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ON THE EFFECT OF FRICTION IN TESTING OF SMALL-SCALE CONCRETE CYLINDERS

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Abstract: *Testing of concrete to assess its mechanical properties is inherent to any concrete structure's design and production process. Eurocode defines standardized dimensions of specimens to be used, cubes and cylinders, to ensure representative results. However, occasionally it may be necessary to use smaller specimens, especially if testing is done with cylindrical drill-core specimens, obtained from an existing structure. The crucial geometry parameter which defines a cylindrical specimen is the slenderness ratio. It has been shown in the literature that specimens of slenderness ratios lower than two experience different mechanism of failure because of the effect of friction between the specimen and the loading platens and subsequently withstand a higher load. The effect is quantified in Eurocode by a correcting coefficient. The present contribution aims to model the phenomena with a mesoscale lattice discrete model of concrete, evaluate correcting coefficients based on the obtained data, and compare the result with experimental values and the correcting coefficients given by czech national annex to Eurocode, ČSN.*

Keywords: Concrete, Testing, Friction, Lattice Discrete Particle Model, Eurocode.

1. Introduction

Testing of concrete is everpresent when dealing with concrete structures and obtaining correct results is of crucial importance. Among other methods, the material of existing structures is commonly assessed by obtaining cylindrical drill-core specimens and subjecting them to a uniaxial compressive test. Extensive research was performed in the past to assess whether and how results of uniaxial compressive testing are affected by the size of specimens. Results of the efforts were published for example in Kotsovos (1983) and Van Mier (1984). Later on a committee was established to investigate the matter, with findings being summarized for example in Van Vliet and Van Mier (1996) and Van Mier et al. (1997).

The above mentioned references postulate, that results are not affected as much by the diameter or depth by itself, but rather by the ratio of the two. The variable of interest is called *slenderness ratio* λ and is expressed as the ratio of the cylinders depth h to its diameter d as $\lambda = h/d$. The results showed a significant increase of measured strength of specimens with lower slenderness ratio than $\lambda = 2.0$. For higher values of λ, the differences were only minor.

European standards (Eurocode 2, 2005) and the czech national annex for testing of hardened concrete (CSN EN 12390-3/Z1, 2012) specify possible dimensions of drill-core specimens, which are used for such tests. Standardized cylinder measures 150mm in diameter, while the smallest diameter allowed in a borderline scenario is 50mm. The conclusion of above described research works is reflected by the recommended slenderness ratio of specimens, which is to be equal to 2 or higher. Czech national annex (CSN EN 12390-3/Z1, 2012) than specifies a procedure to obtain representative material strength from cylinders of slenderness ratios as small as 1.

The present contribution aims to first describe the origin of the phenomena and the way it affects mechanism of failure of specimens. The handling of the affected results as suggested by (CSN EN 12390-3/Z1, 2012) is

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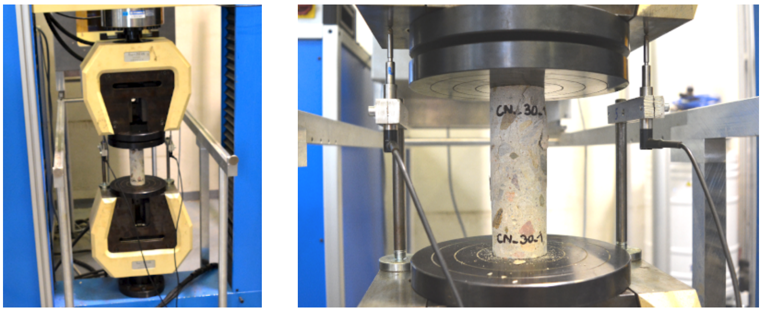

Fig. 1: Testing of concrete drill-core specimen in uniaxial compression, photos are courtesy of Ing. Dominik Lisztwan of Institute of Building Testing, Faculty of Civil ENgineering, Brno University of Technology.

outlined. Subsequently, a calibrated discrete mesoscale model of concrete (LDPM) (Cusatis et al., 2011a,b) is employed to simulate the uniaxial compression of cylinders and computational results are compared with experimental ones and with the correcting coefficients provided by (CSN EN 12390-3/Z1, 2012).

