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Tentative Characterization of Old Structural Concrete through Mechanical Fracture Parameters

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Abstract

Structural concrete of the building of Vítkovice railway station from 1970s is characterized via mechanical fracture parameters. In this paper, six core-drilled cylindrical specimens with diameter of 75 mm were provided by a Chevron type notch of depth of 12 mm. Three-point bending fracture tests were conducted on these specimens supported as beams with the span of 170 mm. Load vs. deflection and load vs. crack mouth opening displacement diagrams were recorded from which modulus of elasticity (E), fracture toughness (K_{Ic}) and fracture energy (G_{F}) were determined using linear elastic fracture mechanics approach and work-of-fracture method. Mean values of these parameters (with their coefficient of variability) were obtained as follows: E = 39.4 GPa (29.1 %), K_{Ic} = 0.90 MPa·m$^{1/2}$ (18.5 %), G_{F} = 174.0 J/m^2 (26.0 %). These parameters can serve as first guess or indicative values for structural assessment and life-time predictions.

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Keywords: Structural concrete; core-drilled samples; cylindrical specimen; Chevron notch; fracture test; mechanical fracture parameter.

1. Introduction

Among the most frequently used building materials one can primarily name silicate-based, particularly cement-based composites [1]. Thanks to their character and to the production technology, these materials are very adaptable and utilizable for a wide range of applications. Thus, from the perspective of the modern construction concepts of the last almost two centuries, concrete can be definitely regarded as a traditional material. Many reinforced concrete buildings are, therefore, already designated as cultural monuments, several ones also in the Czech Republic. Within

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the project “Analysis and presentation of the values of modern architecture of the 1960s and 1970s as part of the national and cultural identity of the Czech Republic” a particular attention is paid to diagnostics of selected reinforced concrete structures and heritage procedures for restoration of building cores. In this paper, structural concrete of the building of Vítkovice railway station from 1970s is characterized using standard fracture test and described via parameters of selected relevant fracture-mechanical models. These parameters are important indicators of the material behaviour, although common contemporary engineering practise is usually limited to elastic and strength characteristics only which can be derived from ‘simple’ compressive tests. However, the material brittleness vs. ductility can’t be expressed by these classical parameters and thus characteristics describing the resistance of the material against the crack propagation are becoming important for many types of analyses and assessments of the structures nowadays.

2. Specimens

Six cylindrical specimens were obtained as cores drilled out from the above mentioned building. These samples were geometrically adjusted to create regular beam-shaped specimens with circular cross-section and then provided by the Chevron type notch (see Fig. 1). Tab. 1 introduces specimen dimensions (according to the sketch in Fig. 2) used in further calculations. Note, this shape of specimen and notch type is typically used for determination of mechanical fracture properties of rocks [2–4].

Fig. 1. Specimens before (left) and after fracture test.

Table 1. Dimensions of tested specimens.

			Specimen ID					
	Symbol	Unit	V7	V9	V13	V15	V17	V18
Diameter	D	mm	74.09	74.16	74.97	75.05	74.99	74.68
Length	L	mm	215	237	211	224	196	194
Notch tip depth	a_0	mm	11.28	11.46	11.98	11.77	11.94	12.55
Notch depth	h_0	mm	18.54	18.59	19.00	19.30	18.90	19.12
Area of initially uncracked ligament	A_{lig}	mm^2	2742.99	2749.21	2791.35	2751.28	2806.55	2762.72

3. Fracture tests

The mechanical fracture parameters of concrete [5, 6] were determined from experiments on specimens in three-point bending test configurations. The scheme of the testing setup and pictures from the test are shown in Figs. 2 and 3, respectively. Specimens were loaded under displacement control; therefore, it was possible to record the load vs. displacement and also the load vs. crack mouth opening displacement curves (*F–d* and *F–CMOD* diagrams) during the course of the test. The load span was set to 170 mm. The initial Chevron type notch was made before testing with a diamond blade saw. The fracture tests were carried out using a Heckert FPZ 100/1 testing machine with measuring range of 0−10 kN; the speed of the induced displacement of the upper support was equal to 0.02 mm/min.

