ORIGINAL RESEARCH

# Relative density of sand in physical modeling using multi-curtain pluviator

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**Abstract:**

The physical modeling of homogeneous sand with specific relative density has an important role in studying the behavior of cohesionless soils in the geotechnical engineering. In this research, a new method i.e. multi curtain pluviator, based on the air pluviation method, has been developed. Traveling pluviator with one, two, three, and four longitudinal slits on pluviation plates, have been used to prepare large-scale sand specimens. The effects of different parameters such as the number of longitudinal slits, pluviator traveling speed, falling height of sand on the relative density of a Firuzkuh sand (#161) have been considered. In this method, a wide range of relative densities can be obtained. The comparison of results of tests on the plats with different number of longitudinal slits showed that the increase in deposition intensity in a constant-speed pluviator with an increasing number of pluviation curtains has an insignificant effect on the relative density. investigation of different separation distance of longitudinal slits it has been demonstrated that when pluviation curtains are separated enough, it is possible to achieve the target relative densities in a shorter time and provides reproducibility of target density.

**Keywords:**
Sedimentation, multi-curtain, Models (Physical), Relative density, Traveling pluviator.

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## 1. Introduction

Providing an undisturbed specimen of sandy soils is a bothersome and costly process. Thus, the reconstruction of sandy soils at a controlled density for laboratory testing or physical modeling is a proper way to study the behavior of soils and geotechnical structures. Reconstruction of sand specimens with required and repeatable relative density has a significant and determinant role in the trustworthiness of the results of tests. Reconstruction method should have the capability to create a wide range of relative densities (for loose-to-dense sand specimens), constant void ratio throughout the sample, no segregation and crushing of sand grains, and simulation of deposition of the fabric properly (Kuerbis and Vaid, 1988; Stuit, 1995). The soil fabric is affected by the reconstruction process. Besides the density, the mechanical properties of soil (stress-strain behavior and Young's modulus) are influenced by the soil fabric. Hence, the modeled soil fabric in laboratory should be similar to that in the soil deposit. The fabric of coarse-grained soils depends on the shape of grains and the process of sedimentation. (Arthur and Menzies 1972; Oda 1972; Ladd 1974; Mulilis 1975; Silver et al. 1980; Miura and Toki 1982; Vaid and Negussey 1988). To control the void ratio, physical soil modeling is performed by two different methods (Butterfield and Andrawes 1970; DeGregorio 1990; Lo Presti et al. 1992; ASTM D4254-16): In the first method, the porosity changes by some techniques like tamping and vibration. This method causes heterogeneous physical properties in layers and different voids ratios along the depth of the specimen. (Hansen 1961; Lo Presti et al. 1992; Boushehrian and Hataf 2003). In the second method, the amount of void ratio is checked during the bed preparation. The pluviation method is regarded in this group. This method is divided into three categories of air pluviation, vacuum pluviation, and water pluviation (Kolbuszewski 1948; Kolbuszewski and Jones 1961; Butterfield and Andrawes 1970, Miura and Toki 1983; Lo Presti et al. 1993; Fretti et al. 1995; Stuit 1995; Cresswell et al. 1999; Vaid and Sivathayalan 1999).

The relative density and homogenous distribution of density are prominent and influential parameters in physical modeling so the pluviation method is more heeded due to the possibility of obtaining a wide range of densities, modeling in less time, creating homogenous density, and repeatability. Soil samples prepared using the tamping method, result in nonuniform density distribution, and the load required to reach a certain displacement could be 25% lower than that for samples prepared using the pluviation method. The relative density in the rained pluviation method depends on two parameters: deposition intensity and falling height of sand. The deposition intensity is defined as the mass of poured sand on the unit of area per unit time ($g/cm^2s$), measured in the outlet of the hopper. The deposition intensity depends the slits width and the traveling speed of the pluviator. By conducting a test, Lo Presti et al (1993) demonstrated that increasing the slits width, enhances the deposition intensity and decreases the density of the bed. As well, these scholars showed that an increase in the traveling speed of pluviator leads to the reduction of deposition intensity and, consequently, the increase of relative density by considering two different velocities of 3 and 8 cm/s. An increase in the traveling speed of pluviator results in the creation of a thinner layer and smoother surface based on the researchers' findings (Kolbuszewski 1948; Rad and Tumay1987; Vaid and Negussey 1988). The falling height is another determinant parameter in the obtention of the desired relative density. Assuming that the soil grains are spherical, the movement of a spherical object with the mass of $m$, while free falling in a fluid with the specific mass ($\rho$) is obtained from the equation (1) in which ($a$) is the acceleration of particle; ($g$), represents the gravitational acceleration; $A$ and $V$ are the area and volume of the particle; ($\nu$) is the velocity of the particle; and ($C_d$) is the drag coefficient related to the Reynolds number.

$$m \times a = m \times g - V \times \rho \times g - C_d \times \rho \times A \times V^2/2 \quad (1)$$

For the free fall of the particle ($\upsilon_0=0$) during sand rain, the initial acceleration is $a_0=g\ (1-V\rho/m)$. The velocity of the particle increases after the fall until reaching the terminal velocity. Then, the particle's velocity does not increase, and the acceleration of the particle will be equal to zero (a=0). The terminal velocity is higher in particles with a bigger diameter. Thus, the fall of sand from a more elevated than the terminal height does not affect the velocity of particles and energy of sediment, and, consequently, there would be no change in relative density. (Vaid and Negussey, 1984). Increasing a particle's diameter causes its velocity to rise, the particle reaches the terminal velocity at a longer distance. In the articles by Tatsuoka et al. (1982) and Kolbuszewski (1984), the height of pluviation is heeded as an influential parameter on relative density. They showed that increasing fall height had a significant effect on relative density. The highest effect of pluviation height has been in the range of 0 to 50 cm. In contrast, the pluviation height has been considered inconsequential by Mulilis et al. (1975). The pluviation height has not affected relative density at all in the article of Miura and Toki (1982). By conducting tests on Ottawa sand and Leighton Buzzard sand, Vaid and Negussey (1984) observed that the highest effect of pluviation height has been in the range of 0 to 30 cm and has a little effect on relative density in the range of 30 to 70 cm. The relative density depends on the average size of grains, soil gradation, deposition intensity, and properties of sampling mold including the diameter of mold and roughness of the mold surface.

EI-Shafee et al. (2024) showed differences in shear-wave velocity linked to fabric variations in dry-pluviated versus hydraulically deposited sands.

