# Assessment of portable traveling pluviator to prepare reconstituted sand specimens

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**Abstract.** Air pluviation method is widely adopted for preparation of large, uniform and repeatable sand beds of desired densities for laboratory studies to simulate in-situ conditions and obtain test results which are highly reliable. This paper presents details of a portable traveling pluviator recently developed for model sand bed preparation. The pluviator essentially consisted of a hopper, orifice plates for varying deposition intensity, combination of flexible and rigid tubes for smooth travel of material, and a set of diffuser sieves to obtain uniformity of pluviated sand bed. It was observed that sand beds of lower relative density can be achieved by controlling height of fall, whereas, denser sand beds could be obtained by controlling deposition intensity. Uniformity of pluviated sand beds was evaluated using cone penetration test and at lower relative densities minor variation in density was observed with depth. With increase in relative density of sand bed higher repeatability of uniform pluviation was achieved.

**Keywords:** portable traveling pluviator; deposition intensity; height of fall; sand bed uniformity.

## 1. Introduction

It is often difficult to prepare uniform reconstituted sand specimens for laboratory testing. In the past, efforts were made to develop methods to control uniformity (Fretti *et al.* 1995, Zhao *et al.* 2006, Choi *et al.* 2009) and to achieve required relative density (*RD*) of sand specimen (Muira and Toki 1982, Rad and Tumey 1987, Lo Presti *et al.* 1993, Choi *et al.* 2009). Out of the available methods, air pluviation technique is widely accepted due to its ability to replicate natural soil deposition. This technique is mainly advantageous when reconstituting large specimens for model tests or calibration chamber tests within short time (Fretty *et al.* 1995).

A reconstituted sand bed preparation technique must fulfill the following criteria (Kuerbis and Vaid 1988): 1) the method must be able to produce loose to dense sand beds in the unit weight range expected within an in-situ soil deposit; 2) the sand bed must have a uniform void ratio throughout; 3) the sand bed should be well mixed without particle size segregation, regardless of particle size gradation or fines content; and 4) should simulate the mode of soil deposition commonly found in the soil deposit being modeled.

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## 2. Literature review

The pluviator may be sub-divided depending on type of opening under the sand storage as (1) single nozzle, in which nozzle is moved in regular pattern to rain entire soil surface (Fretti *et al.* 1995) (2) Curtain rainer, in which sand from hopper rains through a narrow slot in the form of a thin curtain (Butterfield and Andrawes 1970, Stuit 1995) (3) Sieve rainers, where one or multiple sieves under the hopper rain sand over an area equals or slightly larger than the sample container (Muira and Toki 1982, Cresswell *et al.* 1999, Abbireddy 2009). Depending on mode of raining, pluviator can be subdivided as (1) stationary-commonly used for preparation of triaxial specimen and (2) traveling-used for model sand bed preparation. A traveling pluviator may be preferred over stationary pluviator to reduce the spatial variability of the specimen *RD* and gradation of large reconstituted specimens (Lo Presti *et al.* 1993).

## 3. Pluviation mechanism

The *RD* obtained by air pluviation depends primarily on deposition intensity, height of fall, uniformity of the sand rain and particle characteristics (Kolbuszewski 1948, Kolbuszewski and Jones 1961, Butterfield and Andrawes 1970, Rad and Tumay 1987, Vaid and Negusey 1988, Lo Presti *et al.* 1992, 1993, Fretti *et al.* 1995, Lagioia *et al.* 2006).

### 3.1 Deposition intensity

Deposition intensity (*DI*) is the mass of soil falling in the chamber per unit area per unit time and is controlled by varying the effective area through which the soil exits the hopper (Lo Presti *et al.* 1993). For a given height, an increase in the *DI* increases the porosity of deposition (Kolbuszewski 1948, Rad and Tumey 1987, Vaid and Negussey 1988). *DI* incorporates the effect of inter-particle interference due to the simultaneous fall of many particles. Butterfield and Andrawes (1970), Lo Presti *et al.* (1993) and Stuit (1995) controlled the moving velocity of hopper to achieve a range of *RD*. Muira and Toki (1982), Rad and Tumay (1987), Zhao *et al.* (2006) used two sieve meshes with different aperture size to regulate flow of sand and obtain large range of *RD*.

