

Optimization and Parametrical Investigation to Assess the Reconstitution of Different Types of Indian Sand Using Portable Travelling Pluviator

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Abstract By using the air pluviation technique, it is aimed to achieve the desired relative density with uniform void ratio throughout the specimen in order to maintain the homogeneity and to avoid the spatial variability. Further, in order to achieve the maximum deposition intensity, a systematic optimization study has been carried out rigorously in a test tank to determine the diameter of the orifice to be employed for the sieve plates of different porosity and the number of sieve plates to be installed in the diffuser sieve sets. The study has been conducted with four different patterns of sieves with different porosity to achieve a wide range of relative densities for four different uniformly graded Indian sands. The dynamic penetrometer which is considered to be one of the cost effective instruments has been efficiently used to determine the soil resistance at various locations of the test tank for every given height of fall in order to check the uniformity of placement density throughout the sand bed. The study reveals that the sand beds of different relative densities could be achieved using different patterns of diffuser sieves at optimum sand flow rate without compromising the uniformity. The effect of height of fall as well as porosity of diffuser sieves on the relative density of different sands has been studied in detail. The deposition intensity and the

relative density obtained from the present study are compared with the values available in the literature.

Keywords Deposition intensity · Diffuser sieves · Height of fall · Orifice opening · Porosity · Relative density · Soil resistance · Uniformity

1 Introduction

Most of the geotechnical structures are investigated experimentally in the laboratory by performing physical modeling, either through the model scale testing in case of $1g$ or through the centrifuge in case of ‘ N ’ g , where g is the acceleration due to gravity. Most of the testing facilities in various research laboratories across the globe are not equipped with the gigantic centrifuge, not because of the technicality involved, but simply because of the cost involved in creating the same. On the other hand, because of the low stress level observed in the soil while performing the model scale testing with the boundary of 0.5–1 m, the various test results generated are adversely affected compared to that of the real time field situation. Consequently, performing large scale model testing with a considerably larger domain size has been necessitated in order to take a middle path amidst the centrifuge and the small scale models. Further, the results obtained from the large scale model testing would also be quite reasonable in correlating the actual field condition.

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However, the biggest challenge in front of the researchers is to prepare the soil specimen of such a large quantity to accommodate the tank of volume 8–10 m³ without any change in its mechanical properties. The most widely used 1g laboratory testing facilities for analyzing the foundation systems and retaining walls are generally performed with dry cohesionless soils. To ensure the repeatability and reproducibility of the test results, it is important to reconstitute the soil sample of desired density within a stipulated time frame without altering its physical properties and mechanical behavior, for every given test to be performed in a series of experiments.

Three basic necessary conditions to prepare the sand sample can be identified as (1) to achieve the desired density, (2) to maintain the uniformity in the density throughout the specimen, and (3) to adopt the optimized rate of deposition intensity (DI), where the DI can be defined as the mass of the sand particles getting deposited per unit area of the test tank per unit time. Among the two majorly used methods such as (1) layer by layer tamping and compaction or vibration, and (2) air pluviation either by stationary pluviators or portable travelling pluviators, generally the air pluviation techniques have been recognized to produce the reconstituted sand sample in a more appropriate way compared to the compaction technique (Rad and Tumay 1987; Cresswell et al. 1999; Lagioia et al. 2006) without any particle breakage and also meeting all the basic necessary conditions.

The test set up considered in the current study as shown in Fig. 1 is in line with those reported by Fretti et al. (1995), Zhao et al. (2006) and Dave and Dasaka (2010). The most challenging task for a geotechnical engineer is to prepare the homogeneous sand bed with uniform void ratio throughout using such advanced pluviators, which needs sufficient information about the various parameters involved to optimize the design of the components used. Using the air pluviation technique, it is aimed to achieve the desired density with uniform void ratio throughout the specimen of four different Indian sands (Ennore, Quartzanium, Kalpi and Bhadar) to maintain the homogeneity as well as to avoid the spatial variability. Various parameters such as the diameter of the orifice and the holes, the number of holes in the sieve plate, the pattern of the hole arrangement in the sieve plate, the spacing between the sieve plates, the orientation angle between the sieve plates need to be optimized in order

to prepare the sand sample. Further, the preparation of the large-sized sand sample involves the time factor in the form of DI which also needs to be optimized. The terms such as (1) deposition intensity, (2) relative density and (3) soil resistance are used as the scaling mode to optimize the three necessary and essential conditions as mentioned earlier.

2 Materials and Methods

2.1 Materials

It has been reported by several researchers (Vaid and Negussey 1984, 1988; Kuerbis and Vaid 1988; Lagioia et al. 2006) that in case of well graded sands, the pluviated samples may not be homogeneous due to falling back of the finer particles on account of their smaller velocity and lesser impact energy as compared to those of coarser particles. Hence, it is generally recommended to select the uniformly graded particle distribution without significant amount of fines content in order to prepare the sand bed which is expected to be well mixed without any particle segregation. The traveling pluviator apparatus is reported to be best suitable for poorly graded medium to fine sand in order to prepare uniform and repeatable sand beds (Dave and Dasaka 2012). Hence, four different sands (Ennore, Quartzanium, Kalpi and Bhadar) of same gradation (0.5–1 mm) collected from different parts of India are considered in the present study, out of which the first two are standard sands of grade—II as per IS 650:1991, whereas the last two have been collected from the river beds of the Yamuna river at Kalpi (Uttar Pradesh) and from the Bhadar river at Jasdhan (Gujarat), respectively. The river sands used in the present study are eventually sieved (retained on 425 μ m and passing through 1 mm sieve) to obtain the grade—II specification as per IS 650:1991. The novelty behind the adoption of different sands of same grade is to study and compare the details of standard sand with those of the river sand using the pluviation mechanism for preparing the large sand bed for model scale testing. The grain size distribution of different sands adopted in the present study is plotted in Fig. 2a, whereas Table 1 provides the physical properties of various sands used in the present investigation. The minimum and maximum void ratio are evaluated following ASTM D4253 (2014) and ASTM D4254 (2006), respectively. In order to provide an