The accurate preparation of sand specimens with controlled relative density is a fundamental requirement in geotechnical physical modeling. To improve upon traditional air pluviation, recent studies have introduced novel equipment and techniques. One such advancement is the use of traveling curtain pluviators with variable slit configurations, which allow for greater control over deposition intensity, fall height, and discharge uniformity (Al-Yasir & Al-Taie, 2023). These systems can achieve relative densities approaching 99% by adjusting parameters such as air pressure, nozzle geometry, and the height from which sand falls. Similarly, Al-Salih and Al-Abboodi (2023) demonstrated that the elevation of the storage hopper plays a critical role in ensuring consistency in relative density throughout large-scale samples. Their results emphasized that uniformity and repeatability are attainable when mechanical controls are applied during sedimentation. Other studies have explored the mechanical aspects of multi-slit traveling pluviators, especially in controlling sample preparation time without compromising density. For example, razmkhah and et al. (2024) introduced a traveling multi-slit pluviator and revealed that increasing slit number and adjusting slit separation can regulate modeling time while maintaining consistent densities.

The accurate physical modeling of soil behavior plays a vital role in geotechnical engineering, particularly for understanding the mechanical response of cohesionless soils such as sand under different stress and loading conditions. Achieving a specified relative density in large-scale laboratory models is critical for the reproducibility and reliability of experimental results. Among the various methods developed for sand deposition, the air pluviation technique has gained popularity due to its simplicity and efficiency in producing homogeneous specimens. However, controlling the relative density uniformly across large-scale samples remains a challenging task.

To address this, a multi-curtain air pluviator system has been introduced and developed, providing an innovative approach to control deposition intensity and uniformity. This system employs multiple longitudinal slits on traveling plates, allowing for controlled distribution of sand particles. Such advancements enable the creation of specimens with a wide range of relative densities, essential for investigating soil liquefaction, bearing capacity, and settlement behavior.

Several studies have highlighted the significance of material innovation and mechanical performance optimization in structural and geotechnical systems. For instance, Eskandarinia et al. (2022) proposed alkali-activated concrete reinforced with recycled tire fibers to enhance mechanical durability. Similarly, Garmeh et al. (2022) introduced SMA-based self-centering frames to improve seismic resilience. These studies underscore the ongoing efforts to refine material behavior and system responses through experimental and numerical assessments. Hojatkashani and colleagues have also contributed extensively to the field through investigations of interfacial stresses, fatigue behavior, and innovative retrofitting techniques (Kabir & Hojatkashani, 2008; Hojatkashani & Kabir., 2012).

Drawing from this foundation of research and innovation in both material and structural performance, the current study focuses on enhancing the precision of sand specimen preparation. By analyzing the effects of slit number, travel speed, and falling height in a multi-curtain pluviator, this research aims to improve the control over relative density distribution. Furthermore, the results provide valuable insights for soil model preparation in geotechnical centrifuge testing, seismic simulation, and liquefaction research.

None of the previous researchers considered it possible to achieve high relative density in minimum time. The studies have focused on the target density, and sample uniformity achieved by air pluviation with an appropriate selection of depositional intensity and fall height. Decreasing deposition intensity causes sand bed preparation time-consuming, and Increasing deposition intensity reduces modeling time but causes reduce the relative density. A review of the literature reveals that so far no studies have been conducted on the air pluviation system, to use for the controlled construction of sand beds with one, two, three, or four longitudinal slits on pluviation plates. A device is here presented for pluviating sand specimens in air, directly onto the container. The apparatus was first designed by the first author at the Department of Civil Engineering, Faculty of Engineering, South Tehran Branch, Islamic Azad University, and used in the present design in the soil mechanics laboratory. This research introduces the air pluviation system, that is used for the controlled construction of sand beds with one, two, three, or four longitudinal slits on pluviation plates. The apparatus facilitates, achieving the required density and preparation of homogeneous sand beds in a short period and at minimum cost. The pluviation of sand is performed through longitudinal slits on the pluviation plate. The apparatus can be adjusted for different conditions of sands, varying the modeling box and falling height. This method can be adjusted for different number and separation of slits, and traveling speed over the modeling box. Combined variations of such variables allow obtaining of different relative densities of the soil. A series of laboratory tests were conducted on Firuzkuh sand (#161) to achieve the target relative densities in a shorter time. The parameters are slits width (a=2mm), number of pluviation curtains/slits (N), traveling pluviator speeds (V), Separation Distances of Longitudinal Slits (S), Height of Fall (HF), and Deposition Intensity (DI).

## 2. Testing set-up

The designed physical modeling system includes a test tank for bed preparation. It has been utilized for modeling of strip footings reinforced with micropiles, as shown in Fig.1. As shown, the system consists of the test tank, loading frame, pluviation system, load cell, displacement gauge, data logger, a control valve, etc. It has been used two skates under the tank, for quick and easy preparation of the sand bed. The rigid chamber has length, width, and height values of 2000, 500, and 1000 mm, respectively. To monitor soil deposition, the front side of container is made of Plexiglas with a thickness of 30 mm.

