INVESTIGATION OF CRACKS IN CONCRETE BEAMS

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Abstract

Three reinforced concrete beams with nominal dimensions 2000x150x150 mm were tested in four-point bending until failure. The width of the cracks in the concrete was measured by various methods; the results were compared and evaluated. Nonlinear numerical simulation of these tests was performed; the results are compared with the experimental results. Crack widths calculated according to the Czech national code are also related to the experimental results. This study is a part of a project on judging the objectivity of various methods used in-situ for measuring crack widths on concrete highway and road bridges

Keywords: crack width; concrete structure, non linear numerical analysis

1 Introduction

Reliability, durability and usability of concrete structures are limited by the occurrence of cracks. Concrete is an inhomogeneous material with relatively low tensile strength in comparison to its compressive strength; if the tensile strength is exceeded, cracks occur. In order to check the condition of concrete structures it is necessary to analyze the width of the cracks, which should not exceed the limits defined in the standards for various types of structures. Currently used in-situ crack measurement methods (crack scale, magnifier) can be influenced by subjective classification.

In order to verify the objectivity of different measurement methods, a set of reinforced concrete specimens was tested in laboratory conditions until failure. The incurred cracks were measured using various methods, and the results were compared with each other with the results of a numerical simulation of the tests and with values calculated according to the Czech code.

Crack growth can be considerably reduced by an appropriate admixture of fibres. Fibre concrete has, in general, much higher ductility in comparison to the conventional concrete. Its fracture energy (energy consumption necessary for crack growth) can increase significantly depending on type and contents of fibres. This fact can be considered also in the nonlinear numerical simulation of fibre concrete specimens or structures, where the

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determined fracture energy can be exactly accounted in the material model. The investigation of cracks in fibre concrete structures will be performed in near future.

2 Experimental program and results

Three reinforced concrete beams 2000 mm in length and with a cross section of 150/150 mm were subjected to testing [4]. The test specimens were manufactured in a building site milieu from a concrete mix of nominal class B35/45, and two months after casting they were tested in laboratory conditions. The beams were reinforced by a pair of straight bars Ø R 16 in the lower part and by two bars in the upper part of the specimen. Stirrups were placed at an average distance of 150 mm. The material characteristics of the concrete used for casting the beams were verified by compression prism tests (52 MPa), by a Schmidt impact hammer on the beams (49 MPa) and by tensile bending tests (4.0 MPa). Any variation in the geometrical dimensions, reinforcement cover and mechanical properties of individual beams was taken into account in the evaluation and in the numerical calculations.

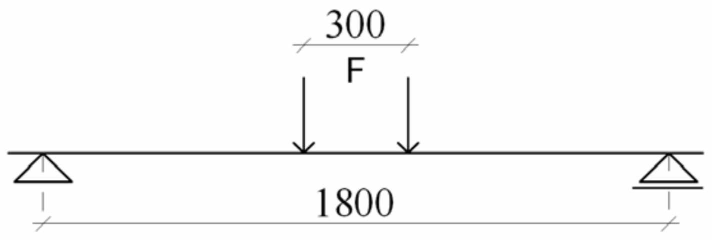

Fig. 1 Test scheme

In the testing machine the beams were simply supported on a span of 1800 mm and loaded by two coupled forces in the middle of the span with a distance of 300 mm, see Figs. 1 and 2.

Fig. 2 Beam in the hydraulic testing machine

The maximum loads of the individual tested beams were 60.23 kN, 63.92 kN and 63.16 kN, with limit deflection between 26 and 28 mm. During the loading process of the beam (continuously at a rate of 0.2 kN/s), the deflections were monitored in the middle of the span (the resulting diagram is presented in Fig. 3) and occurrences of cracks were marked on the beam. Final crack pattern of the beam No. 2 is shown in Fig 4. The first opening of the cracks was also monitored by an acoustics analyser.

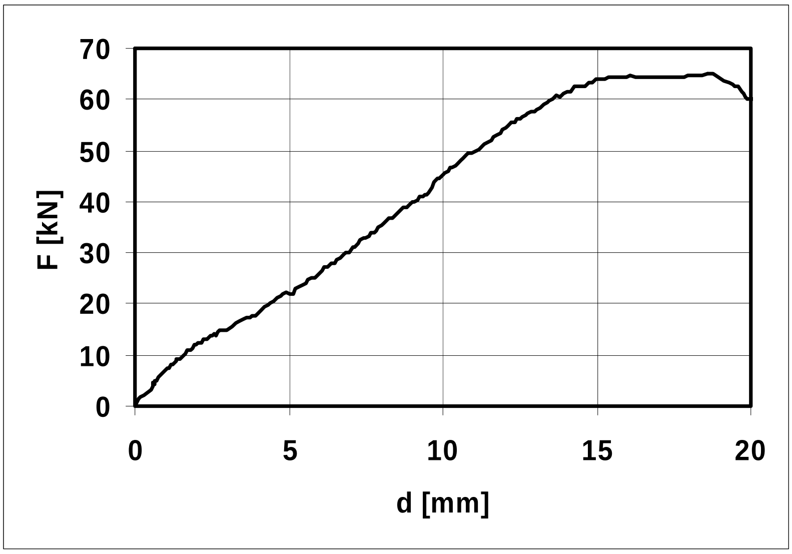

Fig. 3 Measured load-deflections response of the beam

At a load level of 60 kN all visible cracks were carefully measured by three different methods: crack surface scale, enlarging magnifier (comparator), and microscope. These measuring methods are described in greater detail in [1].

