EVALUATION OF MINIMUM AND MAXIMUM DENSITY OF A SPHERICAL FRICTIONAL PARTICLE ASSEMBLY USING DISCRETE ELEMENT METHOD

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Introduction

Evaluation of minimum and maximum density of a granular assembly is useful in understanding its ability to achieve desired strength and stiffness characteristics. BS1377:Part4 describes methods to evaluate the minimum and maximum density of a sand experimentally. In this study, the behaviour of an assemblage of granular particles under simulated conditions of above test procedures is investigated in relation to particle size distribution using a 2D discrete element method (DEM) (Cundall and Strack, 1979) utilizing the software PFC^{2D} (Itasca, 2004). The evaluation of the minimum density was simulated by allowing gravitational forces to act on an assemblage of particles in alternating directions for several cycles. The assembly thus obtained was subjected to an isotropic confining pressure in determining the maximum density. The influence of the confining pressure and the friction coefficient on the maximum density of a particle assembly is also studied in relation to the particle size distribution. The numerical results are compared with a limited number of laboratory experiments performed on sand.

Methodology

Initially, sand samples (Gs=2.66) were selected for laboratory testing to consist mostly of rounded particles.

The laboratory determination of the minimum density was performed according to BS 1377: Part 4. The numerical simulation of the above laboratory experiment was carried out by first dividing the particle size distribution curve of the laboratory test sample into 13 classes of particle size and evaluating the weight of sand particles corresponding to each class. Therefore, it is possible to compute the number of particles corresponding to each class of particle size, which enables to generate an assembly of cylindrical particles that corresponds with any given particle size distribution curve. Two well graded sand samples (PSD1 and PSD6) were selected for carrying out laboratory tests and four particle size distribution curves (PSD2 to PSD5) were selected for the numerical analyses where PSD2 was selected to represent particle size distribution curve of the sand sample (PSD1) used for laboratory tests. The numerical simulation of the above test procedure was run by initially generating the particles within a container of dimensions 1000 mm x 65 mm x 385 mm and allowing the gravitational forces to act on the particles. The laboratory procedure of inverting the cylinder was simulated by allowing the gravitational forces to act in the upward direction thereby making the particles to move in the opposite direction. The above procedure was repeated four times until all the particles have come to a stable position, thus making it possible to obtain a value for the minimum density.

The experimental and numerical evaluation of maximum density was carried out by applying a static load. The sand sample was placed in a compaction mould to a thickness of about 1/3rd of its height and the desired static load was applied through a steel plate using a Bellofram cylinder. The procedure was repeated three times to enable uniform compaction of the sample. The numerical simulation of the above procedure was carried out by applying a uniform pressure to act on the walls of the container so that the walls will move inwards until the pressure developed along the wall becomes equal to the specified confining pressure. The friction coefficient was 0.4 for all the analyses.

Results

The particle size distribution curves of the sand samples used for laboratory experiments and numerical analyses are shown in Figure 1. It is noted that the PSD2 curve utilised for numerical analyses was selected to coincide with that of a sand sample used for laboratory tests (PSD1-Lab1 curve). The minimum density obtained from laboratory tests are given in Table 1.

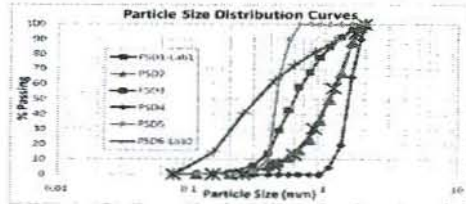

Figure 1. Particle size distribution curves used in numerical and experimental analyses

Table 1. Minimum density (Experimental)

Sample	Minimum Density (kg/m^3)
PSD1	1351.4
PSD6	1612.9

Figure 2 shows the intermediate configurations of the particle assembly during the simulation of the laboratory procedure of the above. The minimum density values obtained from the numerical simulation is shown in Table 2.

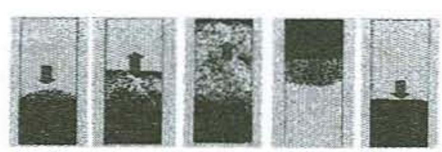

Figure 2. Numerical simulation of minimum density

Table 2. Minimum density (Numerical)

Assembly	Min.Density (kg/m3)
PSD2	2161.94
PSD3	2152.94
PSD4	2135.89
PSD5	2018.06

The maximum density values of the sand samples obtained experimentally are given in Figure 3. The maximum density values obtained by numerical simulation of the four particle assemblies are shown in Figure 4. Figure 5 shows the influence of friction coefficient on the maximum density for the assembly having a particle size distribution given by PSD3 curve.

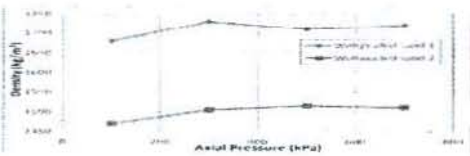

Figure 3. Maximum density obtained from laboratory tests

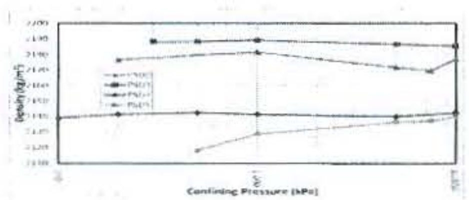

Figure 4. Maximum density obtained from numerical analyses

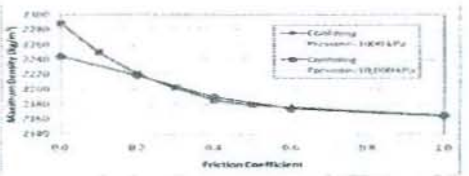

Figure 5. Variation of maximum density with friction coefficient

Discussion

In the context of a 2D numerical simulation of an otherwise 3D laboratory experiment, some degree of quantitative mismatch of minimum and maximum density values between the experimental and numerical results can be expected. In addition, the effects of the value used for particle friction and to some extent on the K_0 conditions applicable for laboratory tests could lead to over-prediction of maximum density. Table 2 and Figure 4 agree with the fact that well graded particle assemblies (PSD2 and PSD3) are easily compactable than the uniformly graded particle assemblies (PSD4 and PSD5). Figure 5 infers that, for a particle assembly of greater friction coefficient, sliding of particles is being inhibited in achieving a higher density.

Conclusions

(1) Numerical test procedures adopted in PFC^{2D} to evaluate the minimum and maximum densities of a sand using DEM can be used to describe the influence of particle size distribution on the minimum and maximum densities.

(2) A threshold value of the inter-particle friction coefficient can be found beyond which the maximum density is independent of the confining pressure.

References

Cundall, P.A., and Strack, O.L. (1979). A discrete numerical model for granular assemblies. *Geotechnique*, 29(1): 47-65.

Itasca Consulting Group Inc., PFC^{2D}(Particle Flow Code in Two Dimensions), version 3.1, 2004 (ICG:Minneapolis,MN, USA).