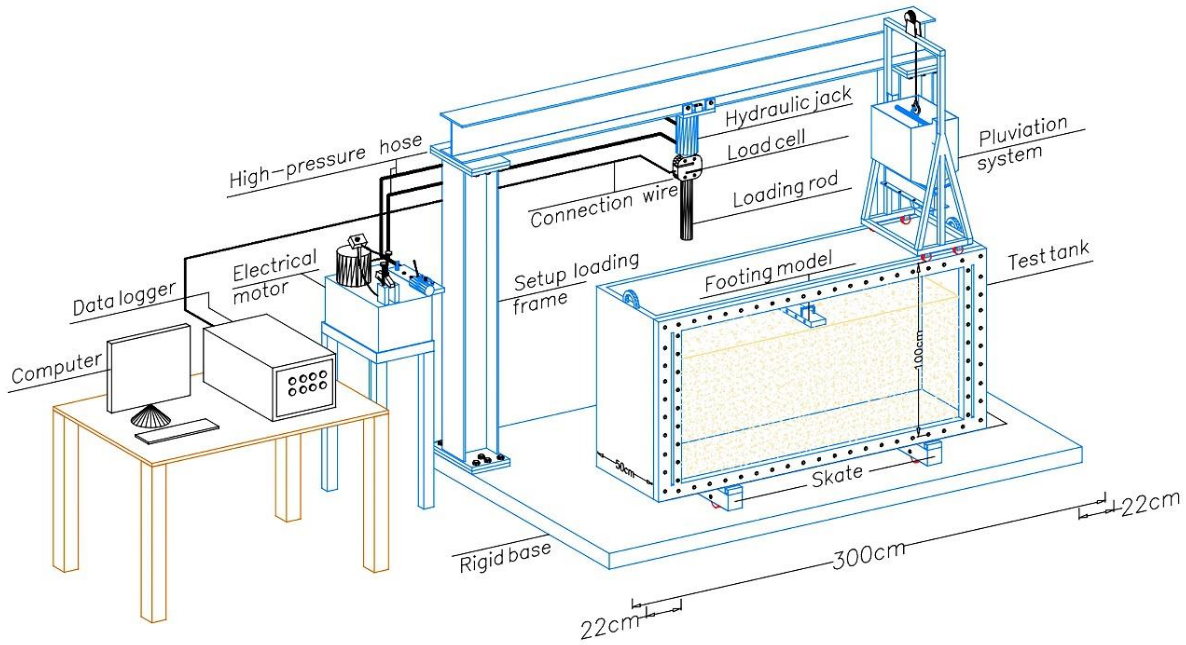



**Fig. 1. Schematic view of the physical modeling system**

The pluviation device consists of a primary hopper, secondary hopper, holder frame, control valve, pluviation plate, and lifting system. The primary hopper is made of steel plate with 3 mm thickness and approximately 40-kilogram capacity. The hoppers, with the assistance of four wheels and the holder frame, have the capability of horizontal and vertical displacement manually. To control the sand flow, a control valve is located at the end of the primary hopper. The width of the primary hopper is smaller than the width of the container, consequently, to have a uniform density on all surfaces of the model the width of the secondary hopper is considered 49.5 cm. So the edges of the model, close to the container wall, cannot have different densities from the central part of the model. To travel easily pluviator in the container the width of the secondary hopper is considered 49.5 cm. So, the secondary hopper has dimensions of 49.5 cm x 6 cm in plan and 8 cm in height, which is made of steel with 3 mm thickness, and a pluviation plate installs on it. The pluviation plate is attached to the secondary hopper with two lines of bolts on each side. Fig. 2 has shown the pluviation system.

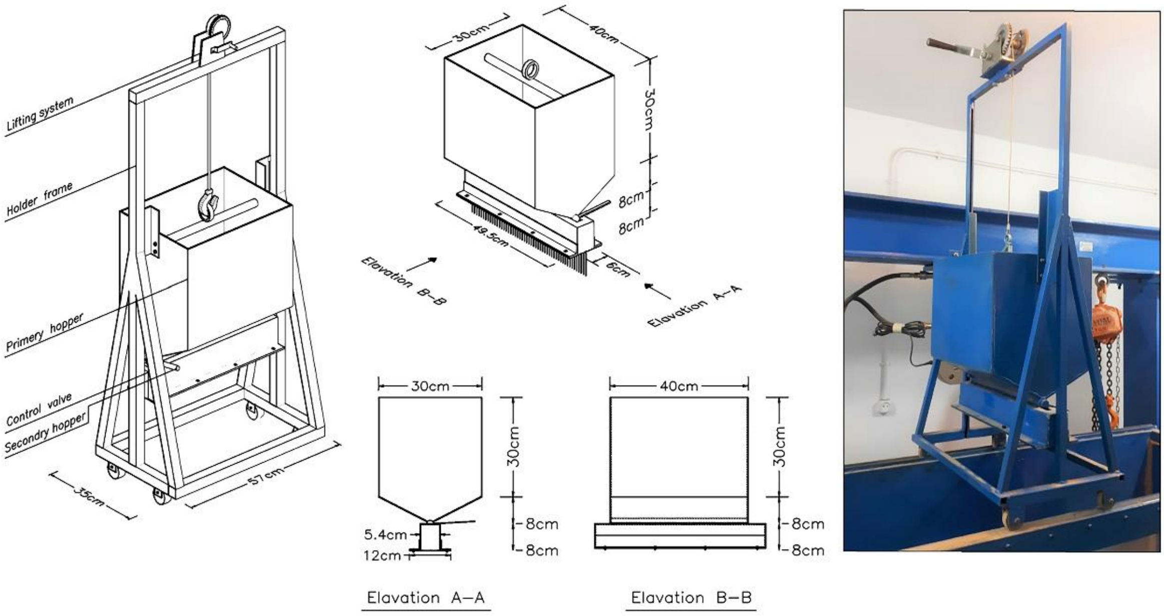



**Fig. 2. view of the air pluviation system.**

It was used pluviation plates with one, two, three, and four longitudinal slits with slits width of 2 mm, to investigate the effect of the number of longitudinal slits on the relative density of the sand bed and its time of preparation. The center-to-center distance of longitudinal slits is 14 mm (sevenfold the groove slits width). The pluviation plates are made from steel of 1.5 mm thickness, and the longitudinal slits on the pluviation plates are created by laser cut (fig. 3).

