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MODELLING OF FRACTURE OF CONCRETE AT HIGH LOADING RATES

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ABSTRACT

It is well known that the loading rate has a significant influence on the structural response. The response depends on the loading rate through the influence of three different effects: (i) through the creep of the bulk material between the cracks, (ii) through the rate dependency of the growing micro-cracks and (iii) through the influence of the structural inertia forces. Depending on the material and the loading rate, it dominates the first, the second or the third effect. For quasi-brittle materials, such as concrete, which exhibit cracking and damage phenomena, the second and the third effects dominate for very high loading rates (impact loading). However, for lower loading rates the first effect is more important.

In the present study the model, which is based on the rate process theory of bond rupture is used for modeling of rate effect [1]. The model is applicable over a many orders of magnitude of the loading rate. It was coupled with the microplane model for concrete [2] [3], implemented into a 3D finite element (FE) code and calibrated based on the available experimental data. The FE code was then used in: (i) fracture studies of plain concrete beams of different sizes and (ii) penetration analysis of anchor into a concrete block.

The influence of the loading rate on the cracking behavior of a notched plain concrete beams loaded in 3-point bending (normal strength concrete) and cantilever beams (normal and high strength concrete) was investigated using 3D FE code. Beams of three different sizes were analyzed. The effect of creep was not considered, i.e. relatively high loading rates were assumed. Both, static and dynamic analyses were carried out. The static analysis was performed using implicit type of the approach whereas in dynamic analysis the explicit direct integration method was employed [4].

The results of the study show that the loading rate significantly influence the peak resistance and failure mode of concrete beams. As expected, with increase of the loading rate the resistance of the beam increases. For static loading failure is always due to bending. In dynamic analysis with relatively low loading rates failure mode and resistance of the beam is similar to that obtained in the static analysis, i.e. beam fails in

bending (Mode-I fracture). However, for normal and high strength concrete, in dynamic analysis with higher loading rates instead of bending failure (lower loading rates) beam failed in diagonal shear (Mixed-mode fracture). Moreover, in the case of cantilever beams there is a relatively strong axial compressive action, which significantly contributes to the shear resistance of the beam. For moderate loading rates the rate dependent crack propagation (inertia effects at the microcrack level) dominate and there is no significant difference between static and dynamic analysis. However, for high loading rates the type of the analysis (static or dynamic) have significant influence on the results. This is due to structural inertia forces, which at high loading rates dominate. The results indicate that the influence of the loading rate is stronger if the concrete strength is lower.

In the second case study the influence of the loading rate on the penetration of anchor into a concrete block was investigated. The objective of the study was to investigate the influence of the loading rate on the penetration of the anchor ino a cocrete block. The 3D finite element code is written in the update Lagrangian formulation [4]. As a strain measure the logarithmic strain tensor is used. To adopt the finite element mesh on the change of the geometry, the strategy that is based on the combination between re-meshing and mesh refinement was used. The element distortion indicator was adopted as a criteria for re-meshing and mesh refinement, respectively. To model impact between anchor and concrete block, dynamic analysis was carried out using explicit integration scheme. The contact between the anchor and the concrete was solved using the Lagrange multiplier approach. The friction between master (concrete block) and slave (anchor) was assumed to be of kinematic type. A Mohr-Coulomb friction law was used. The same as in the above study, as a constitutive law for concrete, the rate dependent microplane model was employed (co-rotational formulation). The parametric study shows that the rate sensitivity plaies important role in the realistic prediction of the penetration of the anchor into a concrete block.

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