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DEM Simulation of Mechanical Behavior of Cemented Angular Sand under Isotropic Compression Test

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ABSTRACT: The mechanical behavior of cemented sand is different from that of uncemented sand because of the presence of bonds between particles. In this study, the effect of bond strength on the mechanical behavior of cemented sand under isotropic compression test is investigated by using a numerical method called as Discrete Element Method (DEM) in a two-dimensional space. DEM is a powerful numerical tool by which, each particle is considered as a rigid body, and the equilibrium condition is satisfied by applying accelerations and displacement along with applied forces from adjacent particles. The novelty of this study in comparison to similar works is to consider the angular geometry of particle shape rather than supposing circular. The particles are connected to each other To simulate the cementation agent. For the simulation of bonds, a bond contact model is defined by considering tension, compression, and shear strengths; the tension and shear resistance of bonds are assumed to be equal. In this model, it is essential for particles to have physical contact and overlap to consider that they are bonded to each other. For the simulation of isotropic compression tests, the samples are loaded isotropically up to 60 MPa under different stress levels. The results indicate that with an increase in the bond strength, the sample resists higher against volume reduction, and also, primary and gross yield stresses increase. Results show that when a cemented sample reaches the primary yield point, the rate of broken bonds increases. The pressure that is carried out by bonds increases as the volumetric strain augments. In this research, the results are validated by existing experiments in the literature.

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1- Introduction

Cemented soil is a type of soil in which the particles are connected by a cement agent. These inter-particle connections can occur for various reasons in nature. For example, the presence of substances such as silica, hydrated silicates, hydrated iron oxides, clay, and silt in the soil structure can create bonds between the soil particles [1]. The behavior of cemented granular soil, which is known as problematic soil in some engineering communities [2], has been the focus of various research studies due to its different behavior compared to granular soil. Cementation plays a significant role, such that the behavior of this soil is influenced not only by stress history and specific weight (density), but also by bond strength. Therefore, it is crucial to study the effect of bond strength on the behavior of such soils. In laboratory studies, the investigation of cemented sand can be carried out in two ways. The first approach involves obtaining samples directly from nature in an intact form (e.g., block sampling), as done in the study by Clough et al [1]. The second approach is a more common method in which, samples are artificially prepared with different cementitious contents using techniques such as gas diffusion or dry mixing in the laboratory. The research conducted on cemented sand can be categorized into laboratory and numerical studies. In laboratory studies, the major tests conducted on this soil include unconfined compression tests, isotropic compression tests, and triaxial tests. The primary application of unconfined compression tests is the classification of cemented samples based on their strength [3]. Various studies like [4] have used triaxial tests to investigate the mechanical behavior of this soil under consolidated and unconsolidated conditions. These studies have examined aspects such as dilation behavior [5], and internal friction angle [6]. Regarding the isotropic compression test, limited researches [4, 7] has been conducted on cemented sandy soil. Rotta et al. [8] investigated the effect of bond formation on the behavior of cemented sandy soil in their research. In this study, the effect of cement content, compaction density ratio, and compaction pressure on the initial yield stress and sample hardness was examined. The results of this research indicated that as the cement content of the samples increased, the value of the initial yield stress also increased. Marri et al. [4] studied the effect of cement content and initial void ratio on the behavior of cemented sand. They observed that with increasing cement content, the value and

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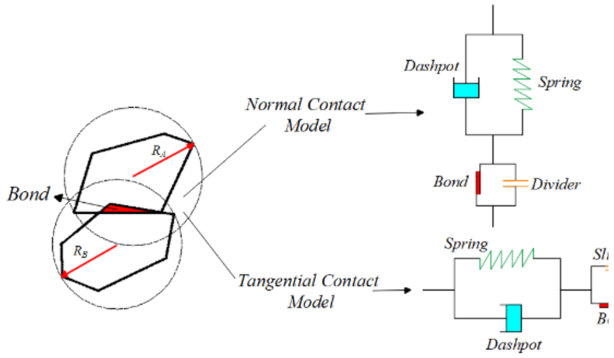

Fig. 1. Schemes of elements defined in the bond contact model employed in the simulation of cemented sand

rate of change in the void ratio decreased.

In the present study, the mechanical behavior of cemented sand with multi-shaped angular particles (two-dimensional) under isotropic compression test with different bond strengths is investigated by using the Discrete Element Method (DEM). A bond contact model is employed to simulate the bond between soil particles, assuming equal resistance to shear and tensile forces for these bonds. This numerical study examines various aspects, including the mechanical behavior of cemented and uncemented samples, bond failure in the cemented specimens, initial and gross yield modulus, and cement matrix strength.