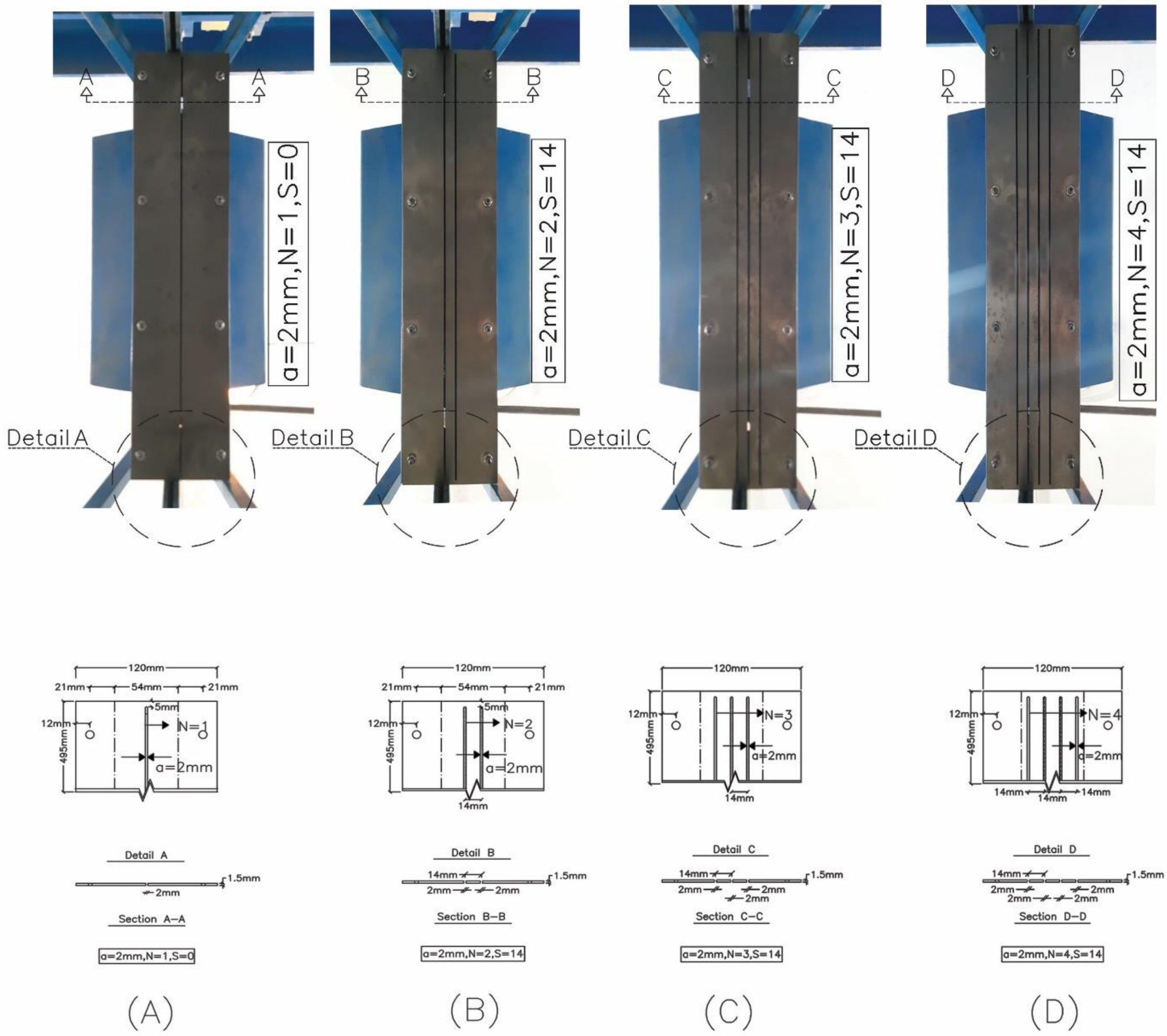



**Fig. 3. View of the pluviation plates. (A): one longitudinal slit; (B): two longitudinal slits; (C): three longitudinal slits; (D): four longitudinal slits, slits width (a), Number of longitudinal slits (N), the separation distance of longitudinal slits (S).**

## 3. Materials

Silica sand (Firuzkuh sand (#161)) was used in this research with a fine-grained content of about 1%. The amount of impurities in the soil is negligible and 98.41% of sand is composed of quartz ($SiO2$). Firuzkuh sand (#161) is known as the standard sand in Iran and has been the most widely used sand for laboratory studies. Based on the Unified Classification System, several experiments have been performed using different laboratory equipment to investigate its physical properties and behavior. Depending on the grain size distribution curve and the physical characteristics shown in fig. 4 and Table 1, the uniformity coefficient ($C_u$) and the curvature coefficient ($C_c$) are 1.87 and 0.87, respectively. Based on the Unified Classification System (USCS), it is categorized in the sandy soil class as poorly graded (ASTM D2487-17e1). The ASTM 4253-16e and ASTM D4254-16 standards were used to calculate the minimum and maximum voids ratios, respectively. (Abdollahi and Bolouri, 2017; Shafiee et al. 2017).

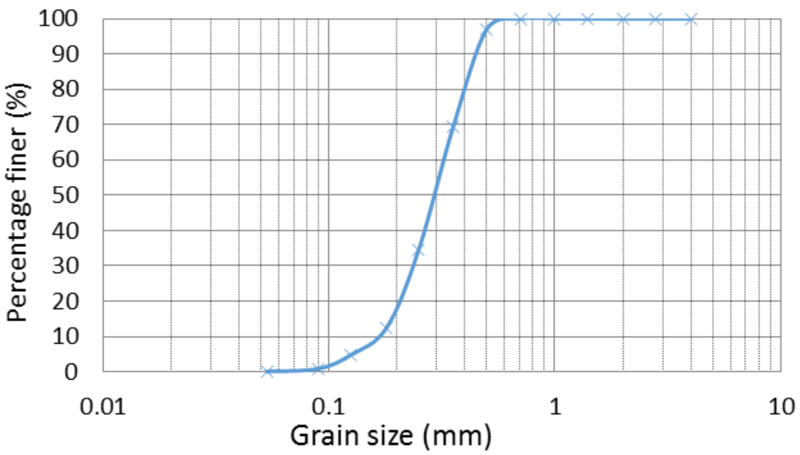



**Fig. 4. Grain size distribution curve of Firuzkuh Sand (No.161).**

**Table 1. Properties of the LRB isolator model**

| **characteristic** | **Passing #200** | $D_{10}$ | $D_{30}$ | $D_{50}$ | $D_{60}$ | $e_{max}$ | $e_{min}$ | $G_s$ |
|---|---|---|---|---|---|---|---|---|
| **Unit** | | **mm** | **mm** | **mm** | **mm** | | | |
| **Value** | 0.01 | 0.16 | 0.21 | 0.27 | 0.28 | 0.943 | 0.603 | 2.658 |

## 4. Test program

Sand beds prepared using the curtain pluviator system and the effects of various parameters, including the slits width of the slits (a=2mm), traveling pluviator speed(V), the height of fall (HF), and the number of slits on the pluviation plate (N) were studied. In the first step, it was evaluated the effect of the number of longitudinal slits on relative density.

**Table 2. Test details**

<table>
<tr><th>Test Series</th><th>Combination of parameters</th><th>HF (cm)</th><th>V (cm/s)</th><th>N</th><th>S</th><th>Iteration</th><th>Number of Tests</th><th>Purpose of the tests</th></tr>
<tr><td>1</td><td>DI, HF, V, N</td><td>40</td><td rowspan="5">2<br>5<br>10</td><td rowspan="4">1<br>2<br>3<br>4</td><td rowspan="4">7a</td><td>3</td><td>36</td><td>To calculate the DI</td></tr>
<tr><td>2</td><td rowspan="3">RD, Hf, V, N</td><td rowspan="2">10<br>40</td><td>2</td><td>48</td><td>the effect of N on RD</td></tr>
<tr><td>3</td><td>2</td><td>48</td><td>relationship between V and RD</td></tr>
<tr><td>4</td><td rowspan="2">10<br>20<br>30<br>40<br>50<br>60<br>70</td><td>1</td><td>84</td><td>relationship between and corresponding HF</td></tr>
<tr><td>5</td><td>RD, Hf, a, V, S, N</td><td>2</td><td>7a<br>9a</td><td>1</td><td>42</td><td>the effect of S on RD</td></tr>
</table>

## 5. EXPERIMENTAL RESULTS AND DISCUSSION

The previous researchers showed that increasing the slits width of the longitudinal slit, enhances the deposition intensity and decreases the density of the bed. In this research, it was shown that using a multi-curtain pluviator (separated slits on a pluviation plat) can increase the deposition intensity without decreasing the relative density.