Cresswell *et al.* (1999) used flow divider to divert the flow from hopper so as to vary *DI* and found that *RD* increases with decrease in *DI* up to a limiting value corresponding to three to four grain thick energy layer causing compaction to take place. The increased *RD* was attributed to adequate time and depositional energy. However, large *DI* promoted arching of sand particle structure, preventing the sand from reaching higher densities (Muira and Toki 1982, Rad and Tumey 1987, Kuerbis *et al.* 1988, Vaid and Negussey 1988).

### 3.2 Height of fall

Height of fall (*HF*) is the distance between the lowermost diffuser sieve/hopper bottom to the top of the sand bed. Significant influence of increasing *HF* on *RD* had been reported by many researchers (Kolbuszewski 1948, Rad and Tumey 1987, Vaid and Negussey 1988, Lo Presti *et al.* 1993, Stuit 1995, Dupla *et al.* 2004). Theoretical studies by Vaid and Neguesey (1988) showed that the impact velocity increased nonlinearly with an increase in *HF* until terminal velocity is reached, and it also increases with increase in particle size. Kildalen and Stenhamar (1977) observed that the impact energy keeps increasing with *HF* until terminal velocity was reached beyond which unit weight of sand bed is independent of actual falling height, defined as terminal height of fall. Rad and Tumey (1987) suggested that pluviation by adjusting *DI* and maintaining constant *HF* is most appropriate for large scale model preparation. However, Bellotti *et al.* (1991) demonstrated that the non-uniformity of a specimen pluviated under the controlled *DI* increases with a decrease in the overall *RD*. Further, when low *HF* was used in sample preparation to obtain lower densities, the deposition device needs to be continuously raised during the pluviation to keep the impact energy, and therefore *RD* constant. However, controlling fall height as a mode for achieving a required *RD* through air pluviation is still accepted (Saussus *et al.* 2000, Dupla *et al.* 2004, Zhao *et al.* 2006, Choi *et al.* 2009).

### *3.3 Uniformity using diffuser*

Achieving uniform distribution of sand is crucial, as this is one of the main requirements of pluviation and controls the uniformity of fabric and *RD*. A diffuser consists of a set of sieves or of interwoven wire meshes with different aperture sizes, oriented at 45° in the vertical axis with respect to one-another in order to break up the sand flow (Muira and Toki 1982, Rad and Tumay 1987, Cresswell *et al.* 1999). An evenly distributed triangular hole pattern, with completely parallel diffusers are preferred for uniformity in pluviation (Rad and Tumey 1987). There is, however, a minimum possible sieve-opening size for a given *DI*, below which sand particles collect on the diffuser before being deposited. Thus, attention should be paid during a test to verify that sand particles are not collected on the diffuser before being deposited in the sand bed. Rad and Tumey (1987) observed that two diffuser sieves were sufficient for uniform raining and further increase in number of sieves has a little or no influence on homogeneity of the specimen and only a minor effect on relative unit weight. However, Cresswell *et al.* (1999) observed that the most effective system for creating an even rain was using nine meshes out of which, three closely spaced diffusers at the top to break up the initial flow and the remaining in a equally spaced series. Further, Abbireddy (2009) used total of twelve meshes out of which four close-spaced meshes at the top and the remaining in a series for even spread.

### *3.4 Verification of uniformity of sand bed*

In the past various methods were adopted in order to evaluate uniformity of sand bed, most commonly used were; penetration test (Walker and Whitaker 1967, Fretti *et al.* 1993, Hsu and Huang 1999, Choi *et al.* 2010), shear wave velocity method (Choi *et al.* 2010), *RD* evaluation with depth using small containers placed through out the pluviated depth (Lo Presti *et al.* 1993, Choi *et al.* 2010) and resin impregnation technique (Clayton *et al.* 1995).

