DISCRETE ELEMENT SIMULATION OF DAMAGE AND FRACTURE OF CONRETE AT INTERFACE ON GPU

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1. Introduction

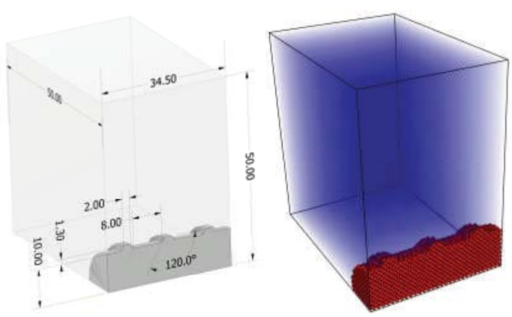
Numerical simulation on a microscopic scale to predict macroscopic properties is becoming conventional approach applied in mechanics of materials. The discrete element method (DEM) suggested in the original work of Cundall and Strack [1] is developed further into powerful simulation tool recognised as suitable technique. Recently, the DEM is extended to various types of continuous and discontinuous solid, macroscopic properties of which are predefined by microscopic structure of bonded particles [2]. Ability to describe discrete nature and inter-particle damage and cracking as a real discontinuity among the particles presents the main advantage of this method. Moreover, the fracture analysis [2] and visualisation [3] at the level of particles has the disadvantage of making DEM computationally very expensive. To increase speed-up, the graphical processing units (GPUs) has been applied in the DEM [4]. The present work was carried out to develop the fast DEM code on GPU for fracture analysis of concrete reinforced interface.

2. Methods

The standard DEM is applied for simulation of behaviour of cohesive visco-elastic particles. The solution domain is covered by the face-centred cubic lattice. The materials properties assigned to the nodes of the lattice. These nodes are considered as discrete spherical particles undergoing translational motion during deformation. The normal and tangential component of the contact force comprises elastic and viscous ingredients represented by a composition of the linear spring-dashpot model. The bonds described by springs can break when the external loading exceeds the strength of bonds, leading to crack formation directly between two particles. The equations of motion are solved by using the 5th–order Gear predictor-corrector scheme. The fast GPU-based DEM code is developed to increase computational efficiency of large-scale simulation of fracture, involving millions of particles.

3. Problem description

The reinforces concrete sample under central tension is considered (Fig.1(a)). The sample provide to phase composite. Interface surface between concrete and steel reinforcement formed by ribs has complicated shape.



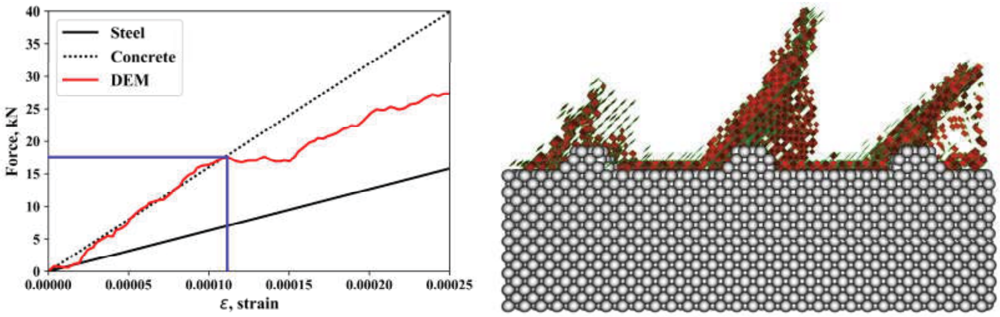
a) b)

Figure 1: a) problem description; b) discretization of space using spherical particles.

The singularities of interface lead to local concentration of stresses and finally to local damage occurring on a small scale. To describe the fracture pattern very fine discretization is necessary. For modelling this problem, the million number of discrete particles may be needed. Therefore code running on GPUs is necessary for solving such type of problem to increase the performance of DEM computations. One quarter and three ribs of the real specimen is simulated. The simulated system (Fig 1(b)) consists of 232320 particles, with the radius of 0.4 mm and 1357548 springs.

5. Results and conclusions

Selected numerical results of simulation are presented in Fig. 2. The constitutive relationship shown in Fig. 2(a) corresponds to analytical prediction and is confirmed by physical experiment. It is obvious that cracks starts to form at first rib at strain 0.00011. Cracks extracted by using the cell centre-based technique in a 3D domain are shown in Fig. 2(b). The crack surfaces [3] are coloured in red colour, while the edges of the faces are represented by green tubes.



a) b)

Figure 1: a) force and strain relationship; b) fracture visualization.

All double-precision computations are performed on the NVIDIA® Tesla™ P100 GPU Computing Accelerator. The same OpenCL code optimized for multi-thread shared-memory architectures is executed on the desktop PC to evaluate the speedup ratio of GPU to CPU. Speedup values up to 10.5 are obtained in spite of intensive usage of advanced vector extensions by OpenCL on CPU. Higher differences become obvious in case of larger numbers of particles. On single GPU attained performance was higher than that reported in the literature in spite of the implemented complex physical model.

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