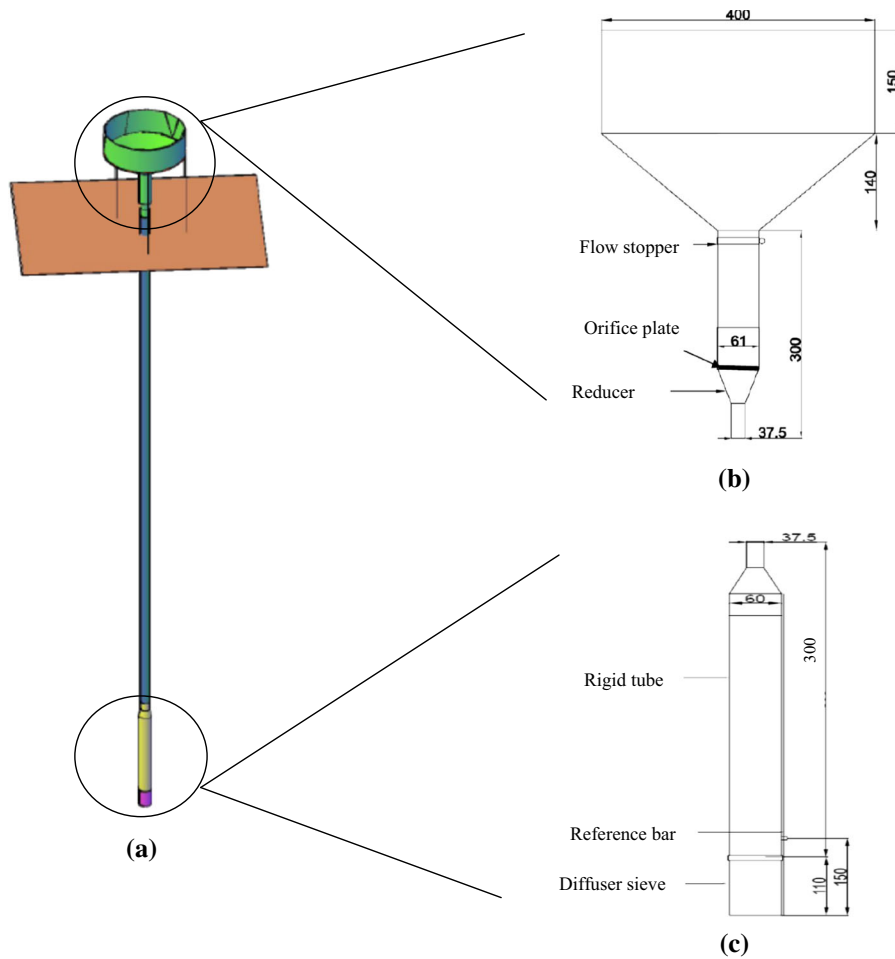


Fig. 1 a, b, c Description of various parts of air pluviation apparatus. Line sketch not to scale. All dimensions are in mm

insight to the strength characteristics, direct shear tests have been performed on different sands. Figure 2b represents the residual shear strength behavior of different sands obtained from the direct shear test at different normal stresses. The critical angle or the constant volume friction angle determined from the failure envelope at residual shear strength is found to be 26.1°, 27.4°, 27.9° and 35.3° for Quartzanium, Bhadar, Ennore and Kalpi sand respectively.

2.2 Development of Experimental Set-up with Brief Background

The apparatus considered in the present study is depicted in Fig. 1. Figure 1a shows the hopper mounted on a tripod stand over a scaffolding of height 3.5 m above the ground level along with the flexible

pipe of diameter 38 mm, where the varying length of the pipe transports the required material from the hopper to the rigid tube. Figure 1b represents the schematic details of the hopper consisting of the cylindrical component of diameter 40 cm and height 15 cm followed by a truncated inverted conical portion having the base diameter same as that of the cylindrical component and height of 14 cm with a tapering slope of 1:1.2. A thin hollow rigid tube of height 20 cm is attached to the hopper along with the flow reducer of height 10 cm beneath it. All the three connections (cylinder-cone joint, cone-thin rigid tube joint and rigid tube-reducer joints) are properly welded using shielded metal arc welding method. Shutter opening is added to the thin rigid tube in order to facilitate the stoppage of flow during the halt period. A 1 mm square mesh is placed at the cylinder-cone

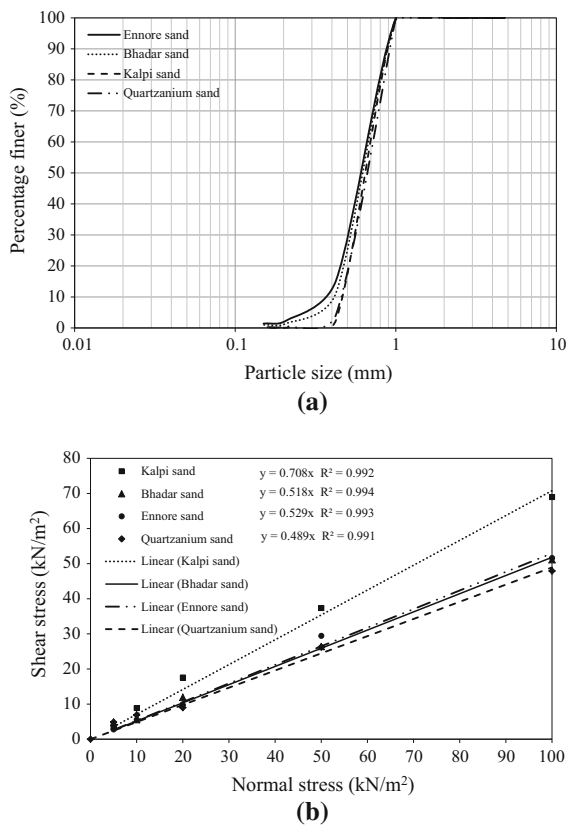


Fig. 2 **a** Grain size distribution and **b** residual shear strength envelope of different sands

joint in order to prevent the entry of foreign materials into the hopper chamber. An orifice plate (a solid plate with a central circular opening) is placed at the junction of the rigid tube-reducer joint in order to

control the flow of the material moving from the upper to the lower level. The entire hopper is painted using powder coating in order to avoid any friction generation between the sand particle and the hopper wall. Figure 1c shows the rigid pouring tube consisting of expander followed by the thin rigid tube of 30 cm to which the diffuser sieve component is attached. The diffuser sieve has the capacity to house 9 sieve plates at a spacing of 10 mm. The sand particles departed from the bottom most sieve of the diffuser component fitted inside the rigid pouring tube to the sand bed disperse through a height, H using the calibrated reference bar.

The orientation between any two sieve plates with respect to the vertical axis is generally optimized at an angle of 45° (Rad and Tumay 1987; Cresswell et al. 1999; Dave and Dasaka 2012). The spacing between the sieve plates has been adopted as 6 mm for the initial portion and 10 mm for the rest by Cresswell et al. (1999), and Dave and Dasaka (2012). The optimization studies performed by Rad and Tumay (1987) reveal that no significant effect can be seen beyond the spacing of 20 mm. The number of sieve plates has been adopted as 2 (Rad and Tumay 1987), 9 (Cresswell et al. 1999), 10 (Dave and Dasaka 2012) and 12 (Abbireddy 2009). It could be inferred from the available studies, that the orientation and spacing between the sieve plates, and the number of sieve plates are optimized to achieve breaking up the sand flow by decelerating the sand particles so as to reduce its falling velocity on the bottom most sieve. This optimization is adopted in order to eliminate the effect of initial falling height of sand particles from the

Table 1 Physical properties of different sands

Physical properties	Indian sands			
	Bhadar sand	Ennore sand	Kalpi sand	Quartzanium sand
Coefficient of uniformity (C_u)	1.67	1.63	1.56	2.00
Coefficient of curvature (C_c)	0.92	0.96	0.96	0.83
Effective size, D_{10} (mm)	0.42	0.40	0.45	0.45
Average particle size, D_{50} (mm)	0.55	0.60	0.65	0.68
Soil classification/group symbol (Unified classification)	SP	SP	SP	SP
Specific gravity (G_s)	2.53	2.58	2.53	2.57
Maximum void ratio (e_{max})	0.81	0.76	0.83	0.95
Minimum void ratio (e_{min})	0.59	0.55	0.60	0.67
Maximum dry unit weight, $\gamma_{d(max)}$ (kN/m^3)	15.9	16.6	15.8	15.4
Minimum dry unit weight, $\gamma_{d(min)}$ (kN/m^3)	14.0	14.4	13.8	13.2

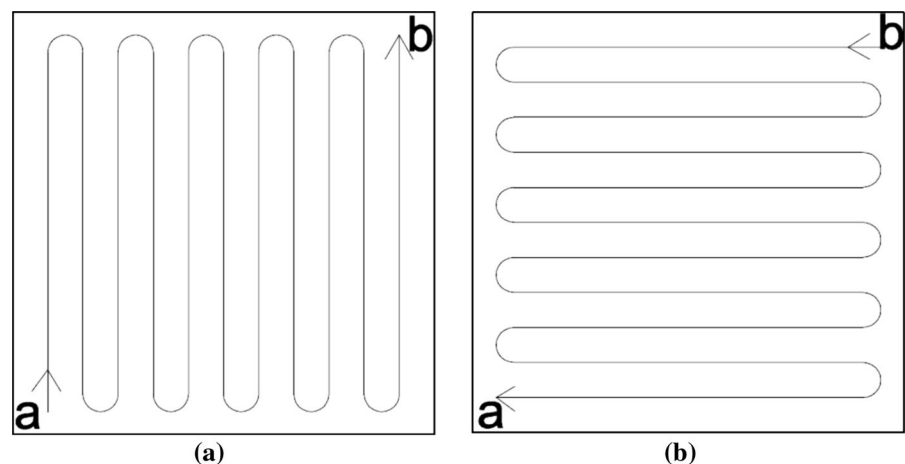
hopper to the rigid tube (Choi et al. 2010). In the present study, the orientation angle and spacing between the sieve plates have been considered as 45° and 10 mm, respectively. The traversing of movable pluviator in the preparation of sand bed adopted by Fretti et al. (1995) and Zhao et al. (2006) has resulted in negligible layering effect of the prepared sand bed. In the present investigation, the rigid tube connected to the stationary hopper through a flexible extension pipe is moved over the sand bed back and forth in alternate serpentine patterns as shown in Fig. 3.

