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A 3D RIGID PARTICLE MODEL FOR SHEAR TRANSFER ANALYSIS IN REINFORCED CONCRETE

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Summary. A 3D spherical rigid particle discrete element formulation based on the Discrete Element Method, DEM, which has been used to model concrete, is described. The model has been shown to give a good agreement in terms of peak strength, fracture localization and crack patterns for various load conditions. An explicit formulation for the reinforcement model which allows the model to be applied to reinforced concrete is presented. The reinforced rigid particle model is validated against known shear transfer tests due to dowel action. It is shown that the model is able to predict the influence of the dowel stiffness and the localized fracture in the vicinity of the initial crack.

1 INTRODUCTION

Through the simulation of the material meso-structure, the rigid particle models [1,2,3,4] prevent localization of damage into regions not sufficiently large when compared to the inhomogeneity size. Particle models are conceptually simpler than a continuum approach, and the development of cracks and rupture surfaces appears naturally as part of the simulation process given its discrete nature[5].

The most straightforward approach to model reinforcement in 3D rigid particle simulations of reinforced concrete would be to discretize the reinforcement bars with spherical particles connected by traditional point contacts or by parallel bond contacts[2]. In order to have a more flexible approach, it was decided to model a given reinforcement bar through several rigid bar segments that are interacting at the nodal locations, where the reinforcement elastic and strength properties are lumped. With this type of approach the reinforcement bar model and the discretization required for contact purposes with the surrounding concrete spherical particles are made independent.

Finally, the reinforced rigid particle model is validated against known shear transfer tests due to dowel action[6]. It is shown that the model is able to predict the influence of the dowel stiffness and the localized fracture in the vicinity of the initial crack.

2 REINFORCED PARTICLE MODEL

2.1 Discrete particles

In the DEM, the set of forces acting on each particle are related to the relative displacements of the particle with respect to its neighbours. An explicit time marching calculation scheme based on the centred-difference algorithm is adopted. At each step, given the applied forces, Newton's 2nd law of motion is invoked to obtain the new position of the particle, then a run is made through all the inter-particle contacts, in order to evaluate the current incremental contribution and the updated contact normal direction. The particle forces are then obtained from the inter-particle displacement increments[2]. For the inter-particle contacts an extended Mohr-Coulomb model with bilinear softening is adopted.

2.2 Reinforcement

A given reinforcement bar is modelled through several rigid bar segments that are interacting at the nodal locations. Within this approach, the reinforcement elastic and strength properties are lumped at the rigid bar segment ends. As in the particle model, each rigid bar element has six degrees of freedom of displacement and force at its centre of gravity.

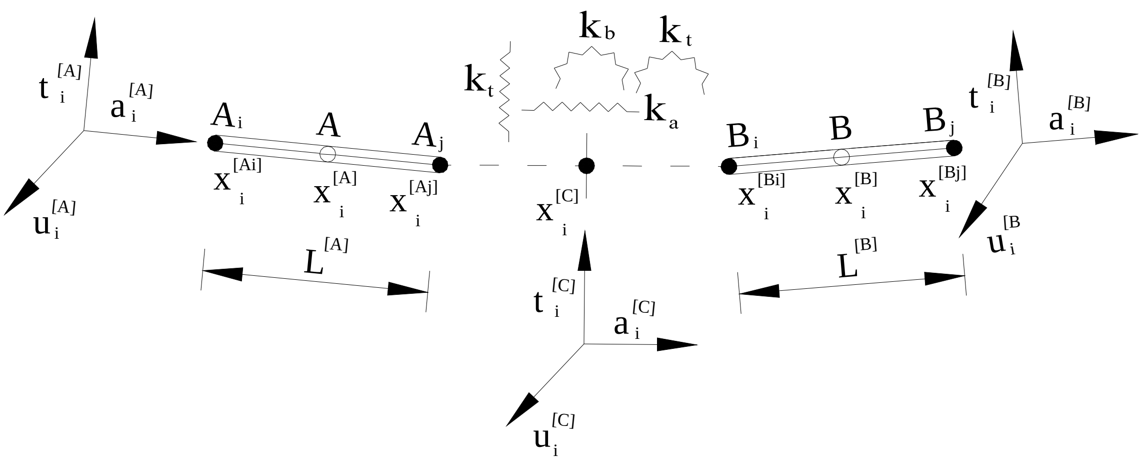


Figure 1: Reinforcement model through nodal lumping

The contact point location, $x_I^{[C]}$, is given by the average nodal location of the nodes that are interacting:

$$x_i^{[A]} = 0.5 \left(x_i^{[AJ]} + x_i^{[BI]}\right) \tag{3}$$

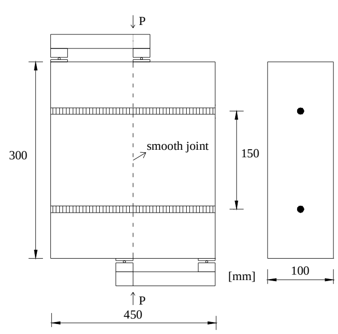
where $x_i^{[AJ]}$ is the location of the end point of rigid element A, and $x_i^{[BI]}$ is the location of the initial point of rigid element B. Both the initial and the end point of each rigid element can be defined at a given time step given the location of the centre of gravity and the current axial direction of the rigid bar. At each time increment the direction of the axial direction of the lumped contact is given by the average of the rigid bar axial directions that are interacting:

$$a_i^{[C]} = 0.5\left(a_i^{[A]} + a_i^{[B]}\right) \tag{1}$$

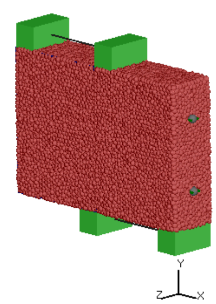
Given the reinforcement nodal lumped stiffnesses the rigid reinforcement model follows closely the contact laws of the parallel bond model[5]. The spherical particles used for contact purposes are rigidly connected to the bar line segment to which they are associated.

3 - SHEAR TRANSFER

The reinforced rigid particle model was validated against experimental data of shear transfer due to dowel action[6]. The micro properties (best-fit values) are obtained from a calibration procedure based on compressions tests on 100 mm cubic particle assemblies. The macroscopic compressive strength, Young's modulus and Poisson's ratio obtained numerically in the 100 by 100 mm particle assemblies are similar to the experimental values. A 10 mm to 16 mm aggregate distribution was adopted on all numerical samples. The void space was eliminated using 5 mm radius particles.



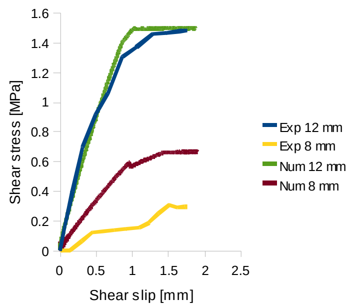
a) Test geometry



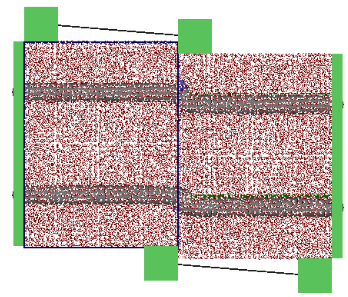
b) Reinforced particle model

Figure 2: Dowel test geometry and reinforced particle model

Figure 3 shows that the numerical models predict quite well the dowel action behaviour in terms of the shear stress versus shear slip for different reinforcement geometries. It is also shown the final displacement of the numerical sample, 10x amplified, where the spherical particles representing the concrete have their radius reduced. From the later it can be seen that at the interface the reinforcement bar suffers a high gradient deformation which leads to localized cracking.



a) Shear stress versus shear slip



b) Final displacement (10x amplified)

Figure 3: Experimental and numerical results

12 CONCLUSIONS

A 3D spherical rigid discrete element formulation based on the Discrete Element Method, DEM capable of modeling reinforced concrete is described. A brief explanation of the explicit formulation adopted for the reinforcement model is referred. The reinforced rigid particle model is validated against known shear transfer tests due to dowel action. It is shown that the model is able to predict the influence of the dowel stiffness and the localized fracture in the vicinity of the predefined crack.

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