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DETERMINATION OF CONCRETE CUBE STRENGTH FROM USED SAMPLES

URČENÍ KRYCHELNÉ PEVNOSTI BETONU U POUŽITÝCH ZKUŠEBNÍCH TRÁMCŮ

Abstract

This paper deals with the determination of compressive strength of concrete. Cubes, cylinders and re-used test beams were tested. The concrete beams were first subjected to three-point or four-point bending tests and then used for determination of the compressive strength of concrete. Some concrete beams were reinforced, while others had no reinforcement. Accuracy of the experiments and calculations was verified in a non-linear analysis.

Keywords

Concrete, strength, pressure, calculation, additional testing, modeling.

Abstrakt

Příspěvek se zabývá určením pevnosti betonu v tlaku. Pro zkoušky jsou použity krychle, válce a použité zkušební trámce. Trámce byly nejprve použity u tříbodové nebo čtyřbodové zkoušky na ohyb a následně využity k určení pevnosti betonu v tlaku. Trámce jsou bez výztuže nebo s výztuží. Pro ověření výstižnosti provedených experimentů a výpočtů je využito nelineární analýzy.

Klíčová slova

Beton, pevnost, tlak, výpočet, dodatečné zkoušení, modelování.

1 INTRODUCTION

The compressive strength of concrete is among key properties used for classification of concrete [1] and calculation of other specific properties [5], [12] and [19]. Those parameters are used when analysing and designing structures from concrete and reinforced concrete [2], [6], [7], [9] and [11].

The compressive strength of concrete is determined using destructive and non-destructive methods. In case of the destructive methods, test bodies need to be prepared and such tests are demanding in terms of material and time [7], [8] and [10]. Typically, test cubes, 150 x 150 x 150 mm, or test cylinders (height: 300 mm, diameter: 150 mm) are used.

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The non-destructive methods result typically in a higher dispersion of results. A Schmidt hammer can be utilised for the testing.

The paper discusses methods used for determination of the compressive strength of concrete and verification of calculations for a cubical and cylindrical strengths [8], [10] and [14] for standard test bodies and for re-use of testing beams, the goal being to obtain a wide statistic file of input data for numerical modelling. The test beams were originally used for three-point and four-point bending tests.

2 TESTING THE COMPRESSIVE STRENGTH OF CONCRETE

The basic test bodies used for determination of the compressive strength are of cylindrical and cubical shapes. Standardised procedures are described in [5] and [8] where the cubical strength of the concrete is calculated as follows

$$f_{ck,cube} = \frac{F}{A}, \tag{1}$$

where:

F – is the maximum failure load [N] and

A – is the cross-section surface of the test body [m^2].

In reality, the test body fails not only in consequence of compression, but also in consequence of transverse tension. Each side of a standard test cube is 150 mm. The cylindrical strength f_{ck} is typically determined for cylinders which are 300 mm high and have the diameter of 150 mm. The strength of common concrete can be calculated using the formula [14]

$$f_{ck} = (0.8 \approx 0.85) f_{ck,cube} . \tag{2}$$

Table 1 and formula [8] can be used for calculation.

$$f_{ck,cube} = \kappa_{cy,cu} f_{ck} , \tag{3}$$

where:

$\kappa_{cy,cu}$ – is the conversion coefficient which depends on the cylindrical strength.

Table 1: Conversion coefficient for the compressive strength of concrete [8]

f_{ck} [MPa]	4.0 – 25.0	25.1 – 35.0	35.1 – 50.0	50.1 – 60.0
$\kappa_{cy,cu}$	1.25	1.20	1.15	1.10

[13] is also used for numerical calculations of the compressive strength in ATENA

$$f_{ck} = 0.85 f_{ck,cube} . \tag{4}$$

3 COMPOSITION OF THE CONCRETE AND TEST BODIES

The test bodies were made of concrete with the following composition for 37 liters: cement 42,5 R 14.06 kg, water 6.20 kg, aggregates 0-4 mm 29.97 kg, aggregates 4-8 mm 5.55 kg, aggregates 8-16 mm 29.05 kg and plasticizer (admixture) 0.0851 l. Fig. 1 shows some test bodies. After 24 hours, formwork was removed from all test bodies. Then, the test bodies were placed in water bath for 28 days. Four test cubes and six cylinders are of standard dimensions. Dimensions of the concrete beams are 700 x 150 x 150 mm. Three concrete beams were cast without reinforcement, while three concrete beams were cast with reinforcement, 2x ø6 mm and three 2x ø8 mm. The concrete beams were used first for three-point and four-point bending tests. The reinforcement is made from steel, B500.

