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EFFECT OF PARTICLE STIFFNESSES ON THE RESILIENT BEHAVIOUR OF AGGREGATE MATERIALS

Mark Lowery[1] and Morched Zeghal[1]

[1]Institute for Research in Construction, National Research Council Canada, Ottawa, Ontario, K1A 0R6

Abstract

This paper presents the results of numerical simulations of a cyclic loading test. Discrete element modelling (DEM) was used. It permits the consideration of the discontinuous and heterogeneous nature of aggregate materials. The simulations were based on assemblies of circular particles confined between top and bottom rigid boundaries and laterally confined with constant stresses. Contact forces and displacements obey a linear relationship. Furthermore, shear forces were restricted to a maximum value (Coulomb's friction law). Compacted samples were subjected to deviatoric repeated loads. The investigation confirmed the linear relation between normal and shear stiffnesses of particles and the resilient modulus.

Introduction

The resilient modulus, M_r, is a mechanical property of the material. It describes its stress-strain relationship under dynamic loading and specified physical conditions. In repeated triaxial load tests, M_r is defined as the ratio of the peak deviator stress (σ_d) to the recoverable axial strain (ε_r):

$$M_r = \sigma_d / \varepsilon_r \qquad (1)$$

The research approach adopted in this study consisted of an analytical simulation using the discrete element method (DEM).

Model Used

The 2-D model used assumes that the particles are soft. An overlap is allowed between particles. It is used to calculate interparticle forces and is a function of the particle stiffnesses and velocities at the time of contact. In this code, calculations are performed based on application of Newton's law for discs and a force-displacement law at the contact point. Newton's second law of motion describes the motion of particles due to the forces acting on them. The force-displacement law is used to calculate the contact forces from relative displacements.

Two groups of input parameters are needed to perform numerical simulations:

1. Data on the positions and radii of discs and the position and orientation of rigid boundaries with respect to a co-ordinate system; and
2. Physical properties such as radius, density, friction coefficient and normal and shear stiffnesses of discs and rigid boundaries.

Simulation of the Resilient Modulus Test

Simulation of the resilient modulus test using DEM required preparation of a sample and application of a repetitive load. Particles were randomly generated during sample preparation and they did not touch one another. The particles were then compacted by moving the lateral rigid boundaries inwards as illustrated in Figure 1, which depicts an intermediate stage of compaction.

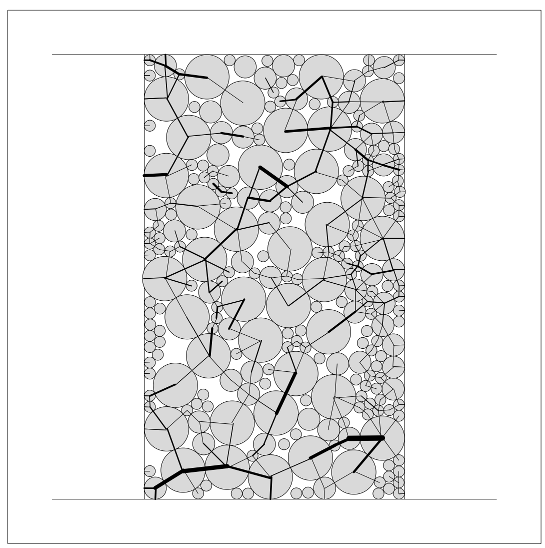

Figure 1. Intermediate stage of compaction

When proper compaction was achieved, the lateral boundary velocities were set to zero and iterations were continued until particle velocities converged to zero (Equilibrium State). Boundary particles of the compacted sample were identified and used to form flexible boundaries and apply confining pressure to the sample. The configuration of these flexible simulated membranes changed during the test and they were updated at regular intervals. A prepared sample for which the flexible boundaries are shown in black is presented in Figure 2. The lines between particles represent interparticle forces and the width of each line is proportional to the magnitude of the force. The lateral, rigid boundaries used for sample compaction were retracted (see Figure 2) and served no function during further testing.

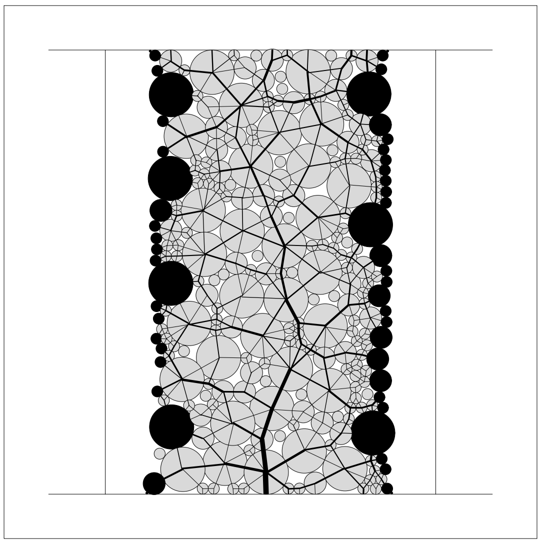

Figure 2. Sample confinement using boundary particles

The loading stage subjected the compacted and confined samples to a 35 kPa deviator stress at the top boundary. The stress cycle had a 0.05 sec loading phase, 0.05 sec unloading phase and 0.9 sec rest period. The repetitive load was continued until the resilient modulus stabilized.

Testing Program

To study the effect of particle stiffnesses (normal and shear) on the resilient behaviour of aggregate materials, three samples made of 250 particles were fabricated, loaded and their resilient modulus determined. The sample contained three different particle sizes, which were proportioned as designated in Table 1. The physical properties of the particles used in the simulations are listed in Table 2.

Table 1. Particle size distribution

Particle Size (mm)	Percentage (%)
10	15
5	20
2.5	65

Table 2. Particle physical properties

Physical Property	Sample #1	Sample #2	Sample #3
Normal Stiffness (kPa)	0.5e5	1.0e5	2.0e5
Shear Stiffness (kPa)	0.5e5	1.0e5	2.0e5
Density (g/cm^3)	2.70	2.70	2.70
Friction	0.5	0.5	0.5

Results

Table 3 presents the resilient modulus results for the three samples studied. As expected, the relationship between the stiffness values and the resilient modulus appears to be linear. A doubling of particle stiffnesses causes a corresponding two-fold increase in the resilient modulus.

Table 3. Resilient modulus results

	Sample #1	Sample #2	Sample #3
Resilient Modulus (MPa)	215	430	864

Conclusions

Numerical simulations of the resilient modulus test showed that DEM is capable of reproducing the resilient behaviour of aggregate materials under cyclic loading. Simulations at three values of normal and shear particle stiffnesses confirmed their effect on the resilient modulus. As expected, the resilient modulus exhibited a linear increase with the increase in particle stiffnesses.

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