## 4. Need for present study

Previous studies highlighted the fact that the factors affecting pluviation needs to be given due consideration to obtain uniform sand beds which in turn enhances quality of laboratory model studies. Though pluviation was well understood and utilized effectively for triaxial sample preparation, pluviation technique needs to be further explored for its successful use to prepare reconstituted model sand beds for large size specimen. Sand raining devices used in the previous studies either consisted of curtain rainer to form thin layers of sand bed throughout the depth or large diffuser sieves of size equal to model container, which make the system bulky. Furthermore, the use of greater *HF* to obtain denser specimen requires large space for operation. Previous research utilized either *HF* control or *DI* control as the key variable to obtain different densities. However, the use of combination of *HF* and *DI* may provide avenues to achieve large *RD* range. Studies by Fretti *et al.* (1995) concluded that the use of a set of diffuser sieves to obtain very dense specimen gives less uniform specimen. However, in the above studies, tubes of different diameters were used to achieve different *RD*. These tubes were entirely filled with sand from hopper to the pluviation end of pipe, which might had caused sand to deposit on the diffuser sieves, and lead to non-uniform sand bed. Sand should not be accumulated on the sieve set before it is pluviated, otherwise it may lead to non-uniformity of pluviated sand bed, as clogging of sieve openings would take place. Zhao *et al.* (2006) used traveling pluviator with diffuser mechanism to obtain uniformity in sand rain and orifices for flow regulation. However, due to large *HF* (in the range of 320 mm to 640 mm, where terminal height of the particles may have already reached), only higher *RD* was achieved. Recent studies by Choi *et al.* (2010) highlighted use of porous plate to obtain uniform denser sand beds. Uniformity was checked with cone penetration test and measurement of shear wave velocity. However, the raining system was too bulky and would require large space.

Present research describes details of pluviation device, designed based on the simultaneous control of *HF* and *DI* to achieve a wider range of *RD* while preparing large size specimen for model testing. Uniformity and repeatability of sand bed prepared using the device were evaluated by miniature cone penetration test.

## 5. Description of pluviation apparatus

The designed apparatus named "Portable Traveling Pluviator (*PTP*)" consists of a stationary hopper of 50 kg capacity connected to a 60 cm long rigid tube by means of flexible tube of various lengths depending on height requirement. The flexible tube provides ease in moving rigid tube manually back and forth to prepare large specimen sand bed for model studies while the rigid tube provides passage for material to fall evenly on the set of diffuser sieves within the rigid tube in the pluviator assembly as shown in Fig. 1. Hopper used in the study could be mounted on a wall or a scaffolding or a ceiling depending on the tank dimensions and space availability. Pluviation was carried out in thin layers by raising the rigid tube continuously to ensure a constant height of pluviation with the help of a reference bar attached to the rigid tube. The height of fall was maintained constant with the use of reference bar, which could be achieved by ensuring that the bottom tip of the reference bar just touches the surface of the sand bed during pluviation process. Rigid tube is continuously raised with respect to the reference bar to maintain the height of fall during pluviation process. A set of orifice plates with central circular opening of 4 mm to 10 mm was designed to place at the bottom of the hopper to control *DI*, and to regulate the flow of material from hopper to flexible tube. To obtain uniform flow of material through pluviator, a set of ten diffuser sieves with 20.8% porosity were introduced. Out of which, top three diffuser sieves were placed at a spacing of 6 mm and remaining were placed at regular spacing of 10 mm using spacer rings and guide rod; details of the diffuser are shown in Fig. 2. Diffuser sieves were oriented at 45° vertically with respect to each