## 6. Relative Density

Four cans each one with a diameter of 10 cm, a height of 5 cm, a weight of 48 gr, and a volume of 350 cm³ were utilized to calculate the relative density of the pluviated sand. (fig. 5.A). The distribution of cans along the area ensures the uniformity of the sampling to measure the resulting density.
With respect to the pluviator being supported directly on the container, the effect of unwanted vibrations is negligible on the relative density of sand, so the differences in the relative density of the models were about 2%. Therefore, the relative density of sand in all experiments was about ±2% difference in the results. The relative density was controlled with four cans which express the results represent the average values of all four samples. The cans were placed according to Fig 5.B. at every 10 cm height of the container. The average relative density in 4 samples, was considered as the relative density of each layer. The amount of relative density (in percentage) is obtained by using equation 2 after weighing the samples.

$$D_r = \frac{\gamma_d - \gamma_{d\,(min)}}{\gamma_{d\,(max)} - \gamma_{d\,(min)}} \times \frac{\gamma_{d\,(max)}}{\gamma_d} \times 100 \qquad (2)$$

Where $\gamma_{d\,(max)}$ $\gamma_{d(min)}$, and $\gamma_d$ are the maximum, minimum, and natural state dry unit weights of the soil. Relative density is generally expressed as a percentage.

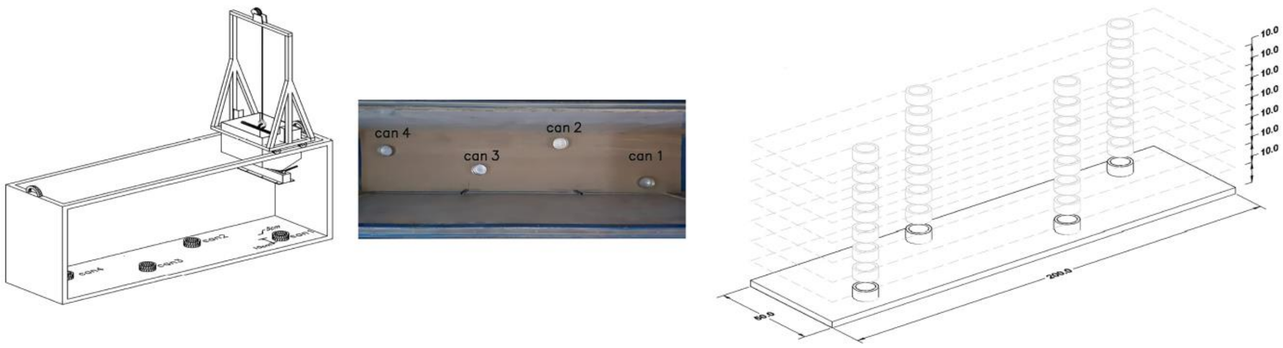



**Fig. 5. (A). Plan of the sampler on the chamber (B). The height distance of placing the cans**

## 7. Deposition Intensity (DI)

The effect of depositional intensity on density has never been questioned. As the depositional intensity increases the sample density reduces, as sand grains cannot move to the minimum potential energy position. when the sand is delivered from the stationary hopper, sand flow is modified by changing the number of slits. In order to calculate the deposition intensity (DI), 36 experiments were administered at a constant fall height (40 cm) at different traveling pluviator speeds (2, 5, 10 cm/s). The mass of pluviated soil per effective unit area of the cans per unit of time was measured. The experiments were done three times per each pluviator speed to ensure outcomes were accurate.

## 8. Number of Slits (N) - Relative Density

When the pluviator speed was 2 and 5 cm/s, with two, three, and four longitudinal slits at sand fall heights 10 and 40 cm, the relative density of the sand bed were approximately the same as the relative density obtained by using a single slit. Moreover, the relative density of the prepared sand bed with two, three, and four curtains, at the fall height of less than 40cm, even at the pluviator speed of 10 cm/s, because it is assumed that there are no interferences between the grains, and they were same as one curtain. This means that each longitudinal slit acts separately and independently. In the pluviation plats with two, three, and four longitudinal slits, while the pluviator speed achieves 10 cm/s, at a fall height of more than 40 cm the kinetic energy of sedimentary particles reduces during sand rain because of collision particles. As a result, the relative density of specimens prepared with multi-slit decreased as compared to the relative density of one slit. In the traveling pluviator speed of 2 and 5 cm/s, each pluviation curtain acts independently, and the increase in the number of curtains does not collision of curtain particles. Therefore, the relative density remains constant and physical modeling is performed in less time. The relation between the number of pluviation curtains (N) and relative density is illustrated in FIG. 6 for the traveling pluviator speeds of 2, 5, and 10 cm/s in the height of fall equals 10 and 40 cm.