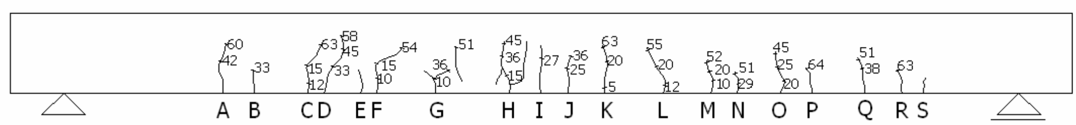

Fig. 4 Crack pattern

Eleven cracks were less than 0.1 mm in width, seven were less than 0.5 mm, and the maximum measured width was equal to 2.5 mm. The differences among the measurements acquired using the microscope, using the crack surface scale, and using the enlarging magnifier can characterize the accuracy of the method. The standard deviations of these differences were equal to 0.08 mm for both experimental methods**.**

3 Numerical simulation

Numerical simulation of the tested beams was performed using the ATENA nonlinear finite element program [2, 3]. This is a well established finite element program for realistic computer simulation of damage and failure of concrete and reinforced concrete structures, including evaluation of crack widths in concrete. Since concrete is a complex material with a strongly nonlinear response, even under service load conditions, special constitutive models for the finite element analysis of concrete structures are employed.

The tensile behaviour of concrete is represented by non-linear fracture mechanics combined with the crack band method and the smeared crack concept, Fig. 5. A real discrete crack is simulated by a band of localized strains in finite elements. Tensile softening (i.e., a drop in tensile stresses after crack initiation) is assumed in an exponential form and is driven by fracture energy consumption. The real crack width is automatically evaluated from the localized strains and the crack band width (adjusted finite element size) in post-processing of results from the analysis.

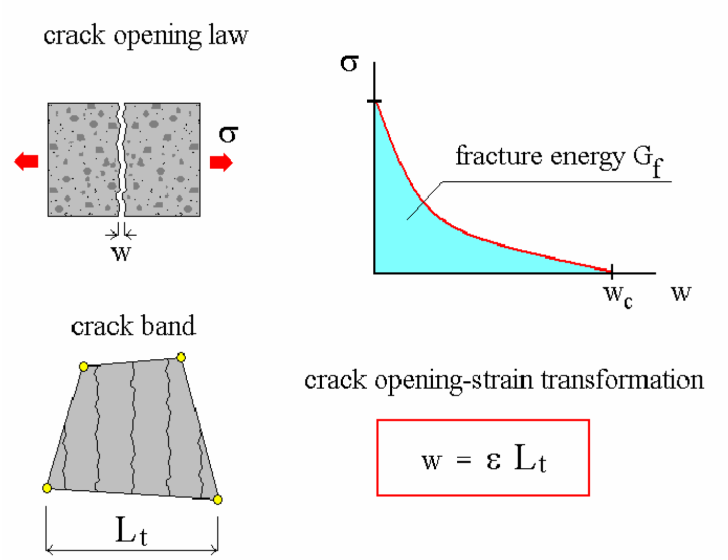

Fig. 5 Smeared crack model for tensile behavior of concrete

A finite element model of the tested beam was created from the real geometry of the produced specimen, the real reinforcement layout and the measured material properties. The model with 1400 finite elements was simply supported on a span of 1800 mm and loaded by two coupled forces in four - point bending (Fig. 6).

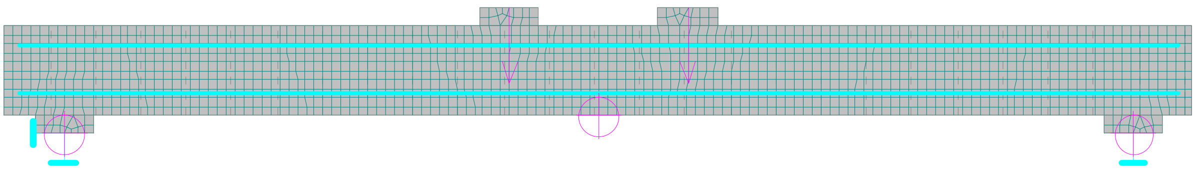

Fig. 6 Finite element model of the four-point bending beam with reinforcement, boundary conditions and measurement points

Elastic steel plates above the supports and under the loading forces are used in the model (by analogy with the experiment) to avoid local concrete failure. The deflection in the middle of the beam and the vertical support reaction were measured in order to obtain the load-deflection response during the testing procedure.

The numerical analysis was performed in loading steps of 2 kN until model failure. The final load-deflection diagram is shown in Fig. 7. The total failure load of the modelled beam was 64.5 kN and the maximum deflection in the middle of the beam at failure was 26.6 mm, which is in excellent agreement with the real tests. The beam collapsed due to compressive failure of the concrete under the loading plates and simultaneous yielding of the bottom reinforcement.