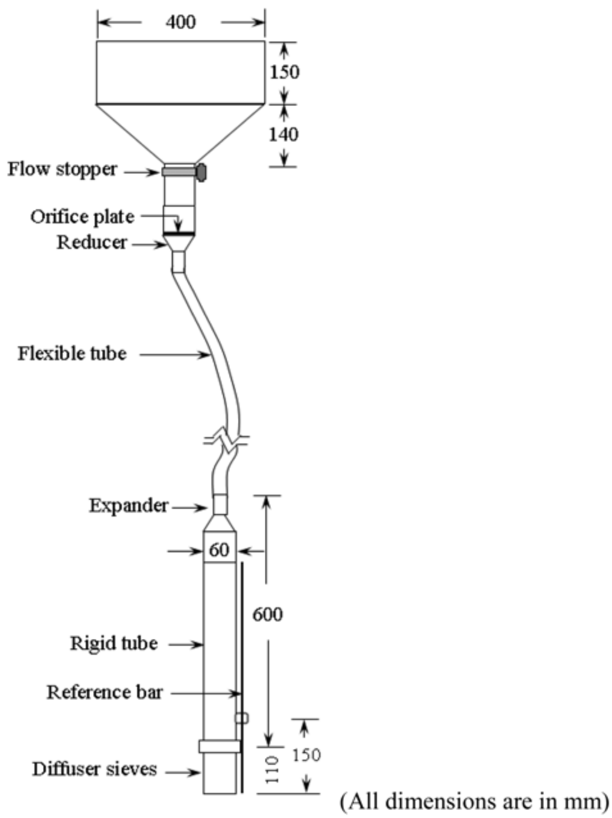


Fig. 1 Details of portable traveling pluviator assembly

other for breaking up the sand flow. Sand was pluviated in thin horizontal layers with rigid tube being vertical so as to achieve proper dispersion of sand. Care was taken to avoid accumulation of sand on diffuser sieves by flow regulation and thus to ensure uninterrupted uniform sand rain. Sand was pluviated using U-turn traveling loop because of its suitability in accordance with Chen *et al.* (1998).

## 6. Experimental procedure

### *6.1 Materials*

In the present study two types of sands (Indian Standard sand, commercially known as Ennore sand of Grade II and Grade III) were used, hereafter referred to as Grade II and Grade III and their typical particle size distribution curves are shown in Fig. 3. Various index properties of these sands are presented in Table 1. Both sands were classified as poorly graded medium to fine sands as per unified soil classification system. Maximum unit weight achieved was determined by pluviation avoiding particle crushing following the procedure suggested by Lo Presti *et al.* (1992). The minimum unit weight was obtained in accordance with the standard procedure (ASTM D4254-00).

