TECHNICAL NOTE

RELATIVE DENSITY OF PLUVIATED SAND SAMPLES

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ABSTRACT

Possible explanations regarding the often conflicting views on the effect of drop height on relative density of pluviated sand samples are presented. Assuming that the relative density achieved would be related to the particle energy at impact, it is shown theoretically that the drop height effects are of no significance for pluviation through water. In air pluviation, however, the relative density achieved depends very much on the drop height, although the range of drop heights over which densification is effective depends on the average particle size. Preliminary test results on a sand together with some test results from literature are presented in support of the ideas advanced.

Key words : density, laboratory test, sand, test procedure, (pluviation) (IGC : D 2/D 3)

INTRODUCTION

Reconstituted samples of sand are often prepared in the laboratory by pluviation through water or air. The sand is poured either through a concentrated opening or is rained from a surface which may cover the full cross-sectional area of the sample. Deposition in large size samples in model tests by the raining technique is carried out by some form of mechanism which traverses over the plan area of the sample.

Pluviation technique is considered to approximate a natural deposition process. Both the nature of anisotropy and soil fabric obtained by pluviation methods have been found to duplicate those observed in a natural alluvial environment (Oda et al., 1978). Hence this technique of preparation of laboratory samples allows a convenient study of mechanical response of natural sands. The height through which sand drops during pluviation has been used to obtain samples of various relative densities, although researchers have differing opinions as to the degree of its success. Most of these studies have been confined to pluviation through air. The influence of increasing height of drop on relative density obtained has been reported to be significant (Tatsuoka et al., 1982; Kolbuszewski, 1948 a, 1948 b), minor (Mulilis et al., 1975) and insignificant (Miura

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and Toki, 1982). In this note an attempt is made to seek a rational explanation to these apparently diverse conclusions. Energy of sand particles at impact during deposition is considered to control the relative density achieved. Results from literature together with some new test results are presented in qualitative support of the proposed theoretical explanation.

**VELOCITY AT IMPACT**

The motion of an isolated spherical particle of mass \( m \) undergoing free fall in a fluid of mass density \( \rho \) is described by

\[
ma = mg - V\rho g - C_d \rho A \frac{v^2}{2}
\]

in which \( a \) = particle acceleration, \( g \) = gravitational acceleration, \( V \) and \( A \) = volume and projected area respectively of the particle, \( v \) = particle velocity and \( C_d \) = drag coefficient which depends on Reynolds’s number. The second and third terms on the right hand side of Eq. (1) represent respectively the forces of buoyancy and drag on the particle. Assuming the particle starts from rest \( (v_0 = 0) \) and thus \( a_0 = g(1 - V\rho/m) \) the particle will decelerate from \( a = a_0 \) to \( a = 0 \) when the terminal velocity is reached. Given the properties of the falling sphere and that of the fluid medium, the velocity, acceleration and displacement of the particle can be determined as a function of time from the equation of motion (Eq. (1)) and the assumed initial at rest state. These computations are, however, not straightforward because of the interdependence of velocity and drag coefficient. Hence a trial and error procedure is required, which is described in standard textbooks on fluid mechanics.

The pluviation of a relatively uniform sand may be idealized as a free fall of spheres of an equivalent diameter \( D_{sp} \). Neglecting interference effect due to simultaneous fall of many particles, the time history of velocity, acceleration and displacement of particles can be calculated as discussed above. Fig. 1 shows results of these computations for quartz sand \( (G_t = 2.67) \) with \( D_{sp} = 0.4 \text{ mm} \)

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**Fig. 1. Velocity of a free falling sphere in air and water**

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**Fig. 2.**

(a) Velocity of free falling spheres of different diameters in air. (b) Terminal velocity and drop height to terminal velocity as a function of sphere size.
pluviating through air and also water. The results are shown in the form of velocity attained as a function of height of drop. It may be noted that at equal heights of drop velocities in air are very large in comparison to those in water. This results in high kinetic energy deposition in air. Furthermore, the terminal velocity of 6 cm/sec in water is reached in a mere 0.2 cm drop as compared to a very large drop of 270 cm in air. Consequently, considering practical range of heights of pouring (say up to 2 m used by Kolbuszewski, 1948a) the velocity at impact (and hence kinetic energy) on deposition in air will vary considerably depending upon the height of drop. The largest increase in velocity with a given increase in drop height may be seen to be associated in the low end of the drop heights and would consequently have greatest influence on the relative density of the deposited sample. Height of drop effects on impact velocity for pluviation in water, on the other hand are inconsequential, since no further increase in velocity can occur after terminal velocity is reached when the drop height exceeds a mere 0.2 cm. This would then apparently be the reason that no one talks about drop height control in getting different relative densities in water pluviated sands. In the subsequent discussion, therefore, pluviation in air only is considered.