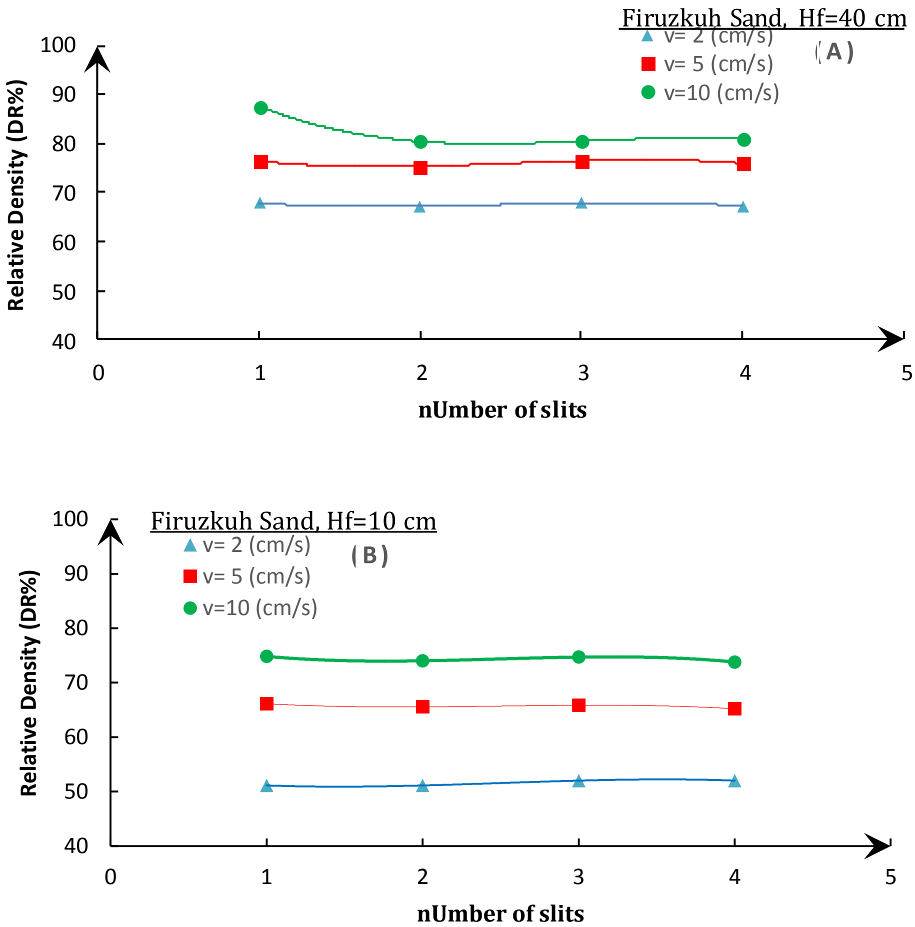



**Fig. 6. Relation between number of longitudinal slits and relative density. (A): HF=40 cm; (B): HF= 10 cm.**

## 9. Traveling Pluviator Speed - Relative density

Pluviator with one longitudinal slit traveling at a faster speed leads to thinner layers and a smoother surface that increases the relative density. Decreasing the relative density of the multi-curtain pluviator at the speed of 10 cm/s, because of collision particles was significant. The relationship between traveling pluviator speed and relative density is shown in FIG. 7.

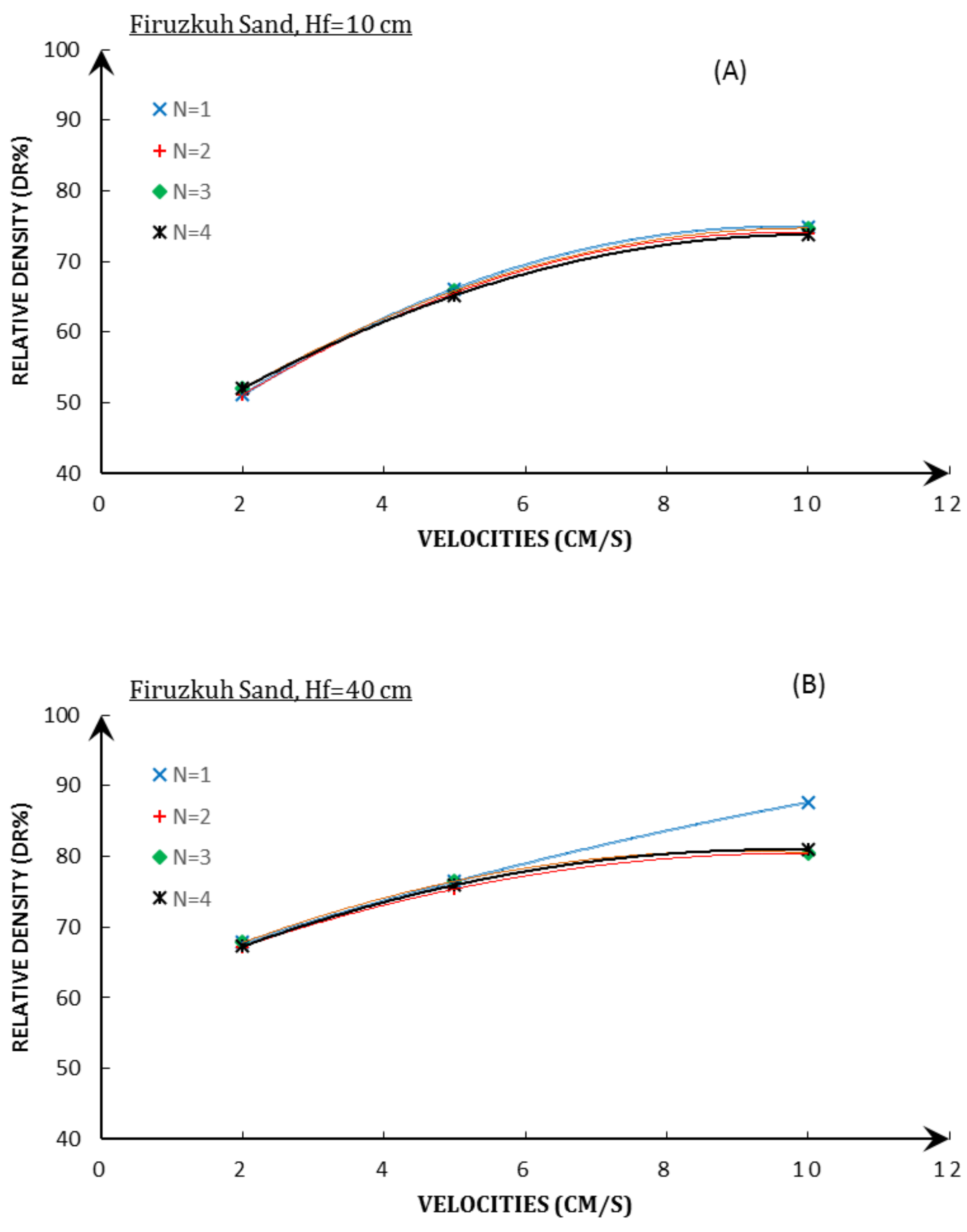
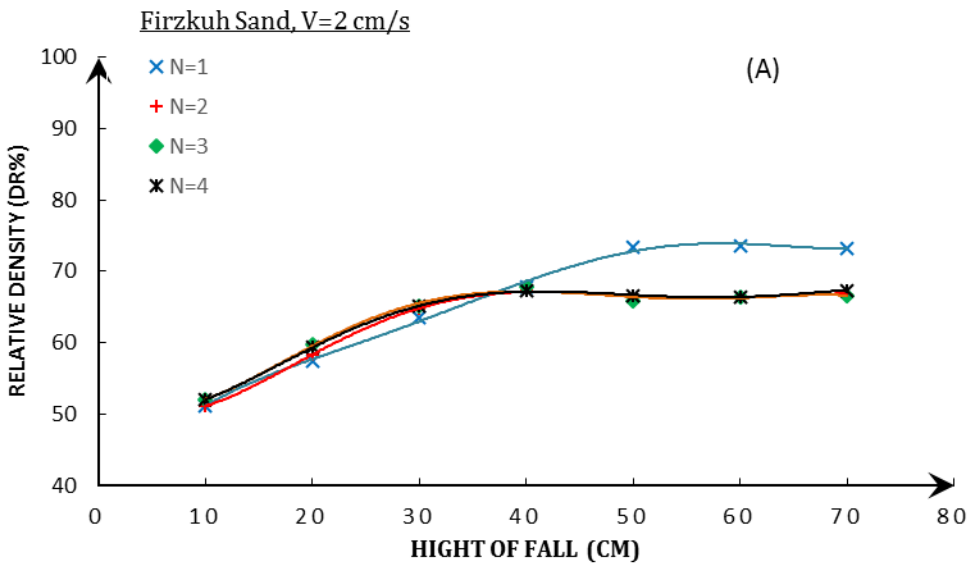