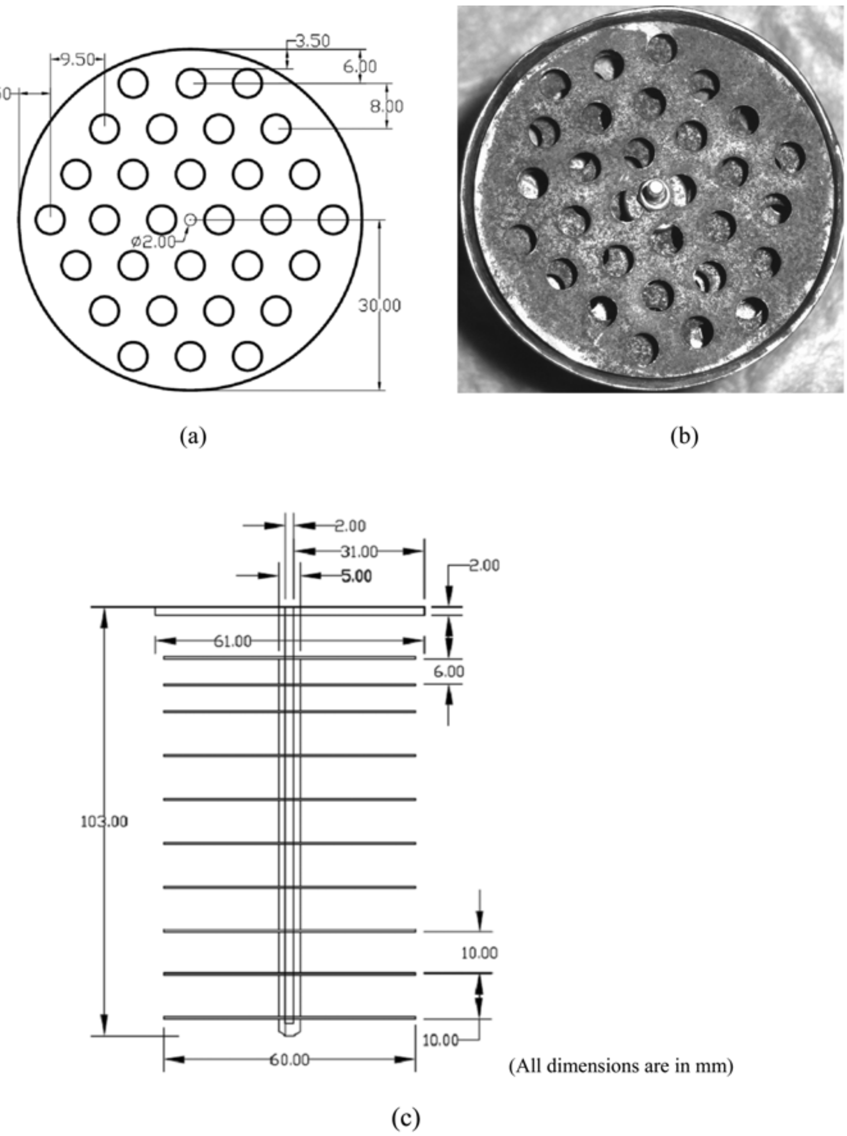


Fig. 2 Details of diffuser sieve set (a) Schematic diagram (b) Pictorial view (c) Sieve set assembly

### *6.2 Pluviation studies*

Tests were performed in order to evaluate effects of *HF*, *DI* and particle size on the *RD* of pluviated specimen. The effects of orifice size on the *DI* for Grade II and Grade III are presented in Table 2. A rectangular tray of volume 1840 $cm^3$ and a cylindrical mould of volume 3250 $cm^3$ were used as receiving containers during pluviation process to evaluate the *DI* and *RD* of sand beds. Several sets of tests were performed to check the consistency of pluviation. Maintaining the *DI* constant, *HF* was varied in range of 2.5 cm to 30 cm from the soil surface, to obtain its effect on densities of specimen for Grade II and III. Similar experiments were performed by varying orifice

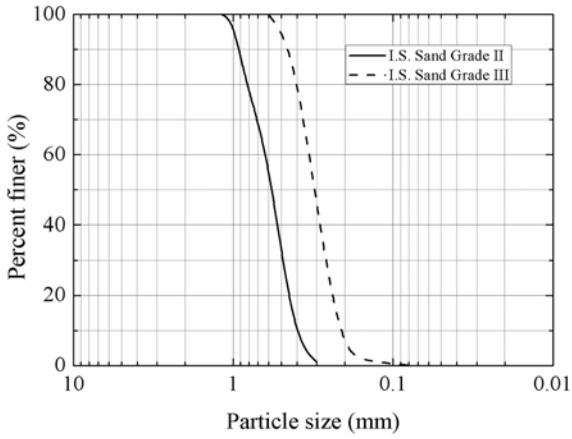


Fig. 3 Particle size distributions for materials used in the present study

Table 1 Physical properties of soil used in the study

| Description | Grade II | Grade III |
|---|---|---|
| $G_s$ | 2.65 | 2.65 |
| $D_{50}$ (mm) | 0.57 | 0.29 |
| $C_u$ | 1.36 | 1.42 |
| $C_c$ | 0.95 | 0.93 |
| $\gamma_{d\,min}$ (kN/m$^3$) | 14.53 (ASTM D4254-00) | 14.58 (ASTM D4254-00) |
| $\gamma_{d\,max}$ (kN/m$^3$) | 17.01 (Pluviator) | 17.10 (Pluviator) |
| Color | Grayish white | Grayish white |
| Mineralogy | 97.4% Quartz, 2.5% Feldspar | 97.4% Quartz, 2.5% Feldspar |
| Shape of grains | Sub-angular | Sub-angular |

$G_s$: Specific gravity of material, $D_{50}$: Mean diameter of soil particles, $C_u$: Coefficient of uniformity, $C_c$: Coefficient of curvature, $\gamma_{d\,min}$: Minimum dry density, $\gamma_{d\,max}$: Maximum dry density

Table 2 Relation between orifice size and deposition intensity for Grade II and Grade III Sands

| Size of orifice (mm) | Deposition intensity for Sand Grade II (g/cm$^2$/sec) | Deposition intensity for Sand Grade III (g/cm$^2$/sec) |
|---|---|---|
| 4 | – [a] | 0.2798 |
| 5 | 0.5731 | 0.7863 |
| 6 | 0.7894 | 1.1546 |
| 7 | 1.2896 | 1.9142 |
| 8 | 1.9556 | 2.9711 |
| 9 | 3.2158 | 4.8096 |
| 10 | 4.0542 | 5.9905 |

a: Material not passing

plate size, and hence material *DI*, and results were obtained. Combined effect of *HF* and *DI* on the *RD* of pluviated bed is shown in Figs. 4 and 5.