Fig. 1: Test beams after concrete work (left) and test beam, 8C – four-point bending (right)

4 COMPRESSIVE STRENGTH OF CONCRETE

The compressive strength of concrete was determined, using four cubes and six cylinders. Fig. 2 shows a sample test body 6A-4 before and after the test. The damaged cube is of a typical truncated shape. Tables 2 and 3 show statistics assessment.

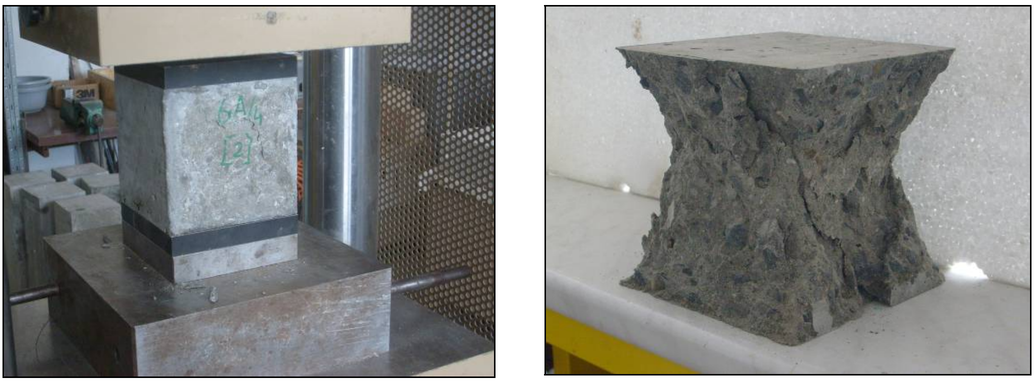

Fig. 2: Test cube 6A-4

Table 2: Cubical strength

Strength of concrete	Strength [MPa]	Standard deviation [MPa]	Lower 5% quantille [MPa]	ρ [kg/m³]	Test bodies	Number of samples
$f_{ck,cube}$	50.21	2.42	46.22	2320.2	Cube	4
$f_{ck,cube,\ converted}$	50.76	0.91	49.26	2351.7	Cylinders	6
$f_{ck,cube,\ converted,\ total}$	50.54	1.71	47.73	2337.6	Cube + cylinders	10

Normal distribution is assumed for calculation of the lower 5% quantille. The table also lists conversion of the strength for all samples using (3). For calculation of the conversion coefficient, linear interpolation has been used.

Table 3: Cylindrical strength

Strength of concrete	Strength [MPa]	Standard deviation [MPa]	Lower 5% quantille [MPa]	ρ [kg/m³]	Test bodies	Number of samples
f_{ck}	44.63	0.63	43.63	2351.7	Cylinders	6
$f_{ck,\ converted}$	44.20	2.13	40.70	2320.2	Cube	4
$f_{ck,\ converted\ ,total}$	44.49	1.50	42.03	2337.6	Cube + cylinders	10

5 CONVERTING COMPRESSIVE STRENGTH FOR TEST CONCRETE BEAMS

Nine concrete beams were used for conversion of the compressive strength. Three concrete beams were made from plain concrete, while six concrete beams were reinforced: three beams with 2x ø6 mm and three beams with 2x ø8 mm. The reinforcement was located 25 mm from the lower edge of the cross-section. The strength of the 6 mm and 8 mm dia. reinforcements was 618 and 612 MPa. For purposes of calculation, the modulus of elasticity of steel is assumed to be 200 GPa.

Fig.3: Test concrete beam 8C-IA (left) and 8C-IB (right)

Fig.4: Test concrete beam 8C-IIC

Visual inspection of the test concrete beam revealed damaged zones with cracks and zones without any cracks. For conversion and calculation of the 28 day strength, [14] was used. Table 4 provides general results of the compressive strength of concrete for each test concrete beam and for each type of damage. Table 5 provides test details for the test concrete beam 8C. Fig. 1 (right) shows the test concrete beam 8C after the four-point bending test. Fig. 3 and 4 show specific parts of the test concrete beam during the compression test.

Table 4: Compressive strength of concrete in test concrete beams

Concrete beams Description	Sample	Strength [MPa] 28 days	Standard deviation [MPa]	Lower 5% quantille [MPa]	Strength [MPa] 34 days	Force [kN]	Number of samples
No reinforcement	No damage	49.54	2.13	46.03	50.46	1135	6
ø6 mm	No damage	50.26	1.40	47.96	51.20	1152	6
ø8 mm	No damage	49.47	1.18	47,53	50.39	1134	4
Total - concrete beams I	No damage	49.79	1.71	46.99	50.72	1141	16
Total - concrete beams II	Damage	39.67	3.29	34.26	40.42	909	5

Table 5: Cubical strength of concrete in a test concrete beams 8C

Description of the concrete beam	Sample	Strength [MPa] 28 days	Strength [MPa] 34 days	Force [kN]
8C-IA	No damage	49.80	50.73	1141
8C-IB	Damage	41.37	42.15	948
8C-IIC	No damage	49.19	50.11	1127