With increase in the opening size of the hole or aperture in the sieves, the DI increases but the relative density decreases, and with respect to the pattern of the aperture arrangement in the sieve plate, evenly distributed holes across the sieve plate generally yield better relative densities (Rad and Tumay 1987). It has been evidently reported by various researchers (Rad and Tumay 1987; Vaid and Negussey 1988; Choi et al. 2010) that in case of large sand bed preparation, the most appropriate method of pluviation is to adjust the deposition intensity keeping the drop height constant in order to obtain the wide range of relative densities. Further, according to Lo Presti et al. (1992), the relative diffuser ratio which is defined as the sieve opening size to the average grain size (D_{50}) of the sand considered is recommended to be in the range of 4.4–17.6 without violating the basic assumptions made by Vaid and Negussey (1984, 1988). Hence, four different design patterns of sieves as depicted in Fig. 4 have been adopted with different aperture openings equally spaced across the cross section of the sieve plates in order to study their effect on the relative

density and in turn, the soil resistance. The details of each design pattern like effective area, porosity, number of holes and their dimensions are presented in Table 2, where the effective area is the summation of area of each aperture opening embedded in the sieve plate and the porosity is the percentage ratio of the effective area of sieves to the cross sectional area of the sieve plate.

Several researchers (Chen et al. 2001; Herrick and Jones 2002; Mohammadi et al. 2008; Alam et al. 2014) have studied the characterization of the soil sample along its depth and plan area using more efficient and cost effective tool, dynamic penetrometer in order to ensure the uniformity of mechanical properties of the soil. It has been proposed by Mohammadi et al. (2008) that the cross section of the mould used in the characterization of sand sample using the dynamic penetrometer adversely affects the results obtained and the mould diameter of greater than 0.5 m does not produce any scale effect. Hence, the tests have been carried out in the test tank of size $0.6 \text{ m} \times 0.6 \text{ m} \times 0.5 \text{ m}$ keeping the total filling volume equal to 0.18 m^3 . Thus, the study on the effect of height of fall for the respective design patterns of sieves has been necessitated to observe its effect on the relative density as well as to check the uniformity of the prepared sand bed. In the present study, the soil resistance has been obtained using Jornada dynamic penetrometer (Herrick and Jones 2002) at different locations of the test tank in order to check the uniformity of placement density throughout the sand bed as well as the resistance offered by the soil mass at different densities (Fig. 5). In order to reduce the dead

Fig. 3 a, b Traversing of rigid tube over the sand bed



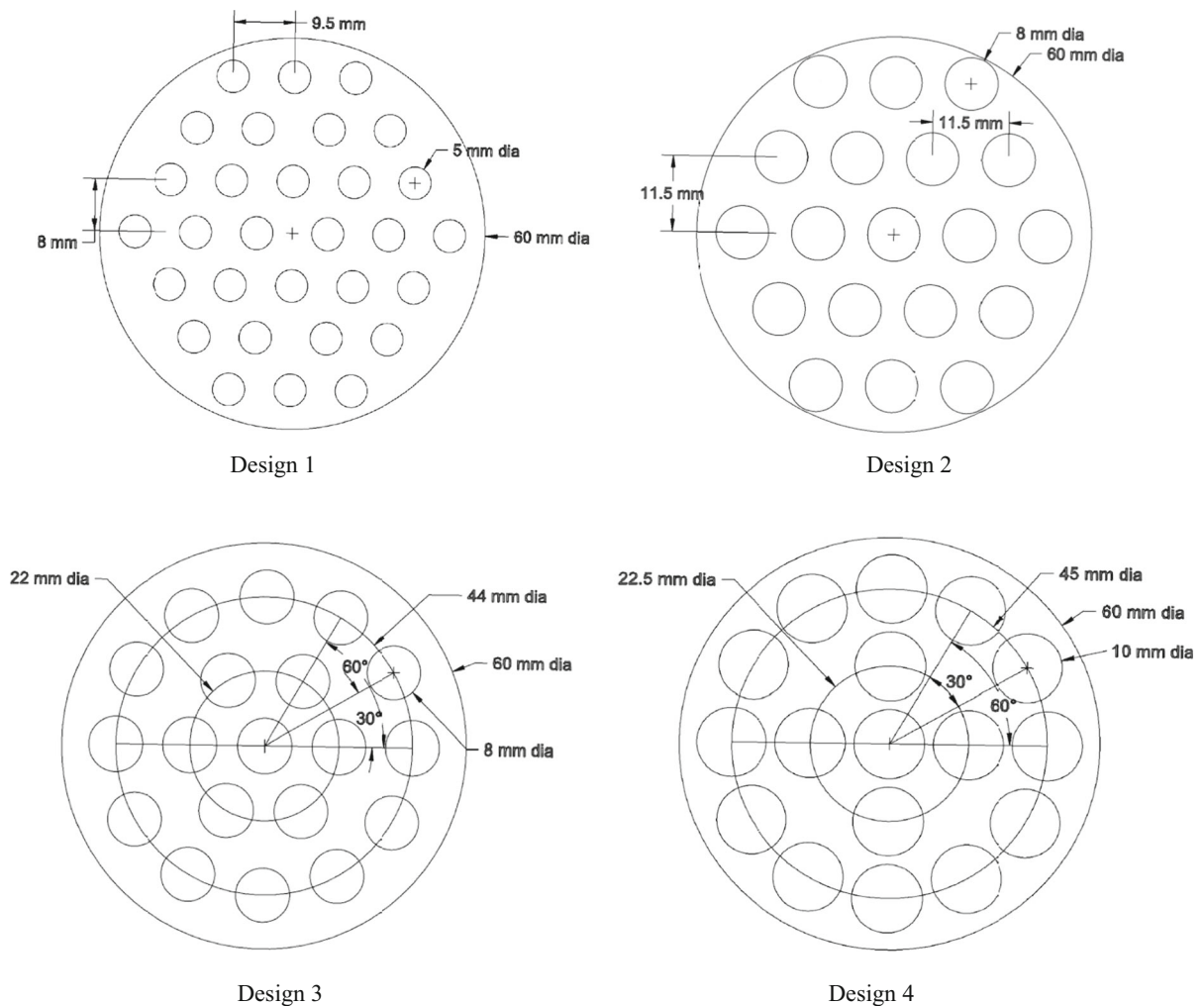


Fig. 4 Different design patterns of sieves installed in diffuser sieve set

Table 2 Details of different design patterns of sieve plates

	Number of holes	Diameter of holes (mm)	Pattern	Effective area of sieves (mm ²)	Porosity (%)
Design 1	30	5	Hexagon	589.05	20.83
Design 2	19	8	Hexagon	955.04	33.78
Design 3	19	8	Concentric	955.04	33.78
Design 4	17	10	Concentric	1335.18	47.22

weight of the instrument, a hollow aluminium pipe is used instead of a solid steel bar and a solid aluminium disc for the circular strike plate. The cone head, adjustable stopper and hammer are made of stainless steel, brass and mild steel respectively. The hollow

tube along with the strike plate weighs as low as 450 gm, whereas the adjustable stopper and the cone head weigh 50 gm each. The hollow aluminium pipe is graduated with a least count of 1 mm in order to ease the fixing of movable stopper as well to measure the