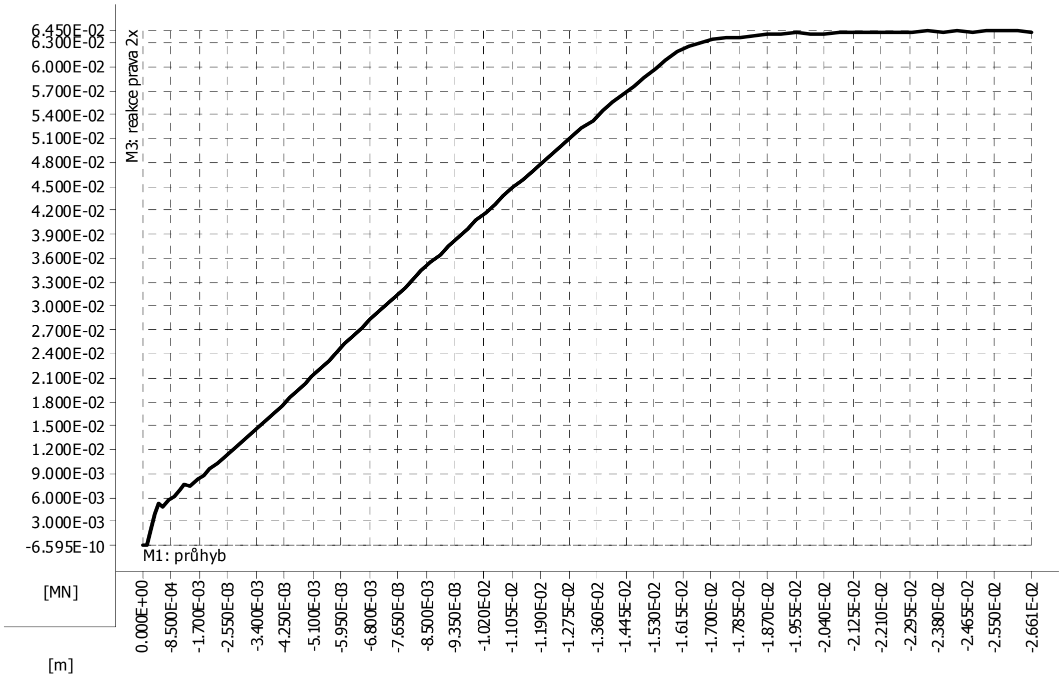

Fig. 7 Diagram of total load vs. deflection in the simulated four-point bending test

The crack pattern at a load level of 60 kN is shown in Fig. 8; this figure shows only localized cracks that are 0.07 mm and more in width. Most of the approx 20 major cracks have typical widths (on the bottom beam edge) between 0.15 and 0.3 mm; the maximum crack width was 0.32 mm. During subsequent loading in the plastic beam response the maximum cracks grew to several mm in width.

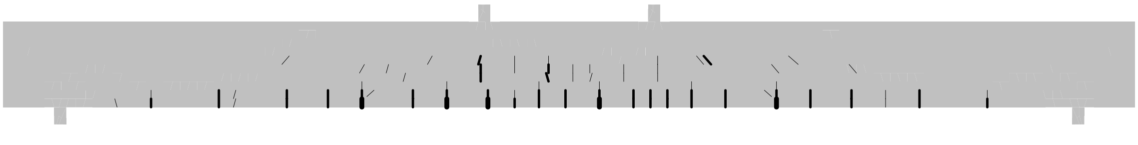

Fig. 8 Calculated crack pattern at a load level of 60 kN (the maximum crack width is 0.32 mm, and only cracks larger than 0.07 mm are shown)

4 Crack width calculation according to the code

At a load level of 60 kN the crack widths were calculated in [5] according to the Czech Standard ČSN 731201. The evaluation was carried out under standard assumptions; the real admissible load should be considerably lower.

According to this theoretical calculation, the widths of four cracks on the beam are less than 0.1 mm, the widths of six cracks are less than 0.4 mm, and the widths of five cracks are equal to 0.48 mm in the middle of the span.

5 Conclusions

The objectivity of various methods for measuring crack widths in concrete structures was verified on laboratory tests and compared with results from numerical simulation and with values calculated according to the Czech standard [1].

The values calculated according to the code are higher than the real values since the assumptions of the codes are considerably stricter than the real conditions. On the other hand, the results from the numerical simulation provided a crack pattern similar to the real tests, since the assumptions and models in the numerical analysis were quite realistic.

The crack widths on the tested beams measured by different methods are rather consistent. The standard deviations of the differences between measurements acquired using a high-precision microscope and using a crack surface scale and an enlarging magnifier were equal to 0.08 mm for both methods. The two methods showed almost negligible differences.

The evaluated methods are suitable also for measurement of cracks in structures made from fibre concrete. Similar investigations as presented here (both tests and numerical simulation) of fibre concrete specimens are planed.

Aknowledgements

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