2- Material and Simulation

In nature, sand particles are often found in polygon shape. In the present study, To better simulate the behavior and approach the reality of sandy soil, the particle geometry has been modeled as a polygon. The particle geometry is considered to be hexagonal to octagonal, with the main enclosed ellipse diameter ranging from 0.4 to 1 millimeter.

In this research, the BDL2D program was used to simulate the granular cementitious media. This program, developed by Honary and Seyedi Hosseininia [9], is based on DEM and has the capability to simulate cementitious and non-cementitious granular media in a two-dimensional space. The BDL2D program utilizes a bond contact model to simulate bonds between soil particles. Figure 1 illustrates the components of this bond contact model. This contact model was previously used by Jiang et al. [2] to simulate circular particles, but in this research, modifications were made to simulate polygon particles. The bond contact model consists of two parts: the normal bond contact model and the tangential bond contact model. For simulating particle contacts, a spring and damper are used, while for bonding, a viscoelastic solid element is employed. The spring represents the pre-yield behavior, and the damper serves as an energy dissipation. In the normal contact bond model, a separator is used, and in the tangential contact bond model, a slider is connected in parallel. The presence of these two parallel elements is to represent the fact that no force is transmitted through the bond after its failure.

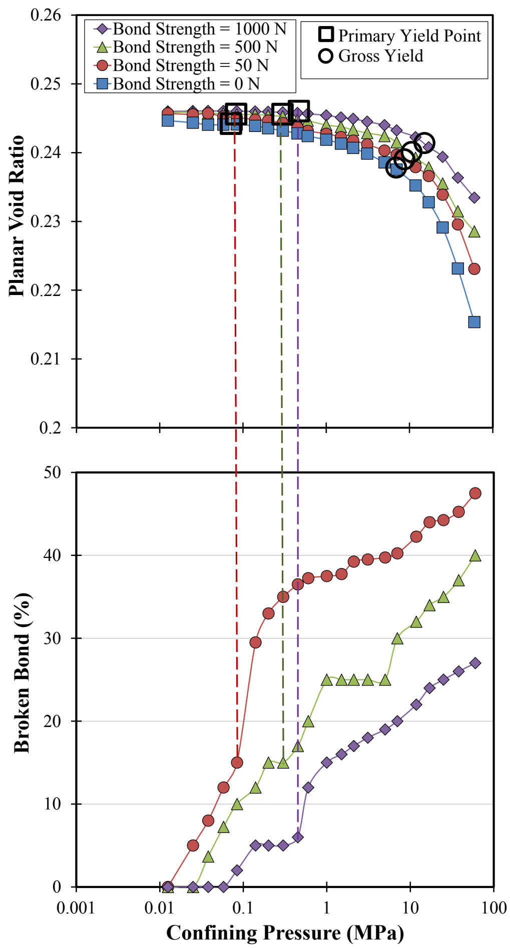

Fig. 2. Changes in void ratio and broken bond ratio in cemented samples along with confining pressure in the current study

3- Results

Figure 2 shows the curves of the variation in the void ratio and the changes in bond failure against the applied confining pressure. From this figure, it can be observed that as the bond strength increases, a lower percentage of bonds are broken with increasing confining pressure. For example, for a sample with a bond strength of 50 N, 50% of the bonds have failed at the end of the test, while for a sample with a bond strength of 1000 N, less than 30% of the bonds have been failed. As seen in this figure, there is a significant increase in the rate of bond failure at the point of initial yield in the sample. The reason for this trend is that the bonds have already experienced progressive failure at this stage. In other words, the failure of some bonds inside the sample has led to the failure of the remaining bonds.

4- Conclusion

In the present study, numerical simulations using DEM have been employed to investigate the behavior of cemented and uncemented sand under isotropic confining pressure test. Unlike most numerical studies, the particles in this research have been modeled as angular to better represent the mechanical behavior of soil. Considering the significant role of bond strength compared to the cement content in the mechanical behavior of cemented soil (similar to study [2]), the effect of particle bonding strength on the mechanical behavior has been examined in this study. The simulations included samples with three bond strengths, 50, 500, and 1000 N, which were subjected to a confining pressure from 10 kPa to 60 MPa. The numerical results obtained from this research have been validated using existing laboratory experiments. Globally, the results of this study are in accordance with those obtained from experimental works in the literature. The findings of this study are as follows:

The addition of particle bonding reduces the tendency of the sample to undergo volume reduction, and with an increase in bond strength, the sample exhibits higher resistance against volume reduction. By studying the variations in bond failure during the tests, it was observed that with an increase in bond strength, a lower percentage of bonds become failed.

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