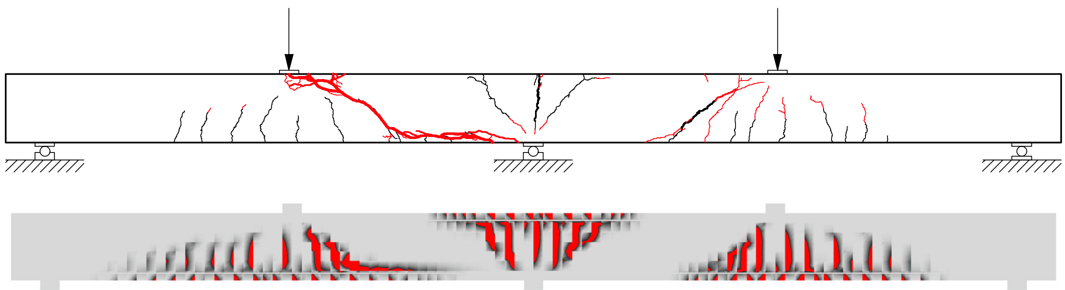

Figure 4: Comparison of observed (top) and computed (bottom) crack pattern for the continuous beam with a fibre content of 30 kg/m^3

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