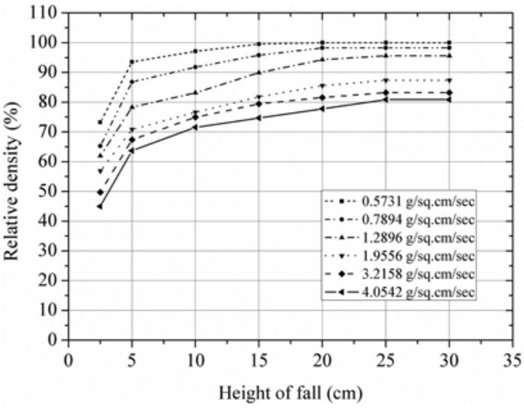


Fig. 4 Effect of deposition intensity and height of fall on relative density - Sand Grade II

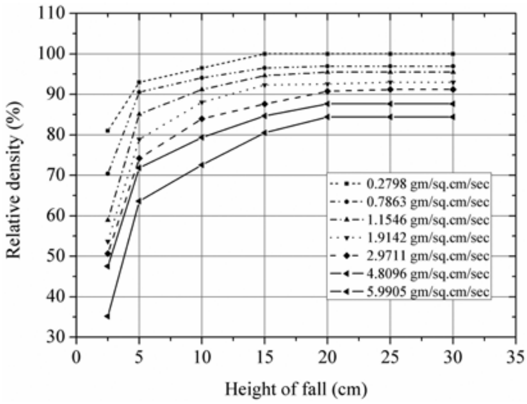


Fig. 5 Effect of deposition intensity and height of fall on relative density - Sand Grade III

### *6.3 Uniformity assessment*

Tests were performed to evaluate repeatability and uniformity of pluviated sand beds. Also tests were carried out to find variation in *RD* within the pluviated sand specimen using a container of size 288 mm × 288 mm × 389 mm. Sand beds with two different *RD* of 59% and 76% using Grade

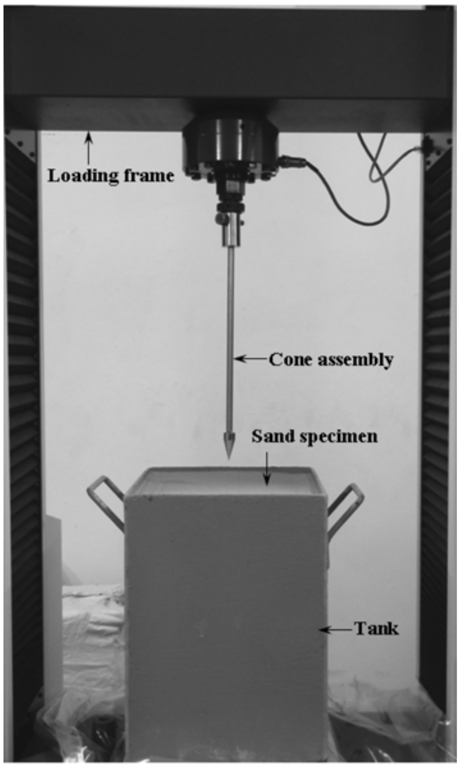


Fig. 6 Pictorial view of cone penetration test set up

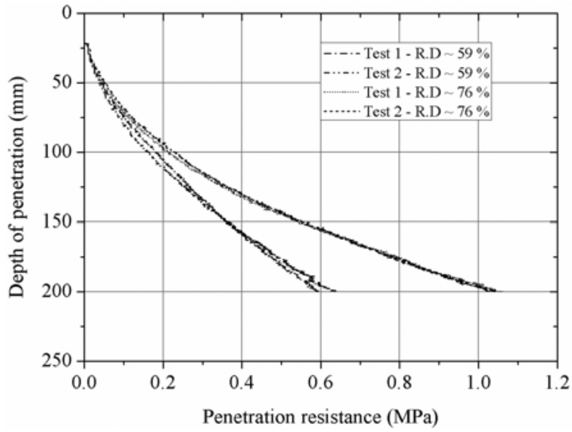


Fig. 7 Results of CPT for evaluation of repeatability and uniformity pluviated bed - Sand Grade II