The influence of particle size on impact velocity as a function of drop height is shown in Fig. 2. As would be expected, the impact velocity decreases with decrease in particle size at all levels of drop heights. In addition, the magnitude of terminal velocity attained increases essentially linearly with increase in particle size, but the drop height needed to attain this also increases. Since, lower deposition energies are associated with small particles (not only due to a smaller impact velocity but also a smaller mass) for a fixed height of drop, relatively lesser densification may be expected in finer sands than the coarser type. Also a quicker approach to terminal velocity in fine sand will imply that range of height drop in which densification is effective will be smaller.

**TEST RESULTS**

Fig. 3 shows the effect of height of drop on the void ratio of air pluviated Leighton Buzzard Sand (Kolbuszewski, 1948a). It may be noted that higher impact energies that are associated with increased drop heights lead to compaction and towards a limiting void ratio. Similar results obtained in this study on Ottawa sand, which has approximately the same $D_{50}$, are also shown in Fig. 3 and may be seen to represent trends similar to that for the Leighton Buzzard sand. It may be noted that $v^2$ (or impact energy) vs. drop height trend illustrated in Fig. 1 approximates a mirror image of that shown in Fig. 3, lending support to the theoretical postulates of associating larger densities to larger kinetic impact energies. It may also be noted in Fig. 3 that the influence of height of drop on densification seems to be the greatest in drop height range of about 0 to 50 cm for the sands studied. This observation is also consistent with the energy versus drop height relationship of Fig. 1 in the region of smaller drop heights. Although, impact energies will keep increasing with increasing drop heights until terminal velocity is reached, it appears from the test results that increase in impact energy beyond a certain maximum magnitude may do little in compacting sand any further. This may explain the results of Miura

![Figure 3](image-url)

*Fig. 3. Effect of drop height on resulting void ratio in air pluviation*
and Toki (1982) who observed insignificant changes in void ratio with change in height of drop. For the range of drop height 30 to 70 cm they investigated, little change in resulting void ratio may be noticed in results shown in Fig. 3. Similar arguments may apply to the observations of Mullis et al. (1975) who noticed only minor effect of drop height on the resulting void ratio.

The arguments presented above are based on idealized assumptions that the sand consists of uniform spheres which undergo free fall without mutual interference. In reality the actual void ratio attained by the sand for a given height drop will depend on some average particle size, gradation, mass rate of pouring and characteristics of the container, such as its diameter and surface smoothness, particularly for small diameters. Higher rates of pouring would introduce interference effects that may inhibit particles from aquiring the most stable (and hence likely dense) configuration while coming to rest (Miura and Toki, 1982; Kolbuszewski, 1948 b). Higher rates of pouring into a cylindrical former may also trap an air front mass ahead, the eventual escape of which may cause a counter upward air current, thus reducing the impact energy and hence result in lesser compaction. A membrane lined sample former, especially of a smaller diameter, will further inhibit denser packing due to frictional side restraint. Thus, for a given sand and sample former characteristics, the height of fall and rate of pouring appear to have opposite effects. Both these effects have been implicitly used to control void ratio of air pluviated sand samples (Miura and Toki, 1982; Tatsuoka et al., 1982; Ishihara and Towhata, 1983).

If the sand is well graded or contains significant amounts of fines, air pluviation will clearly result in segregation because of the finer particles lagging behind on account of their smaller velocities within the fixed height drop (Fig. 2). Homogeneity of such pluviated samples may then be questionable. Even when sand is relatively uniform, a precise control on height of drop is crucial in order to ensure homogeneous samples. The reason for this precise control of pouring height is apparent in Fig. 3, which shows extreme sensitivity of resulting void ratio to the range of pouring height commonly used in air pluviated samples. If low relative densities are desired, relatively small pouring height would be needed. In such cases the position of the pouring tip must be continuously raised as the thickness of the deposit builds up in order to maintain constant height drop at all times. This brings an unnecessary complexity in the deposition process. Pluviation in water in contrast will have no danger of introducing nonhomogeneity in the sample due to variation in height of pouring during deposition. This is because the soil grains reach terminal velocity almost instantly (drop height of 0.2 cm for Dp = 0.4 mm) and maintained until deposition regardless of the height of drop. Higher density samples, if desired, may be obtained by vibrations.

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