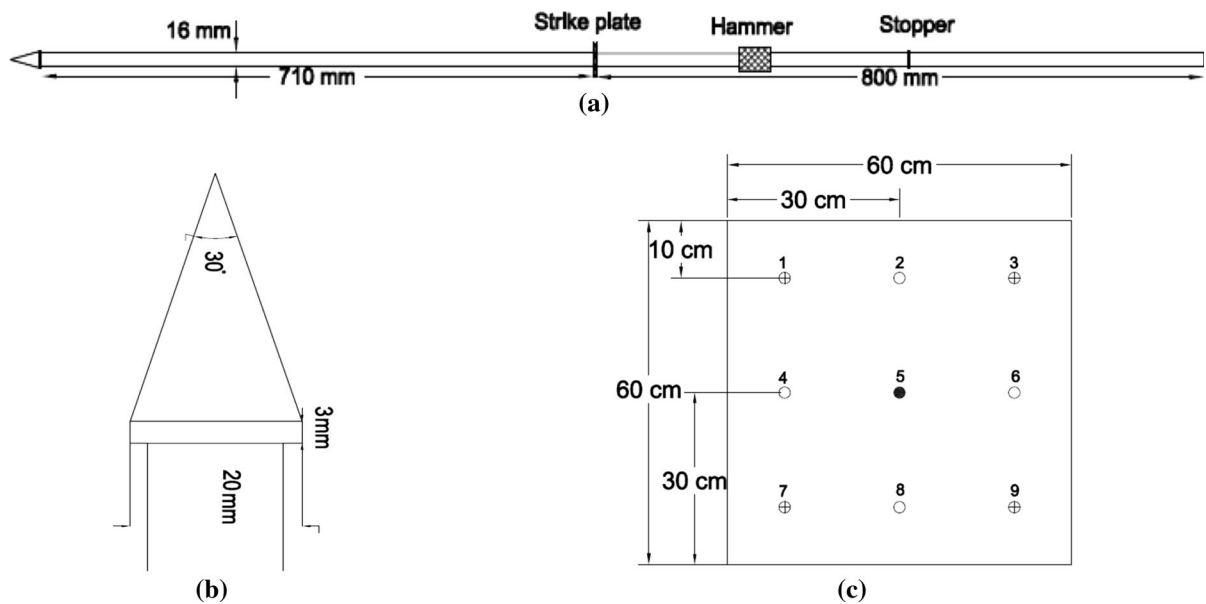


Fig. 5 **a** Jornada impact dynamic penetrometer, **b** cone head used in Jornada impact dynamic penetrometer, **c** penetration test locations in the tank

depth of penetration of the instrument inside the soil mass. The calculation for the soil resistance has been made by following the method explained by Herrick and Jones (2002). Figure 5c shows the plan view of different penetration test locations in the tank where point 5 is referred as the centre point, points 1, 3, 7 and 9 as the corner points and 2, 4, 6 and 8 as the peripheral points.

2.3 Optimization Study for Orifice Opening and Number of Sieve Plates

In order to regulate the flow of sand particles from the stationary hopper to the movable rigid tube without any choking in the flexible tube as well as clogging in the diffuser sieves, a manually changeable orifice plate in the hopper is necessary, which ensures continuous flow from the hopper to the sand bed without any intermittency. It can be clearly observed from the work reported by Zhao et al. (2006) that the flow rate increases with increase in the opening of the orifice. Similar trend has also been observed by Dave and Dasaka (2012). It has been reported by Dave and Dasaka (2012) that at significantly smaller openings of the orifice, intermittent or even no flow of sand particles can be observed; whereas beyond a particular opening,

clogging of sand particles in the diffuser sieves can be seen. Hence, it can be extrapolated that beyond a particular opening of the orifice, the deposition intensity is borne to decrease. Furthermore, it is obvious that the optimized value of the diameter of the orifice depends on the size of the sand particles used in the study as well as the effective area of sieves installed in the diffuser component through which the sand particles rain over the sand bed. The above inference results in intuiting the optimization of the diameter of the orifice plate for different sieve designs and for various sands considered in the present study. It has been reported by Gade et al. (2013) that as the diameter of the orifice increases, the DI increases with a reduction in the relative density. However, there exists optimum deposition intensity or pouring rate at which the maximum density can be obtained (Miura and Toki 1982; Cresswell et al. 1999; Lagioia et al. 2006). In case of large sand bed preparation, the ultimate aim is to achieve much higher filling rate for the test tank without compromising the uniformity of the sand bed. It has also been observed by Gade et al. (2013) that, as the number of sieve plates increases for a particular orifice diameter, the DI decreases and hence the relative density increases. Similar observation has

also been reported by Rad and Tumay (1987). Hence, in order to produce a uniform sand bed at an optimized DI, it is felt to optimize the number of plates to be employed in the diffuser sieve sets.

A systematic optimization study has been carried out rigorously in a mild steel tank whose boundaries are rigid enough so as not to yield under the at-rest earth pressure exerted by the soil mass. Various diameters of the orifice are chosen in the present study such as 8, 10, 15, 20, 25 and 30 mm. It is worth mentioning here that the definition of the deposition intensity considered in the present study slightly differs from that reported by other researchers (Lo Presti et al. 1993; Fretti et al. 1995; Gade et al. 2013) who have incorporated the effective area of the openings in the sieve plate instead of the plan area of the test tank. However, it is felt that the representation of DI with respect to the area of the test tank may provide more fruitful information to understand the filling rate in case of large sized test tanks. The DI is determined as the ratio of the mass (gm) of the sand collected and weighed either in half cycle or full cycle divided by the cross-sectional area (cm^2) of the tank where the sand gets deposited to the time (s) recorded to complete the half cycle or full cycle respectively, where the half cycle represents the movement from point *a* to *b* as shown in Fig. 3 and the full cycle refers the movement from *a* to *b* and back to *a*. The time required to complete one full as well as half cycle has been noted using stop watch with the least count of (1/10)th of a second. The sand deposited in the test tank after the completion of both full as well as half cycle has been collected and weighed. Eventually the reported DI has been calculated by averaging half and full cycle movement of the rigid tube over the test tank for several times. Figure 6 represents the variation of DI with D_o/D_{50} ratio for four different design patterns adopted in the present study for all four sands considering the number of sieve plates to be equal to 4 and the height of fall is 15 cm, where D_o is the diameter of the orifice. With the aim of capturing the post peak behavior in the variation of DI, the orifice opening for the different design patterns has been varied differently such as 8–25 mm for design 1, 10–30 mm for design 2 and 3, and 15 mm to without any orifice for design 4. It can be noted from Fig. 6 that with increase in the orifice opening, the flow pattern shifts from no flow or very less flow condition to the clogging of sand grains in the diffuser sieves for all