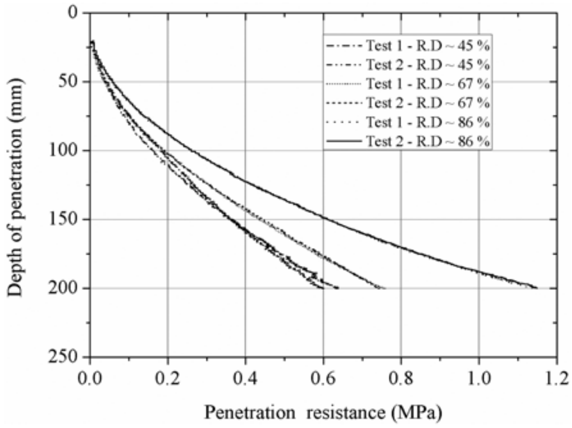


Fig. 8 Results of CPT for evaluation of repeatability and uniformity pluviated bed - Sand Grade III

II sand and three different *RD* of 45%, 67% and 86% using Grade III sand were prepared for evaluation of sand bed uniformity. After completion of pluviation, cone penetration tests were carried out using miniature cone of 200 mm$^2$ area (1/5$^{th}$ of standard cone area) with apex angle of 30°. Smaller cone was selected (1) to check for possible discontinuity (2) to reduce boundary effect by reducing ratio of equivalent cylinder diameter to diameter of cone to 18. Cone was penetrated centrally at a rate of 2 mm/sec which is 1/10$^{th}$ of rate of penetration used in field static cone penetration test. Penetration tests were conducted up to a penetration depth of 300 mm; however test results up to 200 mm (< 10D, where *D* is diameter of cone) were considered in the analysis to avoid boundary effect of container bottom. The cone penetration test set up and test results are shown in Figs. 6-8.

## 7. Test results and discussion

In order to examine the effectiveness of traveling pluviator on *RD* and uniformity of sand bed, tests were conducted controlling *DI* and *HF*. For Grade II sand, pluviation using 4 mm dia. orifice resulted in no flow taking place through the orifice. Whereas, for an orifice of dia. greater than 10 mm, the sand particles were accumulated on diffuser sieves before pluviated to sand bed. This prevents continuous and uniform sand pluviation and hence, for grade II sand, experiments were conducted using orifice of dia. ranging from 5 mm to 10 mm orifice. For orifices of dia. 5 mm to 10 mm, *DI* in the range of 0.5731 to 4.0542 g/cm$^2$/sec and varying the *HF* from 2.5 cm to 30 cm, the *RD* of sand bed is obtained in the range of 45 to 100%. As presented in Fig. 4, pronounced effect of *HF* in the range of 2.5 cm to 5 cm was observed on the *RD*. Considering all orifices in the range of 5 mm to 10 mm, increase in *HF* from 2.5 to 5 cm results in increased *RD* from 43% to 93%. Whereas, increase in *HF* from 5 cm to 15 cm resulted in increase in *RD* from 64.9% to 99.5%.

For Grade III sand, 4 mm orifice resulted in flow rate of 0.056 g/cm$^2$/sec; however, to prevent accumulation of sand particles on diffuser sieve, studies were restricted to 10 mm orifice size. Considering orifice sizes of 4 mm to 10 mm, *DI* in the range of 0.2798 to 5.9905 g/cm$^2$/sec, and

*RD* of pluviated sand bed in the range of 36% to 100% were achieved. As shown in Fig. 5, considering orifice size from 4 mm to 10 mm, varying *HF* from 2.5-5 cm resulted in increase in *RD* from 36% to 93%. Whereas, increase in *HF* from 5 cm to 15 cm resulted in increase in *RD* from 63.6% to 100%. A wider range of *RD* was achieved in this study compared to that achieved by Zhao *et al.* (2006).

