Using of Smoothed Particle Hydrodynamics (SPH) method for concrete application

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Abstract

The paper deals with the Smoothed Particle Hydrodynamics (SPH) method used for the analyses of quasi-static and dynamic problems of concrete structures. The influence of the loading velocity, the particle density, the smoothing length and renormalization are discussed.

Keywords: quasi-static, dynamic, smoothed particle hydrodynamics

1. Introduction

The SPH method was originally used to simulate the fluids flow. Recently, this numerical method successively serves to model the blast impacts and the projectile penetration in solids. The SPH belongs to the meshfree methods and can be useful for simulation of large deformations, damage and fracture of concrete (Fig. 1) and the other quasi-brittle materials.

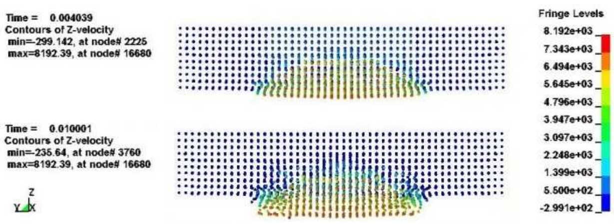

Figure 1: Spalling in concrete slab caused by pressure of 0.1 kg TNT exploded 2 m from the top surface (field of velocity in mm/s).

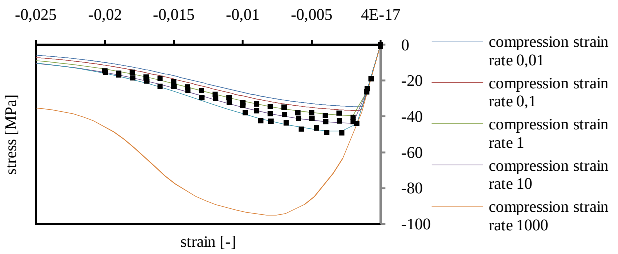

Figure 2: The behaviour of concrete for different strain rates under compression.

The SPH method uses lagrangian description, it means that particles move together with material during deformation [1,2,3]. The time integration procedure is explicit [4]. For quasi-static simulations the influences of the loading velocity, the particle density, the smoothing length, renormalization effect and computational efficiency are discussed.

The discussion of these effects is supported by careful understanding of the concrete properties as softening due to crushing and cracking of its structure. For quasi-static problems the high accuracy is necessary in computations of stresses and strains. When using the SPH method the accuracy of computations decreases, mainly for the areas located in the vicinity of boundary conditions and/or free surfaces [1,2,6].

2. Analysis of concrete by SPH

The simple numerical test (uniaxial compression), is used to present the numerical effects introduced by SPH method parameters. The typical uniaxial compression concrete specimen is accepted (the cube with edge dimensions equal 100 mm). For this quasi-static analysis we accept the parameters for concrete B30 with maximum aggregate size 10mm for ls-dyna material model (Continuous Surface Cap Model [5]). The results of one element FEM tests of this material model are presented in Figs 2 and 3. The first figure presents the results for compression and the second one for tension. The strain rate sensitivity in the behaviour of this material model is clearly seen.

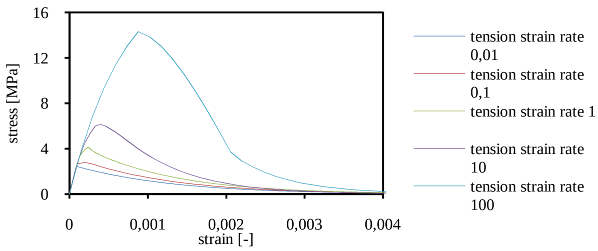

Figure 3: The behaviour of concrete for different strain rates under tension.

Five numerical models are built: four use the SPH formulation and one is the FE model. The results of SPH are compared with FEM. All accepted for compression tests models are presented in Figure 4. All models that use SPH have different particle density. The FEM model has 1000 finite elements in the considered cube. The SPH-10 model has 1000 particles, SPH-20 has 8000 particles, SPH-30 has 27000 particles and the last one SPH-40 has 64000 particles. The simulation processes are controlled by kinematic with a constant velocity applied to the

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upper surface in Z-direction. The bottom surface is permanently fixed.