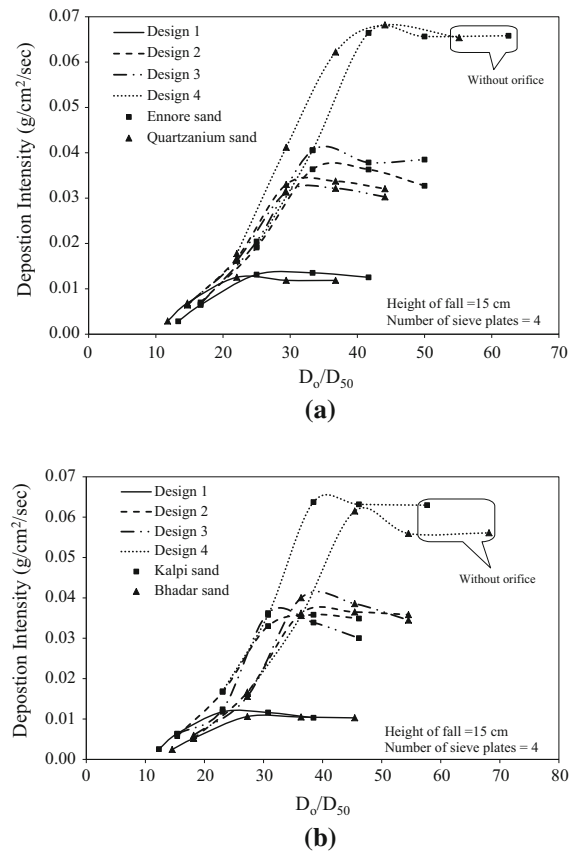


Fig. 6 Optimization of diameter of orifice plate for different sieve patterns for **a** Ennore and Quartzanium sand, **b** Kalpi and Bhadar sand

types of sand. As the diameter of the orifice increases, significant increase in the inflow can be observed and as a result the DI increases. However, beyond a particular critical diameter of the orifice, when the inflow exceeds the outflow, the sand particles are found to be accumulated on the diffuser sieves before getting deposited over the sand bed, which can be established from the trend shown in Fig. 6, where the DI decreases or becomes almost constant with further increase in the orifice opening. Hence, the above optimization results in determining the critical diameter of the orifice for each of the design patterns of sieves adopted for different types of sand. It can also be observed that as the effective area of the sieve opening increases, the critical diameter of the orifice shifts further i.e., increases. It could be ascertained that the DI is found to increase for a particular orifice opening as the effective area increases. Care has been taken to choose the pre-peak points on the curve for

obtaining the optimized orifice opening corresponding to the maximum DI achieved without compromising the uniformity of the sand bed, which can be listed as: 15 mm for design 1, 20 mm for design 2 and 3 for all types of sand, whereas in case of design 4 the value is 25 mm for Kalpi, Bhadar and Ennore sand and 30 mm for Quartzanium sand. It could be understood from the aforementioned observation that the optimized area of orifice opening should be in the range of one-third to half of the effective area of the diffuser sieves. It is worth noting here that no significant difference in the variation of optimized orifice opening is observed among the different types of sand. This might be attributed to the same gradation and close magnitude of specific gravity, G_s of sands used in the present study.

Using the critical orifice opening for respective sieve designs and different types of sand employed in the present study, the number of sieve plates to be housed inside the diffuser sieves has been optimized. For obtaining the optimized number of plates, similar studies have been conducted by varying the number of plates to 1, 3, 5 and 9 spaced at 10 mm interval where each plate has been rotated by 45° with respect to the vertical axis. Table 3 presents the details of observed DI with respect to the number of sieves for all four types of sand, where the height of fall has been maintained as 15 cm. From the test results, it can be observed that for all types of sand and sieve designs 1, 2 and 3, the arrangement with 3 plates is found to provide the maximum DI without sacrificing the uniformity. It has been observed during the test that when 9 sieve plates are used, the sand particles start getting accumulated on the top most diffuser sieve which results in lesser DI. Whereas, in case of 1-plate arrangement, it results in clogging on the bottom most part of the diffuser sieve since the sand particles are not decelerated. However in case of design 4, higher DI is obtained with 9-plate arrangement compared to 3-plate arrangement. This may be attributed to the formation of higher porosity due to some critical orientation of sieve plates in 9-plate arrangement. However, the increase in DI with increase in the porosity might lead to non-uniformity of the sand bed or to the reduced relative density. Therefore in case of design 4, 3-plate arrangement is chosen for further study in spite of higher DI is observed with 9-plate arrangement. The plan view of the arrangement with 3 sieve plates oriented at 45° to each other for all the

sieve designs are shown in Fig. 7, which indicates how the sand particles traverse after entering the diffuser component in the rigid pouring tube. The velocity of the sand particles gets retarded before getting deposited over the sand bed in order to avoid the effect of initial falling height of the sand grains as discussed earlier.

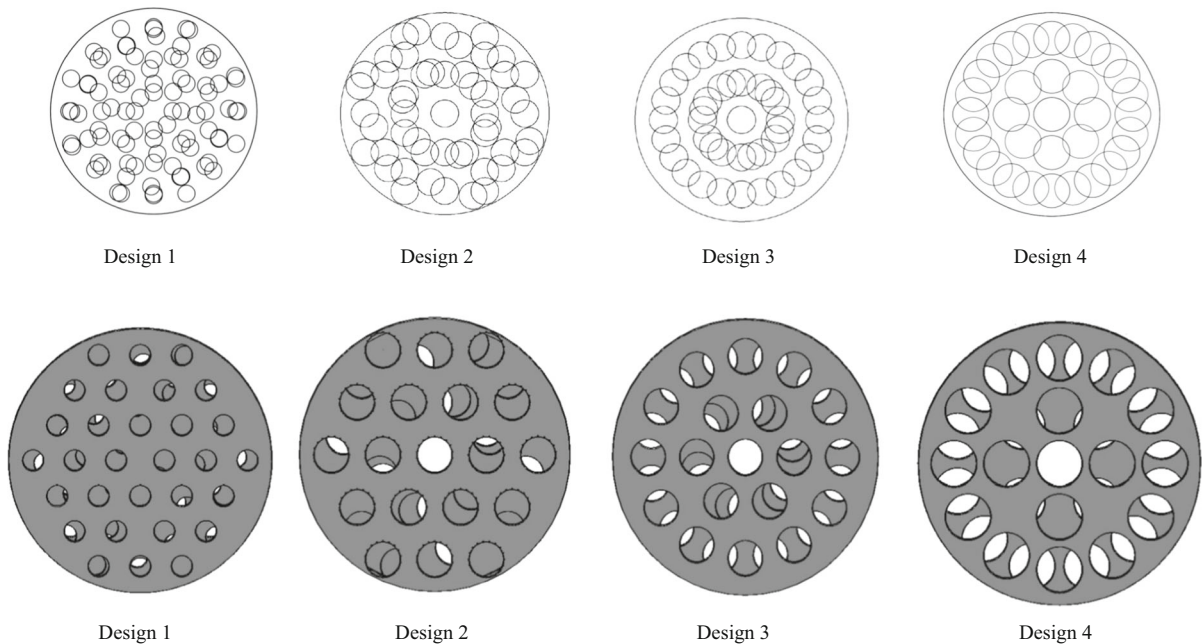
3 Results and Discussion

After performing an exhaustive optimization study on the diameter of the orifice and the number of sieve plates to be employed for different sieve designs and for various types of sand, further studies are performed to explore the effect of the height of fall on the relative density and the soil resistance. After filling the tank using the air pluviation methodology with the optimized orifice plate and the number of sieve plates to be employed for the respective sieve designs for various chosen sands, the tank is evacuated and the total mass of the soil is weighed after each test in order to determine the bulk dry density.