The GTDiPS software [7] was used to correct the raw recorded *F–d* and *F–CMOD* diagrams which essentially represent data points registered by the acquisition system at the same time. The correction consisted of elimination of duplicated data points and substantial reduction of the number of the recorded data points). A selected section of the ascending part of each individual diagram (a linear portion of the steady elastic response) was used for its approximation using a linear regression function. Subsequently, the point of intersection of this straight line with the horizontal axis was determined and denoted as the beginning of the loading; then all points on the diagram were shifted by the same distance so that the point of intersection of the straight line belonged to the origin of the coordinate system. Similarly, the next data modification is motivated by the nature of the experimental system. The configuration of the used experimental system may result in a sudden event, which does not satisfy the requirements of a quasi-static test progress/measurement. During the performed transformations, the violation of such requirements was detected by analyzing the point sequences in time domain which resulted in removing the unsuitable points (the snap-down phenomenon). Then, the resulting gaps in the data sequences were filled with new points generated using an interpolation (gap filling) method based on polynomial approximation. Corrected *F–d* diagrams for all studied specimens are shown in Fig. 4 left. The right figure depicts comparison of a selected measured diagram and the corresponding corrected one.

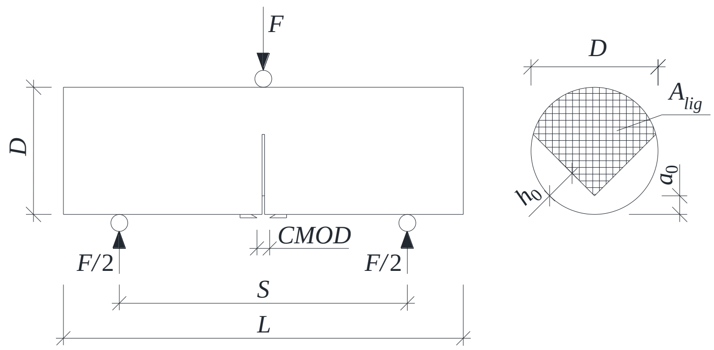

Fig. 2. Scheme of three-point bending fracture test of specimen with Chevron type initial notch.

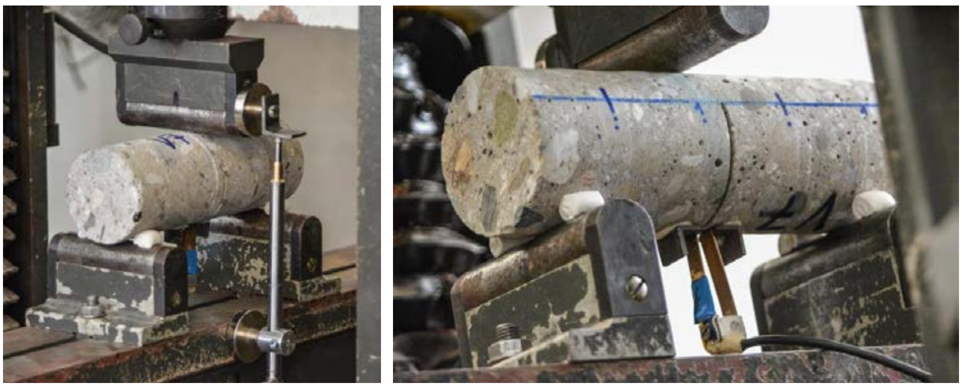

Fig. 3. Three-point bending fracture test of specimen V7 – details of measurement of displacement *d* (left) and *CMOD*.

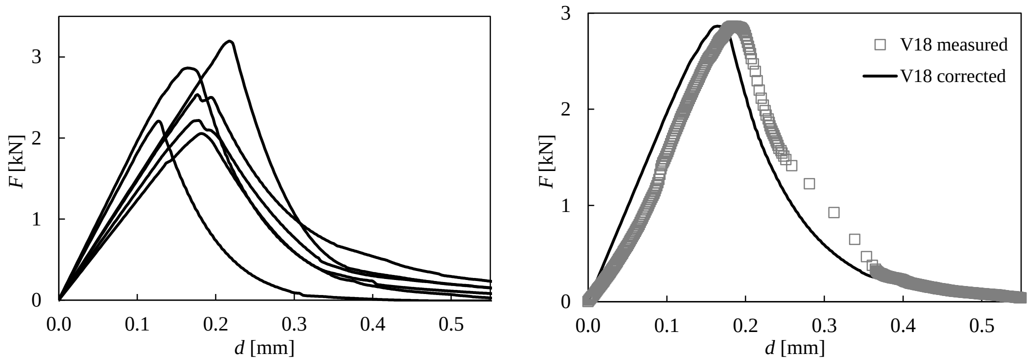

Fig. 4. Corrected load F vs. displacement d diagrams of all fracture tests; measured and corrected diagrams of selected specimen V18 (right).

