INVESTIGATION OF THE NORMAL CONTACT BETWEEN TWO SPHERICAL PARTICLES WITH INTERFACE MATERIAL

***V. Rimša*[1], *S. Pilkavičius*[1], *R. Kačianauskas*[1], *J. Rojek*[2]**
[1]*Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania*
[2]*Polish Academy of Sciences, Pawińskiego ul. 5B, 02-106 Warszawa, Poland*

Abstract

The evaluation of mechanical properties of heterogeneous materials presents multidisciplinary task where the contribution of microstructural effects is of major important. Direct simulating of the material structures as heterogeneous continuum is inappropriate for several reasons, because it requires a large CPU time and did not improve the understanding of the role of microstructure. Recently, multi-scale approach became useful simulating technique, where macroscopic mechanical properties of the heterogeneous solids are defined in terms of grain properties and their interactions.

Among the numerical simulation methods, the Discrete Element Method (DEM), introduced by Cundall and Strack [1] has become the most useful tool. Evaluation of the contact behaviour between particles is decisive in the DEM. Originally, most of the DEM applications are aimed to simulate non-cohesive granular materials with unilateral repulsive normal contact.

Presented report addresses the normal contact between two elastic relatively stiff spherical particles interacting via weaker interface material (Fig. 1a). The problem is considered analytically and by applying the Finite Element Method (FEM). The 3D FE comprises two spheres bonded by the three dimensional cylinder. The above approach is aimed for development of the DEM. Two types of the interface material models were considered. The purely elastic material was examined in the first series of samples and comprising wide range of various parameters. The analytical model comprising combination of three sequential and parallel bonding springs (Fig. 1b) was developed.

The viscoelastic interface material between two contacting particles was examined in the second series of samples. Viscoelastic properties of the solid obey of the Maxwell model (Fig. 1c), while relaxation was described via Prony series [2].

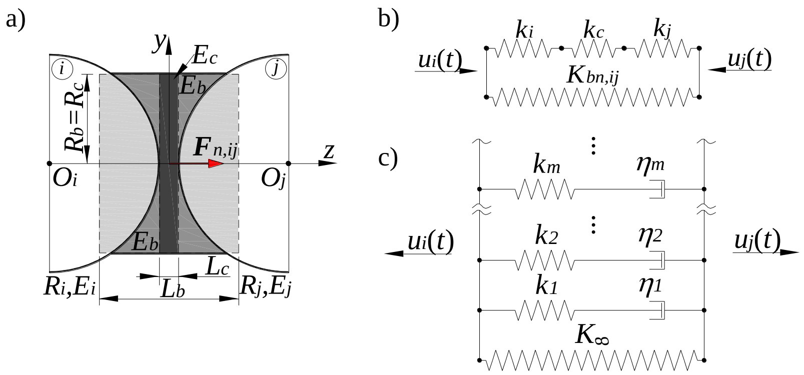

Fig. 1. Modified normal contact model: a) geometry; b) bond model for elastic interface – springs system; c) bond model for viscoelastic interface – springs-dashpots system

Variation of the linear bond stiffness parameters against relative elasticity modulus $E^* = E_{ij}/E_b$ illustrating the weakening of the interface is given in Fig. 2a in logarithmic scale. Here, full interface with the data value $E^* = 5$ corresponds to the heterogeneous case of granite grains embedded into cement paste, while the data value E^* approximately equal to 10000 corresponds to the heterogeneous case of granite grains embedded into asphalt. Dashed horizontal line shows contribution of the stiffness of particles k_i and k_j which are independent on interface. The contribution of interface material expressed in terms of stiffness of the interface layer k_c and the parallel bond $K_{bn,ij}$ exponentially decay with decay of the interface properties. The main observation is that resultant stiffness of the sequentially connected springs K_{ijc} (thin line) and total stiffness $K_{n,ij}$ (bold line) converges to the stiffness of the interface layer k_c. This model as the FEM shows, that deformability of particles is negligibly small and could be neglected in the computational models with the relatively weak interface bonds. Consequently, particles could be presented by rigid surface, thereby, simplifying computational model and reducing the size of the model.

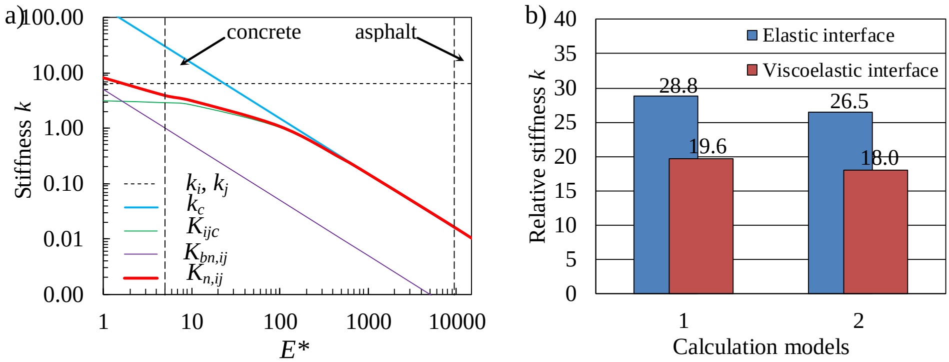

Fig. 2. Illustration of simulation results: a) variation of separate bond stiffness parameters with weakening of the interface; b) comparison calculation models for weaker interface: 1 – FE linear model, 2 – FE geometrically nonlinear model

Comparison of employed elastic and visco-elastic models for the case of weak interface relevant to asphalt in terms of relative stiffness k is illustrated by column-diagram given in Fig. 2b. Here columns 1 and 2 illustrate FE results. Results show that this proposed model fails however for the case relatively weaker interface bonds. The above model of contacting particles with the parallel bond is suitable for the evaluation of contact with thick interface, for the relatively strong bonds. Therefore will be offered corrected normal contact model for weaker interface bonds.

It was found that for weaker interface the FE nonlinear model with large deflection should be applied, because it gives higher accuracy of contact relative stiffness compared with the modified analytical calculation contact model.

Obtained results by FE model clearly demonstrate influence of the viscosity of interface solid. For normal displacement of particles equal to 6.6% of particle radius R, yields reduction of the interaction force up to 56.7% when compared to purely elastic properties.

References

[1] Cundall P. A. and Struck O. D. L (1979). A discrete numerical model for granular asseblies. Geotechnique 29(1): 45-75.

[2] Masad E., Huang C., W., Airey G., Muliana A. (2008). Nonlinear viscoelastic analysis of unaged and aged asphalt binders. Construction and Building Materials 22(11): 2170-2179.