Figure 8 shows the variation of the relative density, determined as per ASTM D4254 (2006), with the height of fall for different sieve designs for different sands. It could be conceived from these plots that the relative density increases with increase in the height of fall. As the height of fall of the dispersing sand grains increases, the impact velocity keeps on increasing exponentially up to a certain height until the terminal velocity of the particle is reached beyond which it becomes constant, i.e., as the velocity of the particle increases, the impact energy increases resulting in enhanced relative density up to the terminal height beyond which the relative density becomes independent of the height of fall. Similar observations have been made by several other authors such as Kildalen and Stenhamar (1977), Vaid and Negussey (1984, 1988), Lagioia et al. (2006), Choi et al. (2010), and Dave and Dasaka (2012). It has been also observed by various researchers (Rad and Tumay 1987; Lo Presti et al. 1992; Cresswell et al. 1999; Lagioia et al. 2006; Dave and Dasaka 2012) that with the help of pluviation technique, the maximum density of sand may increase more than the regular codal recommended value by varying the flow rate, the height of fall and the porosity of the sieve plate. It is worth mentioning here that in the current study, the height of

Table 3 Details of DI for different number of sieve plates and types of sand

Material	Number of plates	Deposition intensity (g/cm ² /s)			
		Design 1	Design 2	Design 3	Design 4
Ennore sand	1	0.01148	0.03348	0.04003	0.04874
	3	0.01470	0.04061	0.04143	0.06257
	5	0.01365	0.04021	0.04029	0.06204
	9	0.01313	0.03742	0.04002	0.06962
Bhadar sand	1	0.00924	0.02807	0.03067	0.05412
	3	0.01664	0.03423	0.03660	0.06082
	5	0.01078	0.02945	0.03282	0.06063
	9	0.00954	0.03254	0.03265	0.06228
Kalpi sand	1	0.00977	0.02857	0.03180	0.05019
	3	0.01221	0.03520	0.03545	0.05533
	5	0.01153	0.03380	0.03326	0.05516
	9	0.01050	0.03352	0.03183	0.06709
Quartzanium sand	1	0.01288	0.03119	0.03270	0.05071
	3	0.01411	0.03740	0.03514	0.06239
	5	0.01346	0.03563	0.03382	0.05990
	9	0.01375	0.03042	0.03275	0.06709

**Fig. 7** Plan view of 3-plate arrangement in different design sieves oriented at 45°

fall could not be increased beyond 50 cm due to some limitation in the present experimental set-up. Therefore, the saturation point, i.e., the terminal height at which the relative density becomes almost constant could be observed in design 1 and 4 for few sands used

in the study and not in the case of design 2 and 3. However, no significant difference in the relative density at lower height of fall could be observed between design 2 and 3 in case of river sands (Kalpi and Bhadar). Whereas, in case of processed sand

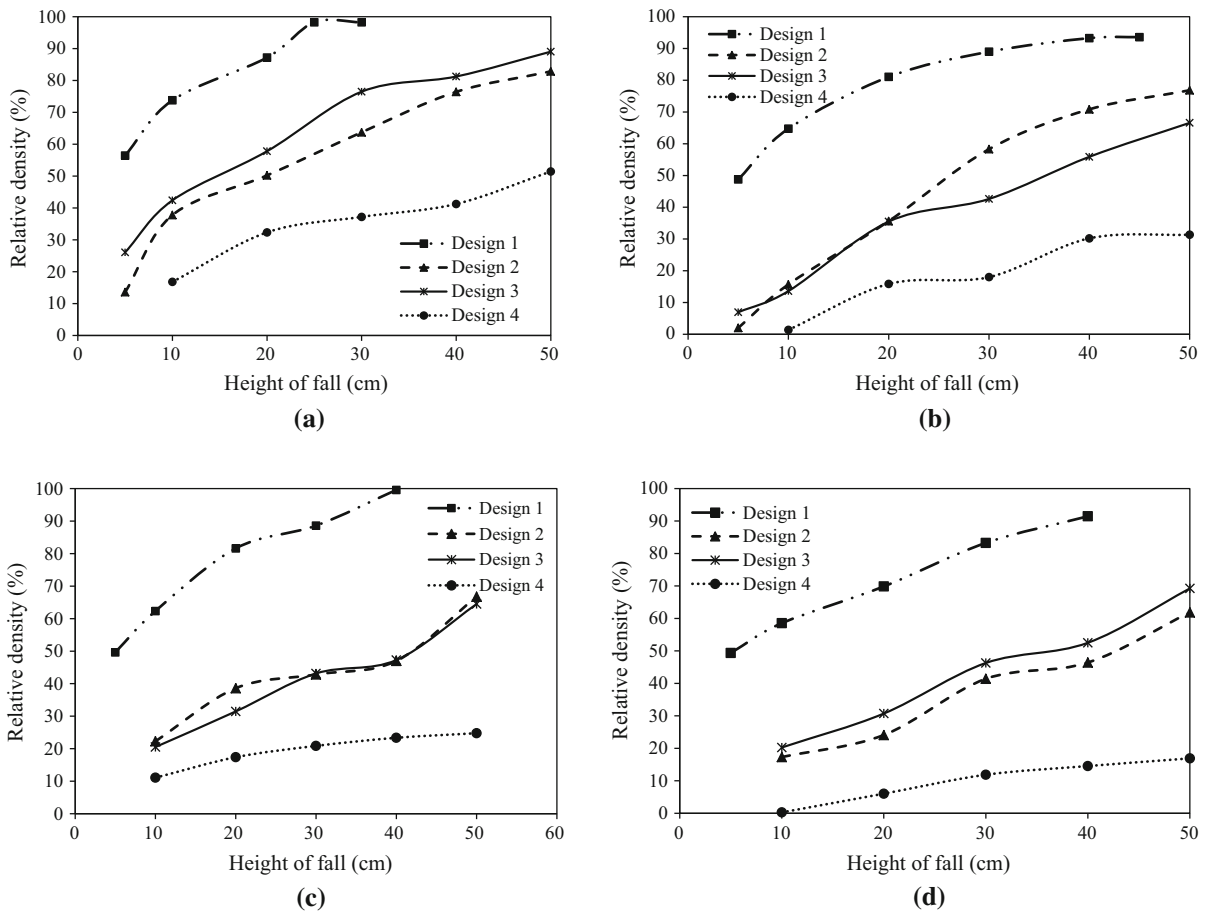


Fig. 8 Variation of relative density with height of fall for **a** Quartzanium sand, **b** Kalpi sand, **c** Bhadar sand, **d** Ennore sand

(Ennore and Quartzanium), design 3 is found to fetch slightly higher relative density than design 2. It can be observed that design 1 yields relative densities in the range of dense to very dense, design 2 and 3 produce between loose and dense, whereas very loose to loose state can be obtained using design 4 in almost all sands. It can be seen that in design 1, the relative density may increase beyond 100 % with increase in the height of fall; however it may also depend on the particle characteristics like shape, size, mineralogy, particle density etc., which are found to be beyond the scope of this paper. The current study also reveals that design 4 is capable of producing more porous soil structure of very low relative density with a void ratio close to e_{max} .

It can be observed that the sieve plates with least porosity produce much higher relative densities, whereas the higher porous sieve plates result in

significantly lower relative densities. Figure 9 depicts that for a particular height of fall, the relative density decreases with increase in the porosity of diffuser sieves i.e., higher the porosity, greater is the DI and hence, there is a drop in the relative density. The effect of DI with respect to the relative density has also been observed by Lagioia et al. (2006). In addition, it has been reported by Gade et al. (2013) that no sieve plate (i.e., 100 % porosity) arrangement results in much higher relative density compared to that obtained with sieve plates installed in the diffuser sieves. Hence, there exists a critical porosity beyond which the relative density starts increasing with increase in the porosity but at the cost of uniformity of the sand bed.