6 NUMERICAL MODELLING

In order to validate reliability of the tests and to determine influence of reinforcement, numerical modelling with respect to the test bodies has been performed in ATENA [3], [4] and [13]. Because many parameters of concrete should be determined in the ATENA nonlinear analysis, the necessary parameters are converted and recalculated using the compressive strength of concrete and [13]. It is assumed in the numerical modelling that the compressive strength of concrete is 50.21 MPa and the tensile strength of concrete is 3.26 MPa. The three original computational models are shown in Fig. 5 and Fig. 8. An automatic generation distributes the set into finite elements. A typical size of a finite element is 20 mm.

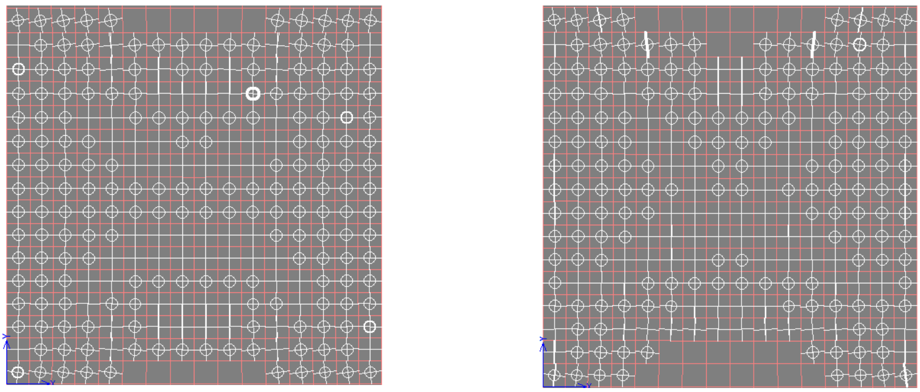

Fig. 5 Cube -1,200 kN (left: no reinforcement, right: with reinforcement)

The calculation has been performed for two alternatives: with reinforcement and without reinforcement. In case of a computational model of a standard test body, an alternative solution is available for a typical size of a finite element being 10 and 30 mm.

Table 6: Maximum force – influence of a finite element size on results in case of a cube

Sample	Force	Size of a finite element [kN] and force			Experiment [kN]
		10 mm	20 mm	30 mm	
No reinforcement	Preliminary failure	1170	1170	1170	1128
No reinforcement	max.	1190	1200	1210	
With reinforcement	Preliminary failure	1170	1180	1180	
With reinforcement	max.	1200	1210	1230	

A finite element method [16] and Newton-Raphson method [15] and [17] are used for nonlinear analysis. A force load was used there [13]. The final strength for the loads is given in Table 6 and 7. Fig. 5 shows a typical development of damage for a test cube with the load being 1,200 kN. The difference in damage in reinforced and non-reinforced concrete is minimum for the cubes. Fig. 6 through 9 shows damage of the test bodies for the concrete beams. Table 6 shows results for the maximum force - it depends on the size of the finite element.

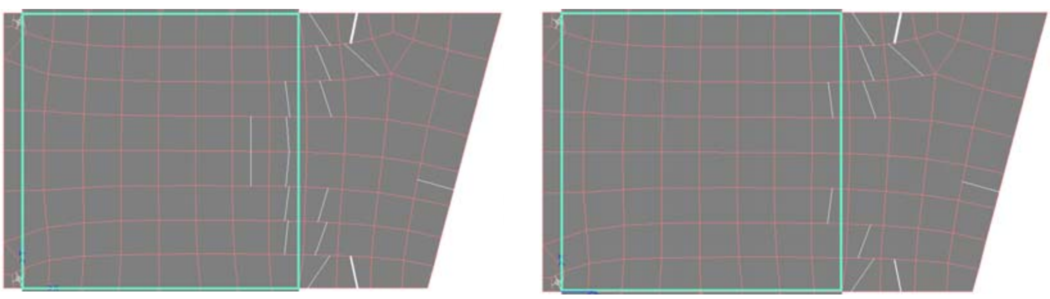

Fig. 6: Test concrete beam, 8C-IIC – 800 kN (left: no reinforcement, right: with reinforcement)

Fig. 7 shows final damage to a part of a test concrete beam 8C-IIC p after conversion for the load of 1,130 kN.

