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NRCC-45679

A version of this document is published in / Une version de ce document se trouve dans :
3rd International Conference on Discrete Element Methods, Santa Fe, New Mexico, Sept. 23-25, 2002, pp. 107-111

USE OF DIGITAL IMAGES TO ENHANCE DISCRETE ELEMENT MODELING

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INTRODUCTION

The discrete element method is recognized as a powerful tool for studying granular materials. The first generation of discrete element models idealized particles with discs in 2-D and by spheres in 3-D (Cundall and Strack 1978; 1979). Later, polygons were used to improve particle shape idealisation. However, polygon elements are demanding on computational time. Ting et al. (1989) reported an increase in execution time of at least one order of magnitude for polygons compared to circular or disc shaped particles. Lately, the use of clusters of particles has been pursued by researchers. This approach does not require much modification of contact detection schemes usually used with circular shapes. However, the composition of analyzed samples in terms of percentage of each particle clustering is taken arbitrarily, which usually is unrepresentative of actual particle size distribution of granular materials. This paper presents the use of digital images to provide a real packing configuration for samples and then uses the cluster concept to improve particle modeling for use in discrete element analyses.

DIGITAL IMAGE ANALYSIS

Sample preparation

If digital image analysis (DIA) is to be used effectively then sample preparation and compaction must replicate the practices followed when preparing laboratory samples and during pavement construction. Further, the position and orientation of particles in a sample must be maintained during the cross-sectioning and polishing phases of sample preparation for digital image analysis. The following is a brief description of the method:

- The granular material used was a representative sample of a standard granular material used in the base layer of pavements in Ottawa, Canada

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- The water (used to achieve 95 % of the standard Proctor density) was replaced with an equivalent amount of an epoxy (13.25 %). This low viscosity epoxy permitted sample compaction and produced an extremely hard sample, once cured, that maintained its integrity during sectioning
- The sample was compacted to 95 % of its standard Proctor density, a typical requirement for field or laboratory applications
- To achieve 95 % compaction, the aggregate-epoxy mixture was applied in three lifts to a 4 by 8 inches (10 by 20 cm) mould. The required density was achieved by vibrating the sample on a vibrating table. The sample was vibrated long enough to achieve adequate compaction without causing excess segregation. The first layer was vibrated for 2 minutes at 20% of the unit's capacity, the second layer for 5 minutes at 50% capacity and the last layer was vibrated for about 6 minutes at 80% capacity
- During vibration, a dead weight of about 11.5 kg was applied to the top of each layer
- The compacted sample was cured overnight to permit particles to set
- 24 hours after preparation, the sample was longitudinally cross-sectioned using a concrete saw with a diamond saw blade.

Sample scanning

The study used commercial software to scan and capture an image for processing and analysis. The image was analysed pixel by pixel and particles were identified, numbered and some morphological parameters were calculated. Figure 1 shows a scanned sample.

Sample discretisation using clusters

The scanned image in Figure 1 provides real grain positioning and orientation following compaction. Importing such an image as input for a discrete element model, however, is impossible due to the irregular particle shapes and thus, coupling digital images with DEM required some simplifications. Representing particles with polygons was an attractive solution; however, as mentioned this method demands increased computational time. Using an existing 2-D program that idealizes particles with discs permitted the scanned image to be transformed so that an association of smaller circles could be grouped into clusters which provided a better morphological representation of each particle. An example of such discretisation is shown in Figure 2.

COUPLING DIGITAL IMAGES WITH DEM

Once the sample is discretised, all measurements (circle diameters and positions defined by a Cartesian co-ordinate system) can be written and exported to various formats. This data can be imported and used as an input file for a DEM model. Thus, the imported particle positions and orientation serve as the first step of any numerical simulations, i.e. the compaction phase of DEM simulation is omitted. Figure 3 shows a discretised sample that was imported to DEM and for which the voids, which were rather large because the smallest particle was 5 mm in diameter, were filled with individual particles to maintain the structure and position of the particles during application of the confining pressure.

APPLICATION

Simulation of the resilient modulus test

A normal simulation of the resilient modulus test using the discrete element method would require compaction and confinement of a sample and application of repetitive loading. However, using digital images, the compaction phase was omitted and replaced by a discretised sample that was imported to DEM.

During the confinement phase a confining pressure was applied to the imported sample by using the boundary particles shown in black in Figure 3. The interparticle forces developed following confinement were represented with darkened lines. The configuration of the flexible boundary (made of these boundary particles) was updated at regular intervals to include any internal particle that migrated and joined the flexible boundary.

During the loading stage, samples were subjected to a deviator repetitive stress.

In repeated triaxial tests, the resilient modulus (M_r) is calculated as the ratio of the deviator stress (σ_d) to the resilient strain (ε_r):

$$M_r = \frac{\sigma_d}{\varepsilon_r}$$

Effect of particle shape on the resilient behaviour

Two simulations were performed to delineate the effect of elongated particles (a cluster of two circular particles) and triangular particles (a cluster of three circular particles). The first simulation used a digital image (Figure 2) as input for DEM and the second simulation used only individual elements. Preliminary results showed that the resilient modulus increases by 20 % when elongated and triangular elements are present in the sample (M_r = 360 MPa compared to 300 MPa when only circular elements are used).

CONCLUSIONS

This paper presented the potential for using the digital image analysis technique to provide realistic grain size distribution, which can be used in conjunction with the clustering technique to improve shape idealisation of particles. Further, it presented the DEM capability of capturing the effect of particle shape on the behaviour of granular materials. Preliminary results showed that particle shape (elongated and triangular) has an effect on the resilient behavior of granular materials.

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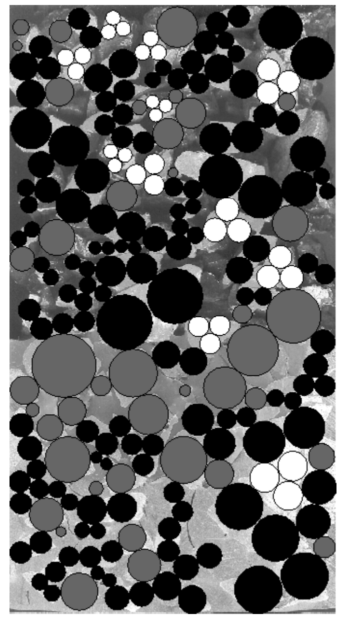

Figure 1. A Scanned Sample

Figure 2. Discretisation of the digital image

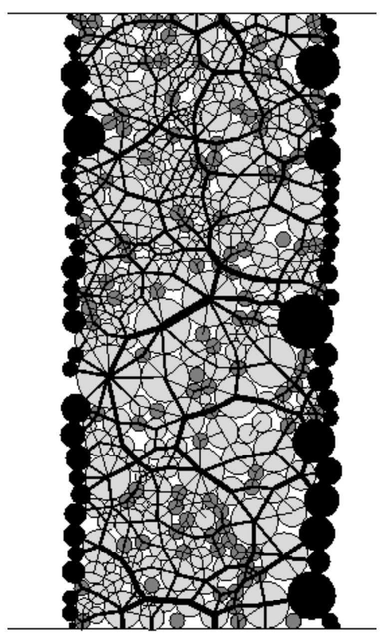

Figure 3. Import of a Discretised Sample to DEM (Dark grey particles added to maintain the sample structure and the associations are not shown in different color)