In order to determine the soil resistance as well as to have a check on the uniformity of the sand bed both horizontally as well as vertically, the dynamic penetrometer has been employed to determine the depth of

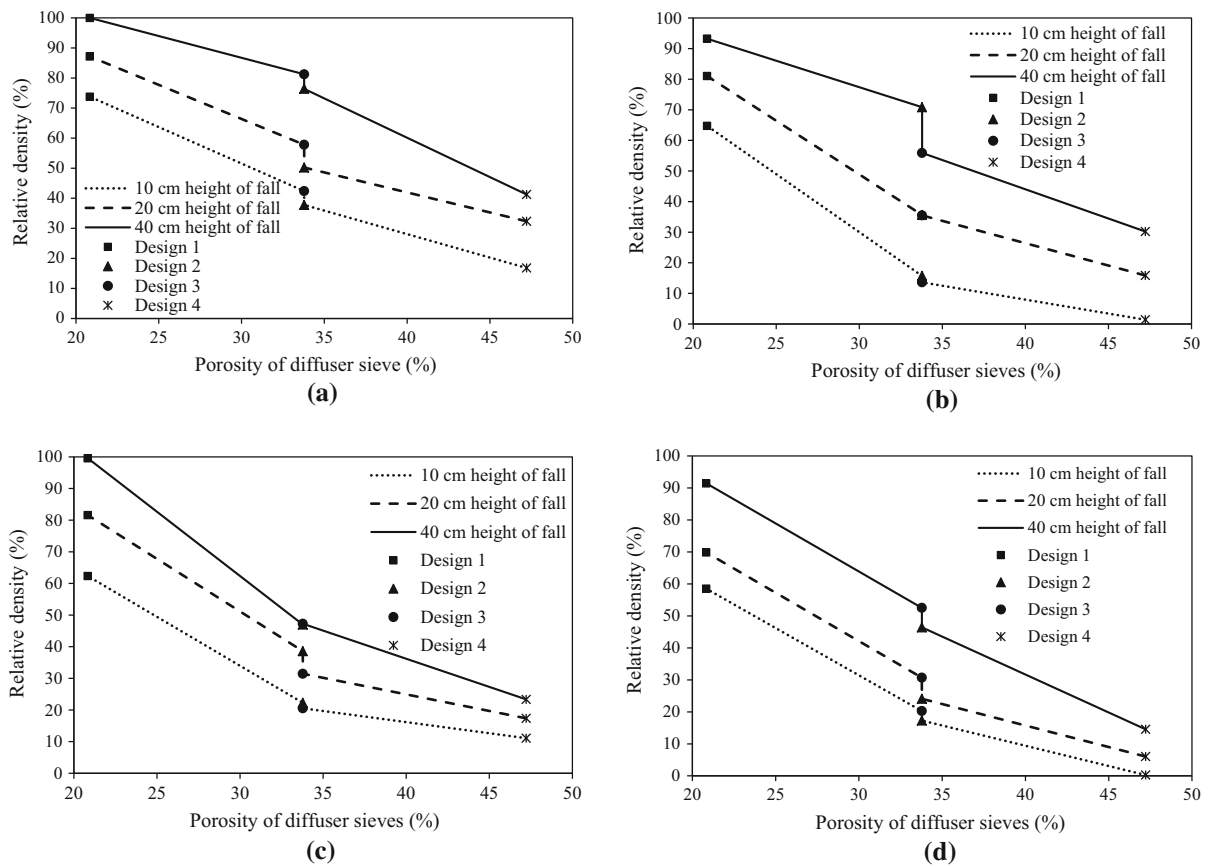


Fig. 9 Variation of relative density with porosity of diffuser sieves for **a** Quartzanium sand, **b** Kalpi sand, **c** Bhadar sand, **d** Ennore sand

penetration at various locations as mentioned in the previous section. The variation of soil resistance with the height of fall is reported in Fig. 10 for each design pattern adopted in different types of sand. The mass (m) of the hammer is kept as 1.7 kg for design 1 and as 1 kg for design 2, 3 and 4 for all sands. The height of drop of the hammer has been varied between 10 and 40 cm depending on the expected range of sand densities. The soil resistance measured at the center, peripheral and corner locations of the test tank ensures the uniformity of the sand bed prepared using different sieve patterns as not much scattering is observed between the mean resistance value and those observed at different locations. Figure 11 shows the variation of the soil resistance with the relative density of the different types of sand considered in the study. It can be observed that there is almost linear relationship between the soil resistance and the relative density of the prepared sand sample which is concurrent with the

results reported by Alam et al. (2014). It is worth noting here that the soil resistance obtained from the aforesaid procedure cannot be directly correlated to the angle of internal friction of the respective sand at different relative densities.

4 Comparison

In Table 4, the magnitude of DI determined for Ennore sand of same grade using conventional calculation process is compared with that reported by Dave and Dasaka (2012) and Gade et al. (2013) for a particular set of orifice opening in design 1. The present values of DI are found to be in good agreement with the results provided by Dave and Dasaka (2012) and Gade et al. (2013). In addition, a comparison is made for the relative densities at different height of fall with design 1 sieve pattern employed for Ennore sand. Figure 12

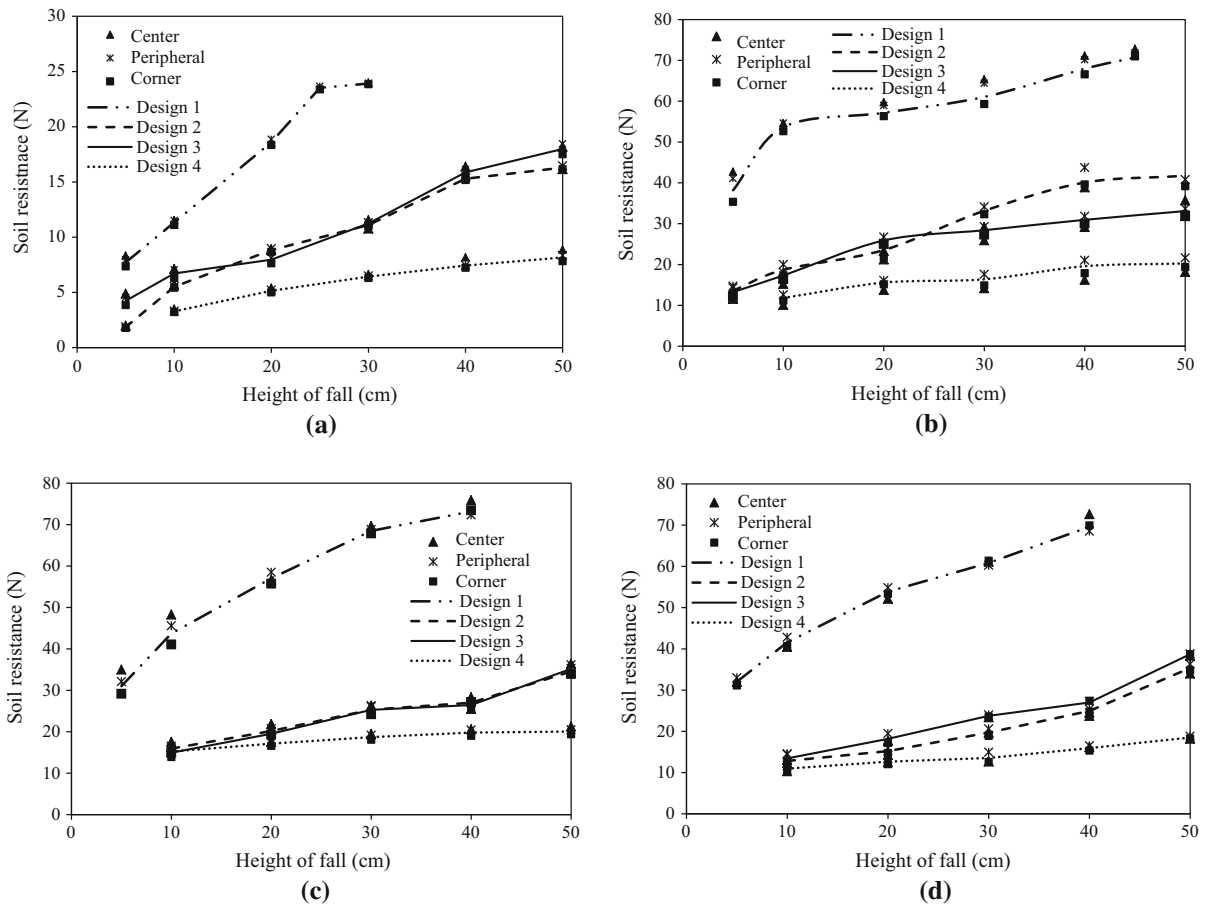


Fig. 10 Variation of soil resistance with height of fall for **a** Quartzanium sand, **b** Kalpi sand, **c** Bhadar sand, **d** Ennore sand

