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DISCRETE ELEMENT METHOD FOR SAND-STRUCTURE INTERACTION

Morched Zeghal¹, Tuncer B. Edil², and Michael E. Plesha³

INTRODUCTION

Many experimental studies have been undertaken to investigate the mechanics of the interface between granular materials and structural surfaces. The direct shear and shaft pullout tests are the most common (Brummud and Leonards, 1973; ElSakhawy and Edil, 1996; Sengara, 1991). A variety of scales, configurations and boundary and loading conditions were used in these tests to capture the elements of the behavior. However, the majority of these investigations rely on measurements taken outside of the structure-medium interface to infer behavior at the interface. Effort has been made to correlate the macro-mechanical response of structure-medium systems to the microstructural characteristics of the interface. Uesugi and Kishida (1986) studied interface grain displacement using a reflex camera through a glass window of a simple shear device. Later, Boulon (1989), working with a modified plane direct shear test and using stereophotogrammetric analysis technique, was able to track the movement of particles. Obtaining microstructural information using laboratory testing techniques is an inherently difficult, tedious and time-consuming task. The use of the discrete element method (DEM) to study and delineate phenomena dictating the behavior of the interface provides a valuable alternative since it takes into account the discrete nature of materials and gives detailed information at the particle level where interface behavior occurs. This paper presents some parametric studies on the effect of modeling parameters on formation of shear zones in structure-medium interfaces.

DEM MODEL

The model used in this research is based on the early work of Cundall and Strack (1978, 1979) wherein a medium is modeled in two dimensions as an assembly of rigid circular discs, or elements. Each element is characterised by its radius, the position of its center and the rotation about its center. Contact between two elements is characterized by a point of contact and a direction that passes through the centers of the two elements. Relative displacements of elements result in a change of normal and tangential contact forces that are determined by the application of a linear elastic

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¹ Research Officer, National Research Council-Canada, Institute for Research in Construction Urban Infrastructure Rehabilitation Program, Building M-20, Ottawa, Ontario Canada K1A 0R6; phone: (613) 991-6273; email: morched.zeghal@nrc.ca

² Professor, Department of Civil & Environmental Engineering, University of Wisconsin-Madison, Madison, WI 53706; phone: (608) 262-3225; email: edil@engr.wisc.edu

³ Professor, Department of Engineering Physics, University of Wisconsin-Madison, Madison, WI 53706; phone: (608) 262-5741; email: plesha@engr.wisc.edu

force-displacement law at the contact. Further, the contact obeys an elastic perfectly plastic law (Coulomb's friction law). Contact stiffnesses can be interpreted as penalty numbers that enforce the constraints of impenetrability and presliding stick as they become larger. Newton's law describes the motion of particles due to the forces acting on them.

SOIL-STRUCTURE SIMULATIONS: A PARAMETRIC STUDY

An assembly of 1000 particles was used. The boundaries of the assembly were rigid. The bottom surface is used to simulate a structure for which roughness was idealized by a saw tooth shape (Figure 4). The equilibrium state, resulting from compaction, was saved and served as the initial conditions for the parametric study. One parameter at a time was varied to determine the influence of that specific parameter on the behavior of the assembly. Table 1 summarises the simulations performed and their objectives.

Table 1. Parametric Study Program

Test	Objective
a) Normal test	- Establish reference
b) Element to element friction varied (0.25, 0.5, 0.75)	- Effect of element to element friction
c) Element to wall friction varied (0.25, 0.5, 0.75)	- Effect of element to wall friction
d) Element stiffnesses varied (1.5e8, 1.5e9)	- Effect of element stiffnesses
e) Wall stiffnesses varied (1.5e8, 1.5e9)	- Effect of wall stiffnesses
f) Damping varied (mass and stiffness damping ; stiffness damping only,)	- Effect of damping

Summary of Results

Based on the numerical simulations performed, it was concluded that the choice of parameters has almost no influence on the general trend of the results. More specifically:

- Element to element friction has a minor effect on the interface behavior. The normal force on the top wall increases with increasing friction.
- Boundary friction has almost no effect on the response.
- Element stiffnesses have no major changes in the outcome of the simulation.
- Boundary stiffnesses: as expected, the normal force on the top boundary increases when the boundary stiffnesses are raised, but no major changes, in the displacement or rotation fields at the contact, are detected.
- The shear band seems to spread a few particles from the rough boundary simulating the structure. In average, the interface thickness was about 5-8 particle diameters. This is in accordance with the value reported by Hoteit (1990) in his experimental measurements.

EFFECT OF STRUCTURE ROUGHNESS ON THE INTERFACE

In order to study the effect of structure roughness on the formation of a possible shear band, 1000 particles were used in the same set up as above. The assembly grain size distribution was the same. The slope of the saw teeth was used as a measure of the degree of the structure surface roughness, and four values were considered (2° , 10° , 20° , and 30°) but results for only two are reported below.

Low Roughness (2° Case)

This simulation was performed to replicate the case of a nearly smooth surface, and results are presented in Figures 1 through 3. The force network displays a more or less uniform force distribution through the sample. The displacement vectors suggest that the shear band is very narrow where the process zone is limited mainly to particles in immediate contact with the surface. Grain displacements and rotations are present primarily in a thin layer not exceeding 2 particle diameters in thickness. Furthermore, the slip zone is straight with no significant undulations.

Figure 1. Interparticle Forces for 2° Roughness

Figure 2. Displacement of Particles for 2° Roughness

Figure 3. Rotation of Particles for 2° Roughness

Rough Surface (20° Case)

Based on the results of the 2° and 10° cases, it was clear that the degree of roughness has an effect on the shear band formation, extent, and characteristics. It can be deduced from Figures 4 through 6, giving the results of the simulation done with the third level of roughness (20° slope), that the undulations in the shape of the shear zone become more important and more particles are involved in the shear process. The interface extends about 4 to 6 particle diameters from the structure.

Figure 4. Interparticle Forces for 20° Roughness

Figure 5. Displacement of Particles for 20° Roughness

Figure 6. Rotation of Particles for 20° Roughness

CONCLUSIONS

A parametric study showed qualitatively that element-to-element and element-to-boundary friction, element and boundary stiffnesses and damping, if not too heavy, have little or no effect on the behavior at the structure-medium. The investigation of surface roughness showed that the shear band is very thin in the case of very low degree of roughness which was used to model a relatively smooth surface. Furthermore, it appears that the shear zone thickness increases as the surface

roughness increases. The shear zone, in general, is a thin layer not exceeding 8 particle diameters. Further, the shape of the shear zone shows greater curvature and undulations with the increase in degree of structure surface roughness.

This information, at the microstructural level, was used to develop a new constitutive law for the interface that takes into account its microstructural features. The slip surface was idealized by a sinusoidal curve.

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