It was observed that with increase in *HF*, there was steep increase in *RD* of sand bed for the lower range of *HF*, but its effect on *RD* of sand bed diminished with increase in *HF*, which is line with the observations from the previous studies (Vaid and Negussey 1988, Stuit 1995, Choi *et al.* 2010). Further, for the same orifice size, with increase in particle size, *DI* reduces. For *HF* in the range of 15 cm to 30 cm, minor effect on *RD* of sand bed was observed for both the sands. However, for this range of *HF*, lower *DI* were found suitable for achieving higher *RD*, this is in agreement with the observations of previous studies (Rad and Tumay 1987, Lo Presti *et al.* 1993, Zhao *et al.* 2006). This may be due to the allowance of sufficient time for sand grain hammering (Cresswell *et al.* 1999). After reaching terminal *HF* (20 cm for grade II and 15 cm for grade III) *RD* was almost constant, however, *DI* was certainly affecting the observed *RD*. It is noteworthy to observe that maximum unit weight of sand bed obtained for Grade II and Grade III using pluviation was higher than that evaluated with ASTM D4253-06, and hence it was considered as maximum unit weight in *RD* calculations as suggested by Barton and Palmer (1989).

It was observed from the results that the *PTP* is useful for obtaining consistent and repeatable sand beds for poorly graded medium to fine sand. The two main advantages of *PTP* are compactness and ease of preparation of sand beds of wide range of densities. However, more studies are warranted to further understand the effectiveness of *PTP* to prepare well graded medium and coarse sand beds. It was found time consuming to prepare large sand beds using *PTP*; hence a mechanized system may be beneficial for preparation of large sand beds.

Cone penetration tests were performed to evaluate uniformity and repeatability of pluviated sand bed. Pluviation was performed to obtain two different *RD* of sand bed for grade II (1) 59% (*HF* of 4 cm and orifice size of 10 mm) and (2) 76% (*HF* of 10 cm and orifice size of 8 mm). Similarly, grade III sand was pluviated to obtain three different *RD* (1) 45% (*HF* of 4 cm and orifice size of 10 mm), (2) 67% (*HF* of 7.5 cm and orifice size of 10 mm) and (3) 86% (*HF* of 15 cm and orifice size of 8 mm). Results of cone penetration test performed on grade II and grade III are presented in Figs. 7-8. It is observed from these figures that no resistance was offered by pluviated sand bed during initial penetration for approximately a depth 2/3 of cone height. Beyond this depth, the penetration resistance started increasing continuously in a curvilinear manner. Similar observations of no penetration resistance were also reported by Bolton *et al.* (1999), when the cone tip resistance was plotted with effective vertical stress. At lower *RD*, a little deviation in the penetration resistance of sand bed was observed. However, at higher *RD*, more uniform and repeatable sand beds were achieved using *PTP*, which disagrees with the observations of Fretti *et al.* (1995). Based on these results it can be noted that the *PTP* is successful in producing repeatable and uniform sand beds.

## 8. Conclusions

Portable traveling pluviator, designed and used in the present study consists of multiple diffuser sieve arrangement for obtaining uniform sand rain and set of orifice plates for *DI* control. In this paper, the pluviator was calibrated using two different sands, namely Indian Standard Sand Grade II and Grade III, and the following major conclusions are drawn from the study:

(1) Portable traveling pluviator is used to prepare uniform and repeatable sand beds for poorly graded medium to fine sand. Suitable combination of diffuser sieves and orifice size could be selected to prepare sand beds of a required *RD*.

(2) Using various combinations of orifice and diffuser sieves, a wide range of *RD* can be achieved in the range of 45-100% and 36-100% for grade II and grade III, respectively.

(3) Effect of *HF* on *RD* of sand bed was predominant at lower heights and it is insignificant with increase in *HF*. *RD* of 93% was achieved with just 5 cm *HF*, when orifice of dia. 4 mm were used. Almost 100% *RD* was achieved with *HF* of 15 cm. Control over *HF* was found beneficial to obtain lower relative densities. Lower *DI* was found suitable for obtaining denser sand beds, though achieving lower *DI* is time consuming.

(4) Uniformity and repeatability of pluviated sand bed using the *PTP* were checked using cone penetration test. At lower relative densities marginal variation in repeatability of sand bed was observed. However, at higher relative densities more repeatable and uniform sand beds were achieved.

(5) Portable pluviation system discussed in this paper can be further extended to reduce the time required for preparing sand bed using a mechanized system.

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