4. Methods

The mechanical fracture parameters of concrete are calculated from corrected *F–CMOD* and *F–d* diagrams. The first, almost linear part of the *F–CMOD* diagram (determined by a selected point with values F_i, $CMOD_i$) is used to estimate modulus of elasticity (E) value with help of geometrical factor g_0 [2]:

$$E = g_0 \cdot \frac{F_i}{CMOD_i} \cdot \frac{1}{D}, \text{ where } g_0 = 20.8 - 19.4 \cdot \frac{a_0}{D} + 142.3 \cdot \left(\frac{a_0}{D}\right)^2 \tag{1}$$

Afterwards, maximal load $F_{\max}$ is used for fracture toughness assessment with help of geometrical factor $A_{\min}$ [2] and span S:

$$K_{\mathrm{Ic}} = A_{\min} \cdot \frac{F_{\max}}{D^{1.5}}, \text{ where } A_{\min} = \frac{S}{D} \cdot \left[1.835 + 7.15 \cdot \frac{a_0}{D} + 9.85 \cdot \left(\frac{a_0}{D}\right)^2\right] \tag{2}$$

The toughness G_{Ic} is then calculated as follows:

$$G_{\mathrm{Ic}} = \frac{\left(K_{\mathrm{Ic}}\right)^2}{E} \tag{3}$$

The work of fracture value W_{F}, and then the specific fracture energy G_{F} value, is assessed from the complete *F–d* diagrams [8]:

$$W_{\mathrm{F}} = \int F(d)\,\mathrm{d}d \tag{4}$$

$$G_{\mathrm{F}} = \frac{W_{\mathrm{F}}}{A_{\mathrm{lig}}} \tag{5}$$

5. Results

All fracture-mechanical properties evaluated using Eq. (1) to (5) are summarized in Table 2; results obtained for each specimen and corresponding basic statistics, i.e. mean values and coefficients of variation, are shown.

Table 2. Mechanical fracture parameters of concrete of each tested specimen; mean values (coefficient of variation in %).

	Symbol	Unit	Specimen V7	V9	V13	V15	V17	V18	Mean (CoV)
Modulus of elasticity	E	GPa	57.6	30.2	43.7	29.2	30.3	45.3	39.4 (29.1)
Fracture toughness	K_{Ic}	MPa·m$^{1/2}$	1.15	0.92	0.79	0.73	0.79	1.06	0.90 (18.5)
Toughness	G_{Ic}	J/m^2	22.8	28.0	14.4	18.0	20.4	24.8	21.4 (22.8)
Work of fracture	W_F	N.m	0.617	0.581	0.474	0.412	0.281	0.519	0.481 (25.4)
Fracture energy	G_F	J/m^2	224.9	211.3	169.8	149.7	100.1	187.9	174.0 (26.0)

6. Conclusions

The main aim of this paper was to demonstrate the possibility of advanced characterization of concrete of the load-bearing structure of an existing building. It was showed on assessment of mechanical fracture parameters of concrete cylindrical specimen. Set of these specimens was obtained as drilled cores of building of Vítkovice railway station from 1970s. Three-point bending fracture tests were conducted on these specimens with Chevron type notch tip. Load vs. deflection and vs. crack mouth opening displacement diagrams were recorded, corrected and processed using linear elastic fracture mechanics approach and work-of-fracture method. Parameters describing the materials ability to resist the deformation and failure propagation, i.e. modulus of elasticity, fracture toughness, toughness and fracture energy were estimated. Variability of the determined parameter values was between 20 to almost 30 %, since they were taken from different parts of the load-bearing structure. Detailed assessment of the results with regard to the evaluation of the building response will follow; this work shows only the way of the (partial) characterizing of the structural material for those planed analyses.

Due to the typical quasi-brittle response of the tested specimens the adaptation of the effective crack length method enabling obtaining of the effective fracture toughness value is planned in the near future. Production of a software support for the assessment of such fracture tests is currently under preparation. Investigations of interfacial transition zone between aggregates and the cement matrix of these several decades-old materials of bearing elements of existing buildings is also planned.

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