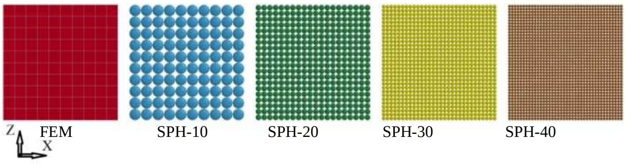

Figure 4: Discretisation of SPH method versus FEM

2.1. Loading velocity effect

The loading should be applied slowly. The only problem that has to be treated carefully is using the explicit time integration scheme for quasi-static case. The important aspect is the stable time increment which depends on a density, Young modulus and the discretisation. In this case the simulation requires many time increments so the computational time increases proportionally. The different loading velocities are considered (from 1 mm/s to 1000 mm/s). The results for loading velocity between 1 mm/s to 100 mm/s are similar. For cases of the higher velocity, a big part of the external energy is transmitted into the kinetic energy. In the next simulations the constant velocity equals 100 mm/s is used. The results are presented in Fig. 5. The differences in stress-strain curves are also caused by strain rate sensitivity. In next steps it is assumed that the strain rate sensitivity will be deactivated for quasi-static cases.

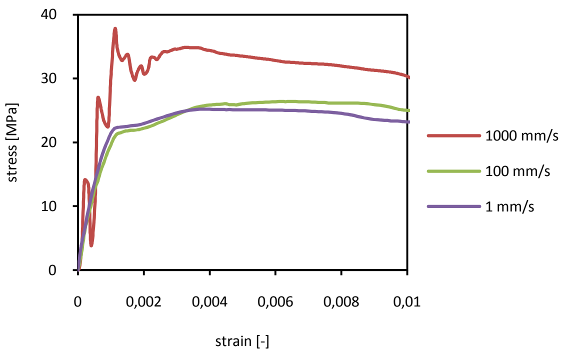

Figure 5: Loading velocity effect

2.2. Particle density effect

Particle density means in SPH method the distance *d* between particles (nodes, see in Fig. 6). It is a very important factor and it influences the accuracy of the computations. The important observations is that stresses increase with increasing of the particle density in SPH method. The results for SPH-30 and SPH-40 are similar to FEM results.

2.3. Smoothing length effect

Typical parameters of SPH method are *d* and *h*. The first is the distance between particles. The second one is called smoothing length. These parameters can change in time during explicit time integration procedure. The method of actualization of these variables is discussed in literature [1,2,4]. The graphical interpretation of these parameters is presented in Fig. 6. The influence of the parameter *h* will be discussed in detail. Generally, decreasing of smoothing length value from 1.2 (default in dynamic problems) to 1.05 increases the strength and stiffness of the concrete.

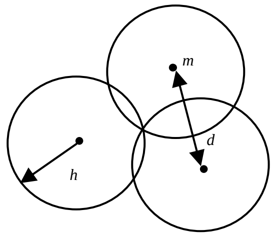

Figure 6: Typical parameters of SPH method.

2.4. Renormalization effect

The important aspect is also the influence of boundary conditions. The stresses in particles which lie close to the boundary surface are inaccurate (lower value). It is the reason for using so called renormalization which is effective for quasi-static problems and reduces this inaccuracy. The detailed description of the renormalization method and the quantitative presentation of its influence will be presented.

2.5. Computation time

The computation time increases with decreasing of the loading velocity. Generally, for using SPH the computation time is higher than for FEM formulation. The correlation with the number of particles is linear.

3. Conclusions

The SPH method is used for quasi-static and dynamic problems in computations of concrete structures. For quasi-static computations by SPH method the influences discussed above (loading velocity, particle density, smoothing length etc.) should be considered.

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