2. Uniaxial compression of concrete cylinders

The principle of uniaxial compression testing is well known. A specimen, concrete drill-core cylinder in the present case, is placed standing in between two steel platens, which might be coated by a teflon sheet. The bottom platen is fixed while the top platen is compressing the cylinder by a prescribed rate of displacement. See the experimental set up in Fig. 1.

Although lateral movement is not controlled in any way on the surface of the specimen, lateral movement is restricted by friction on the contact between the platens and the specimen. It has been observed, that if friction is not prevented by using coating of the platen or lubrication of some sort, a zone of triaxial compression occurs in areas adjacent to the contact (Van Mier, 1984). The shape of these zones is according to Van Vliet and Van Mier (1996) conical and the volume of these zones depends on the diameter of the cylinder base.

The presence of the confinement zones profoundly affects failure mechanism of the cylinder (see Fig. 3). In tall cylinders, that is cylinders of high slenderness ratio, the zones occupy only minor part of cylinder volume and the specimen is free to fail by lateral strains, accompanied by the formation of splitting cracks. The same mechanism may be observed when coated platens are used. In the opposite case (cylinders of small slenderness ratio) the triaxial compression zones take more of the cylinder volume and prevent formation of splitting cracks. Because crack growth tends to be limited to the unconfined zone, the strength of low slenderness ratio specimens is higher (Van Mier et al., 1997). Deformation in such case localizes less and the cracking pattern is more dispersed.

Although numerous experiments showed the effect to influence material strength in case of higher slenderness ratios as well (up until buckling becomes the mechanism of failure), it is much less pronounced, to the point that its negligible (Van Mier et al., 1997).

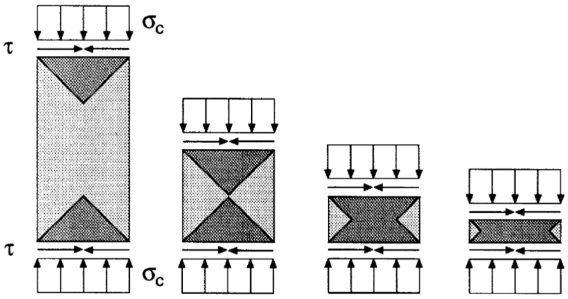

Fig. 2: Zones of triaxial compression, occuring as a result of frictional stress τ, taken from (Van Vliet and Van Mier, 1996).

2.1. Concrete strength evaluation

Czech national annex from 2012 considers strength measured on cylinders of slenderness ratio $\lambda = 2$ and higher to be representative of the material. For $\lambda = \langle 1, 2 \rangle$, the document defines a correcting coefficient $\kappa_{c,cyl}$ to be used in the calculation of the cylindrical concrete strength $f_{c,cyl}$ based on the slenderness ratio λ as:

$$f_{c,cyl} = \kappa_{c,cyl} \times \frac{F}{A_c} \qquad \kappa_{c,cyl} = 0.80 + \sqrt{\frac{\lambda - 0.933}{26.667}} \tag{1}$$

F and A_c stand for the compressive force and the area of cylinder base respectively. The borderline value for $\lambda = 1$ is $\kappa_{c,cyl} = 0.85$, translating to a presumed increase in strength of 17.6% in comparison to the strength measured for cylinders of $\lambda = 2$

3. Model

Discrete mesoscale model of concrete mechanical behavior was used for the simulations described later on. An in house version based on a lattice discrete particle model (Cusatis et al., 2011a,b) using damage-based constitutive law. Detailed description of the probabilistic version of the model may be found in (Eliáš and Vořechovský, 2020).

The model explicitly considers mesoscale geometry of concrete and the interaction of aggregates. The geometry is generated by power tesselation based on randomly placed spherical particles, whose size is determined based on prescribed packing distribution. The particles are considered as rigid bodies, while stress and strains are calculated on their contact based on displacement jump between each two adjacent particles.