**Fig. 7. Relation between traveling pluviator speed and relative density. (A): HF=10 cm; (B): HF= 40 cm.**

## 10. Falling Height - Relative Density

A relationship between the relative density and a corresponding falling height (10, 20, 30, 40, 50, 60, and 70 cm) in traveling pluviator speeds of 2, 5, 10 cm/s is illustrated in figure (9). 84 tests have been conducted to evaluate the effect of height of fall (distance between the pluviation plate to the top of the sand bed) and parameters of deposition intensity on the relative density of the specimen. FIG. 8 illustrates the relationship between falling height (10, 20, 30, 40, 50, 60, and 70 cm) on the relative density at pluviator speeds of 2, 5, and 10 cm/s. It was observed that the effect of increasing falling height until 40 cm was significant on relative density, while in height 40 to 60 cm had a slight impact. as the initial velocity is nil, particle acceleration is maximum and depends only on the ratio of the density of fluid and soil material. the acceleration reduced during the particle fall and eventually becomes zero when a critical velocity is attained, thus the impact energy remains thereafter constant. Void and Negussey (1984) also showed that the critical velocity increases linearly with a sphere diameter. this explains grain segregation and indicates that at equal fall height finer sands will have smaller impact energy, resulting in lower density. the influence of fall height on density has been a controversial matter, as adjectives in the literature range from negligible to strong.

This happens because of the dimensions of particles and their critical velocity. The smaller particles reach the critical velocity at a fall height up to 40 cm, and larger particles reach the critical velocity up to 60 cm. The difference in critical velocity of small and large particles in the range of 40 to 60 cm leads to a collision of particles and a reduction of kinetic energy in this range. Up to the height of 60 cm, approximately all particles reach the critical velocity, and their kinetic energy becomes constant, so more height wouldn't affect relative density. Anyway, by increasing the traveling pluviator speed up to 10 cm/s, the enhancement process of relative density continues. The falling height more than 40 cm and traveling pluviator speed of more than 10 cm/s, do not increase relative density.



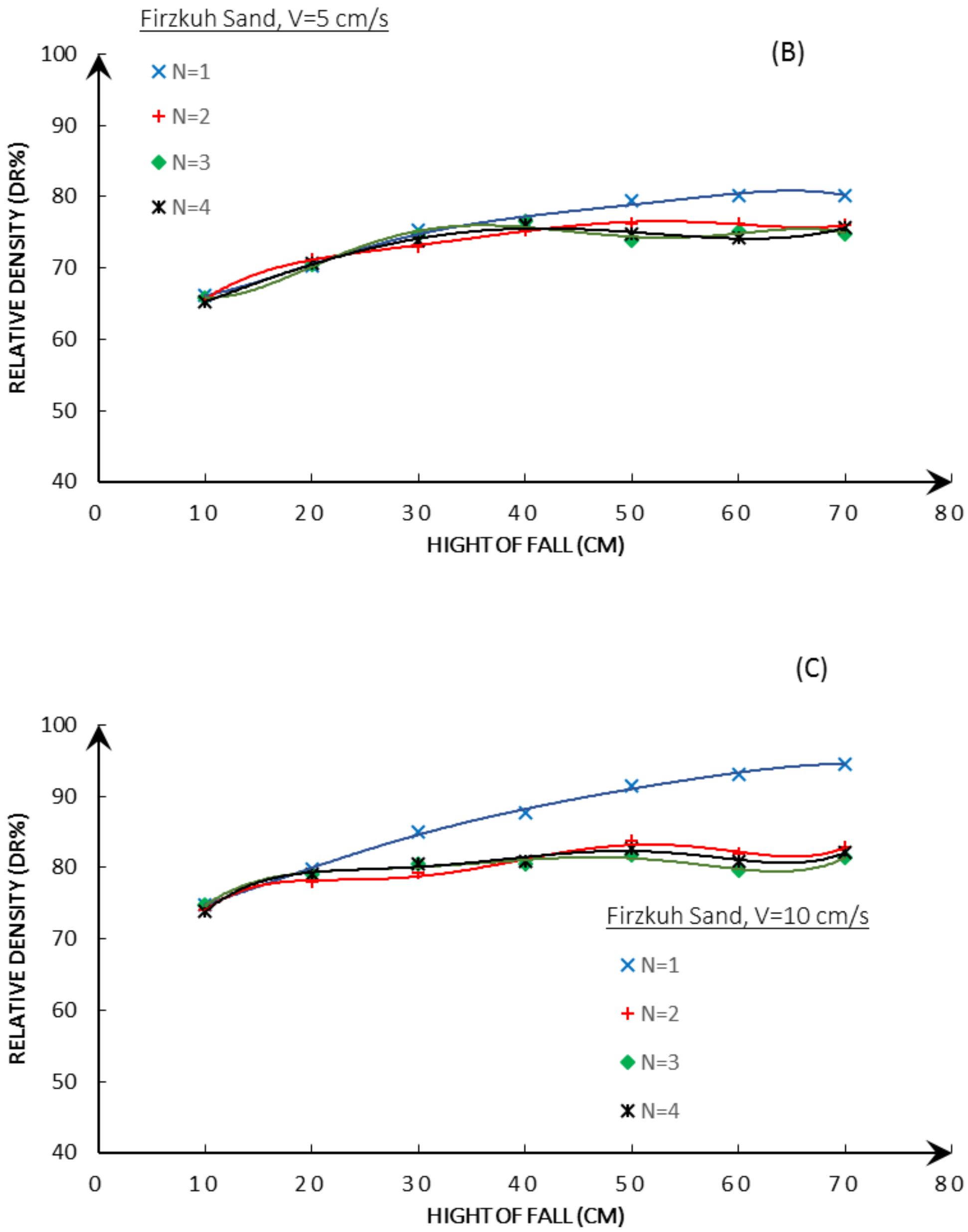



**Fig. 8. The relation between falling height and relative density; (A): V=2 cm/s, (B): V=5 cm/s, (C): V= 10 cm/s**

## 11. Number of Longitudinal Slits - Deposition Intensity

The impact of the number of longitudinal slits in the pluviation plate on deposition intensity at the falling height of 40 cm is shown in FIG. 9. As shown in FIG 9, increasing the number of curtains has led to an increase in deposition intensity. Independent slits led that the pluviation curtains have no collision. So, the pluviation curtains had an independent function, and increasing the number of curtains had no effect on the relative density (if it is assumed that there are no interferences between the grains). Moreover, an increase in the volume of the sand outlet (deposition intensity), leads to prompt sand bed preparation.