depicts the comparison of present magnitudes of relative density with those reported by Gade et al. (2013) where the filling mould capacity has been considered as $3.213 \times 10^{-3} \text{ m}^3$ against the filling volume of 0.18 m^3 considered in the present study. In the present investigation, the orifice of 15 mm diameter along with design 1 sieve pattern and 3-plate arrangement is found to be optimized for the maximum DI. Hence, the present magnitudes of relative density obtained with 15 mm orifice and 3-plate arrangement are compared with the results given by Gade et al. (2013) with 12 mm orifice opening for 2 and 4 sieve plates. A significant difference in the results can be observed since the DI increases i.e., the relative density decreases up to the critical point with increase in the orifice opening. However, the present trend is found to be almost similar to that reported by Gade et al. (2013).

5 Conclusions

In the present study, an attempt has been made to prepare and reproduce large volume sand specimens for large scale model testing facility where the stress level is expected to be in the comparable range with that observed in the field by using air pluviation technique. Reconstitution of sand bed is vital and important in case of model scale testing in order to produce the results ensuring repeatability and reproducibility. Without compromising the uniformity of the sand bed, a detailed procedure is presented for preparing sand beds of large volume wherein wide range of densities could be achieved using different sieve plates whose aperture opening and their distribution along the plate have been varied. The study has been performed on four different patterns of sieve for four different uniformly graded Indian

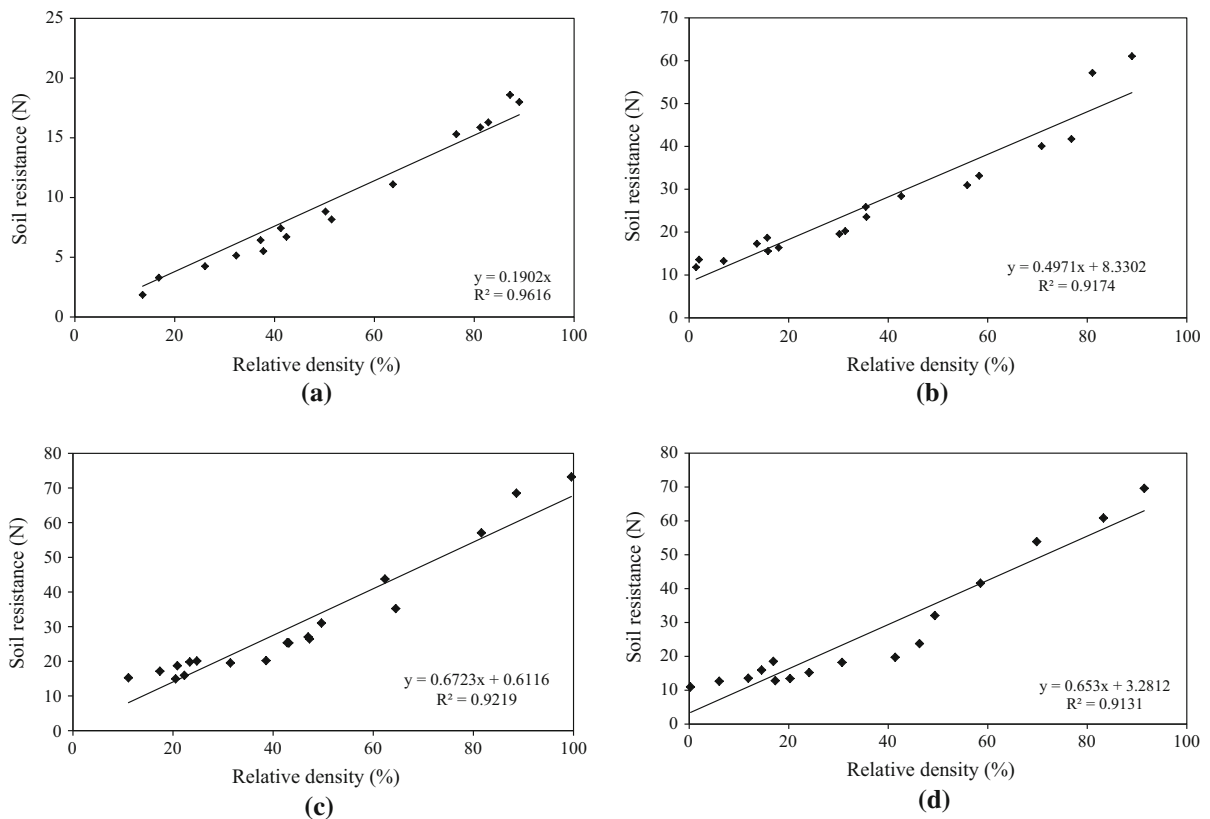


Fig. 11 Variation of soil resistance with relative density for **a** Quartzanium sand, **b** Kalpi sand, **c** Bhadar sand, **d** Ennore sand

Table 4 Comparison of DI for design I sieve pattern in case of Ennore sand (grade-II)

Size of orifice (mm)	DI (as per usual definition) ($\text{g}/\text{cm}^2/\text{s}$)		
	Present study	Dave and Dasaka (2012)	Gade et al. (2013)
8	1.7354	1.9556	1.8570
10	3.9382	4.0542	3.6900
15	8.0391	–	11.5290

sands. In order to achieve the maximum DI, a systematic optimization study has been carried out to determine the diameter of the orifice to be employed for the sieve plates of different porosity and the number of sieve plates to be installed in the diffuser sieve sets. The study reveals that the optimized area of orifice opening should be in the range of one-third to half of the effective area of the diffuser sieves and the arrangement with 3 plates is found to provide the maximum DI for all types of sand and sieve designs without sacrificing the uniformity. It can be noted that the relative density

increases with increase in the height of fall for all types of sand and is expected to become constant at greater height of fall. For a particular height of fall, the relative density decreases with increase in the porosity of diffuser sieves i.e., higher the porosity, greater is the DI and hence, there is a drop in the relative density. It can be observed that there is almost linear relationship between the soil resistance and the relative density of the prepared sand sample. Comparison of DI and relative density with respect to the height of fall is found to be in good agreement with the available literature.

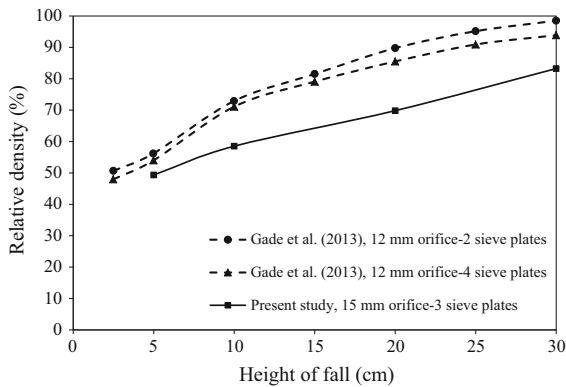


Fig. 12 Comparison of present study with Gade et al. (2013) for design I sieve pattern in Ennore sand

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