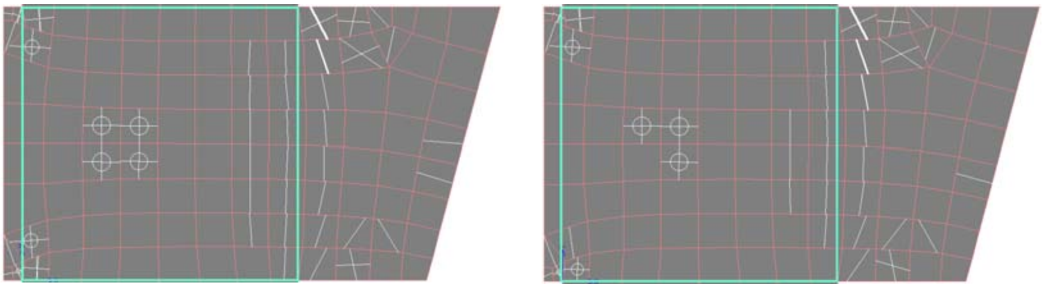

Fig. 7: Test concrete beam, 8C-IIC – 1130 kN (left: no reinforcement, right: with reinforcement)

A tension zone was created in a part of the test body 8C-IIC during the test. The same result was obtained in the numerical calculation. Fig. 6 shows the damage for 800 kN. Tension cracks are evident now along the height of the model for a nonreinforced concrete beam. Results are slightly different for a concrete beam with reinforcement.

Fig. 8 and 9 shows damage for the second part of the test concrete beam 8C. Similarly as with the previous section, the results are shown for 800 kN and then for 1,050 kN. Development of damage is similar as well. The final load is slightly different. Influence of reinforcement is small for the modelled sections of the concrete beam 8C-IA and 8C-IIC as well as for a standard test cube. Table 7 shows the maximum forces obtained in the experiment and calculations of the cube and test concrete beam 8C.

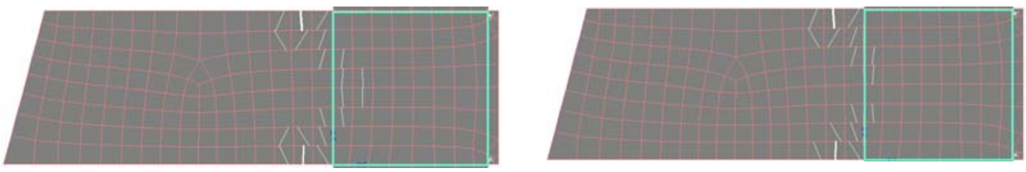

Fig. 8: Test concrete beam, 8C-IA – 800 kN (left: no reinforcement, right: with reinforcement)

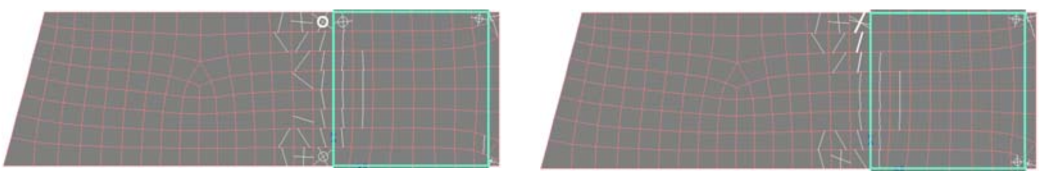

Fig. 9: Test concrete beam, 8C-IA – 1050 kN (left: no reinforcement, right: with reinforcement)

Table 7: Maximum force for a standard cube and test concrete beam 8C

Concrete beams Description	Sample	Maximum failure force [kN]	Maximum force [kN]	Linear calculation [kN]	Experiment [kN]
Cube	No reinforcement	1170	1200	1130	1128
Cube	With reinforcement	1180	1210		
8C-IA	No reinforcement	1050	1080		1141
8C-IA	With reinforcement	1180	1220		
8C-IIC	No reinforcement	1130	1180		1127
8C-IIC	With reinforcement	1150	1160		

7 CONCLUSION

This paper discusses determination of the compressive strength in analyses of reinforced concrete structures [18]. If the real ratio of the cubical and cylindrical strengths are compared with each other and if the conversion coefficient pursuant to (3) is used, it is clear that the difference is very small. Once linear interpolation is used for recalculation of the conversion coefficient, the difference is even smaller. The final average cubical strength for standard test bodies is 50.54 MPa and that for the cylindrical strength is 44.49 MPa. It follows from the analysis of the concrete beams and from the nonlinear analysis that the reinforcement below ø8 mm has really minimum influence on determination of the compressive strength of concrete in the beam section which has not been damaged. The length of the test body plays a little role as well. What is of the decisive influence is the size of the loaded surface. Steel plates were also used in the test - see the photos. The difference between the cubical strength and test cubes was 0.42 MPa only. The final damage in the test concrete beam was different from the final damage in the standard test body. The standard deviation of the compressive strength of concrete is almost same. In damaged samples with cracks, the strength was only 78.5% of the cubical strength of concrete in the standard test samples. Numerical calculations correlate well with the tests of the standard test cubes and test concrete frameworks. The size of a finite element played a negligible role in the computational model.

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