For the uniaxial compression simulation a friction boundary condition was used to simulate friction on the bases of the cylinder. The implementation describes a regularized Coulombs law from Ref. (Wriggers and Moftah, 2006). In the initial phase the tangential force increases linearly. The change of tangential force $\Delta\mathbf{f}_T$ acting at the particles adjacent to the base is obtained based on user-defined tangential stiffness K_T and the lateral movement of the particle $\Delta\mathbf{u}$. The tangential force is limited by a friction force defined as μf_N, where μ is the friction coefficient and f_N is the normal force.

4. Simulations

In order to observe the effect of friction on cylinders in uniaxial compression, a cylinder of the smallest base diameter 50mm was chosen. Following slenderness ratios were chosen: 1.0, 1.1, 1.2, 1.3, 1.4, 1.5 and 2.0. The effect of friction is presumed to be much less pronounced in the higher range between $\lambda = 1.5$ and $\lambda = 2.0$, hence the emphasis was placed on the lower range. Since LDPM geometry changes from one generation to another by a pseudorandom algorithm, five different geometries were generated for each of the slenderness ratios written above.

In accordance to the experimental set-up (Fig. 1), particles adjacent to the bottom base are blocked in vertical direction, while the top base has a prescribed rate of displacement, loading the sample. Lateral movement on the vertical surface of the cylinder is free, lateral movement of the base is restricted as described in section 3, K_T being set to $10^{13}N/m$ and μ to 0.2 based on previous calibration, which is a commonly considered value for contact of steel and concrete. Model parameters were calibrated base on different sets of experiments as follows: normal elastic modulus $E_0 = 35.5GPa$, ratio between normal and tangential moduli $\alpha = 0.24$, tensile strength $f_t = 2.1MPa$, fracture energy $G_t = 50N/m$.

4.1. Results

Load-displacement curves were obtained from each of the simulations and averaged for the same slenderness ratios. The averaged peak force obtained for cylinders of $\lambda = 2.0$, $P_{2.0}$, serves as a reference one for the comparison. The graph below shows the obtained results. Plotted are the ratios of averaged peak force for each λ to the reference force $P_{2.0}$, with the addition of standard deviation to the average values. For the purposes of comparison, experimental results are included as well, obtained from testing of specimens of $\lambda = 1.0, 1.5$ and 2.0. Three cylinders were tested of each slenderness ratio. These experiments did not serve as a reference for calibrating the model. Finally, the increase of peak force for low slenderness ratio specimens as described in (CSN EN 12390-3/Z1, 2012) is plotted as $1/\kappa_{c,cyl}$ (based on Eq. 1).

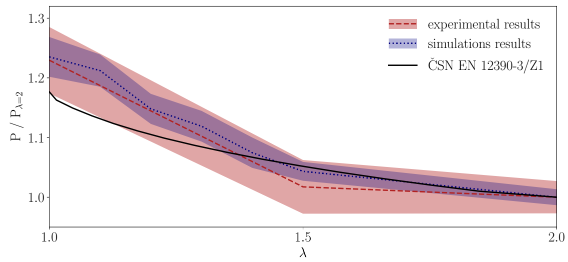

Fig. 3: Difference between reference peak force obtained from cylinders of $\lambda = 2.0$ *to the peak force of lower slenderness ratios.*

5. Conclusions

The results presented above exemplify the effect of friction on cylinders of small slenderness tested in uniaxial compression. The increase of maximum force occurs only slightly for values of λ higher than 1.5, both for computational and experimental simulations. It is worth noting, that the experimental results show higher deviation. For lower slenderness ratios, the increase is more significant both for experimental results and for the simulation results, both following similar increase.

The most noticeable deviation from the coefficient proposed by ČSN is in close proximity to the lowest slenderness ratio allowed ($\lambda = 1.0$). While the ČSN values suggest increase of about 17% to the reference value of $P_{2.0}$, both experimental results and the simulations report increase of about 23%, which is about 6% higher. The results suggest, that using the coefficients adopted by ČSN might lead to a slightly overestimated value of material strength, when testing cylinders of small slenderness ratios.

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