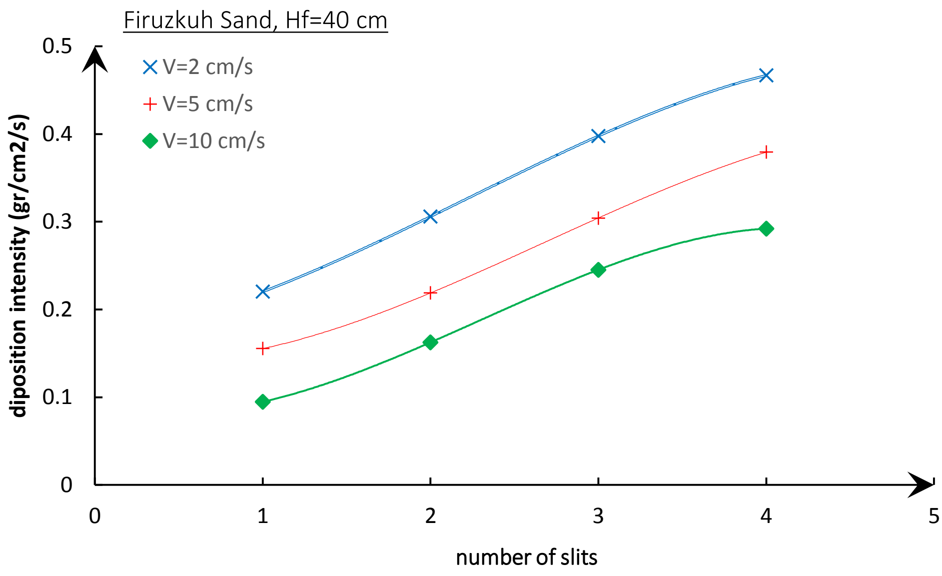



**Fig. 9. The relationship between the number of openings and deposition intensity**

It means, by increasing the number of pluviation curtains, deposition intensity increases, and the relative density of specimens until the pluviator speed of 5 cm/s increases. In multi-slit plates at the pluviator speed of 10 cm/s, the relative density of the sand bed decreases compared to one slit, because of interferences between the grains as a result reduction of their kinetic energy during the sedimentation.

## 12. Deposition Intensity - Relative Density

Figure (10) shows the effect of deposition intensity on relative density in fall height of 40 cm, separately for traveling pluviator speeds 2, 5, and 10 cm/s. The number of slits is the main factor affecting the deposition intensity. As presented in FIG. 10, for a given height of fall, the relative density of a reconstituted specimen at the pluviator speeds of 2 and 5 cm/s, the number of slits is not the main factor affecting relative density. So, an increase in the number of pluviation curtains (slits) has a negligible influence on relative density, but it leads to an increase in deposition intensity and accelerate modeling.

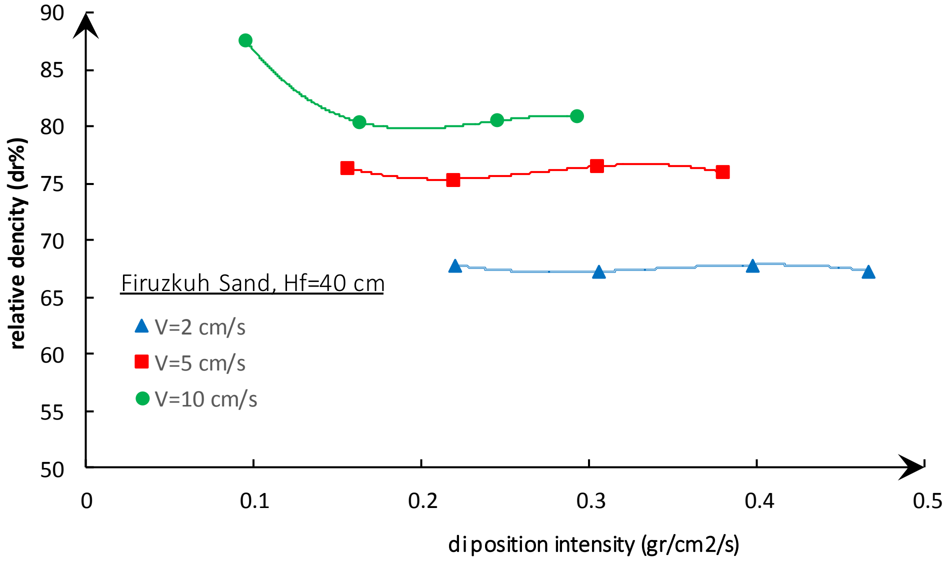



**Fig. 10. Effect of deposition intensity on relative density with constant height (Hf=40 cm) with different values of traveling pluviator speeds (2, 5, and 10 cm/s)**

## 13. Separation Distance of Longitudinal Slits (S) - Relative Density

In addition, 42 tests were conducted for investigating the effect of the separation distance (center-to-center) of longitudinal slits (S) on the relative density. For this purpose, two pluviation plates each with two longitudinal slits were used. The slits width of longitudinal slits was equal to 2 mm and it was the same in both pluviation plates. The center-to-center distance of longitudinal slits in one of them was sevenfold of the slits width of the slit, i.e.,14 mm, and in another one ninefold of the slits width of the slit, i.e.,18mm (fig.6).

To investigate the effect of distance between longitudinal slits on relative density, two series of tests with two slit pluviation plate, have been conducted: longitudinal slits spaced 18 mm, and longitudinal slits spaced 14mm. As shown in Figures 12A, 12B, and 12C, the comparison of results showed that the obtained relative density with separation distance of longitudinal slits 18 mm is higher than the longitudinal slits spaced 14mm.

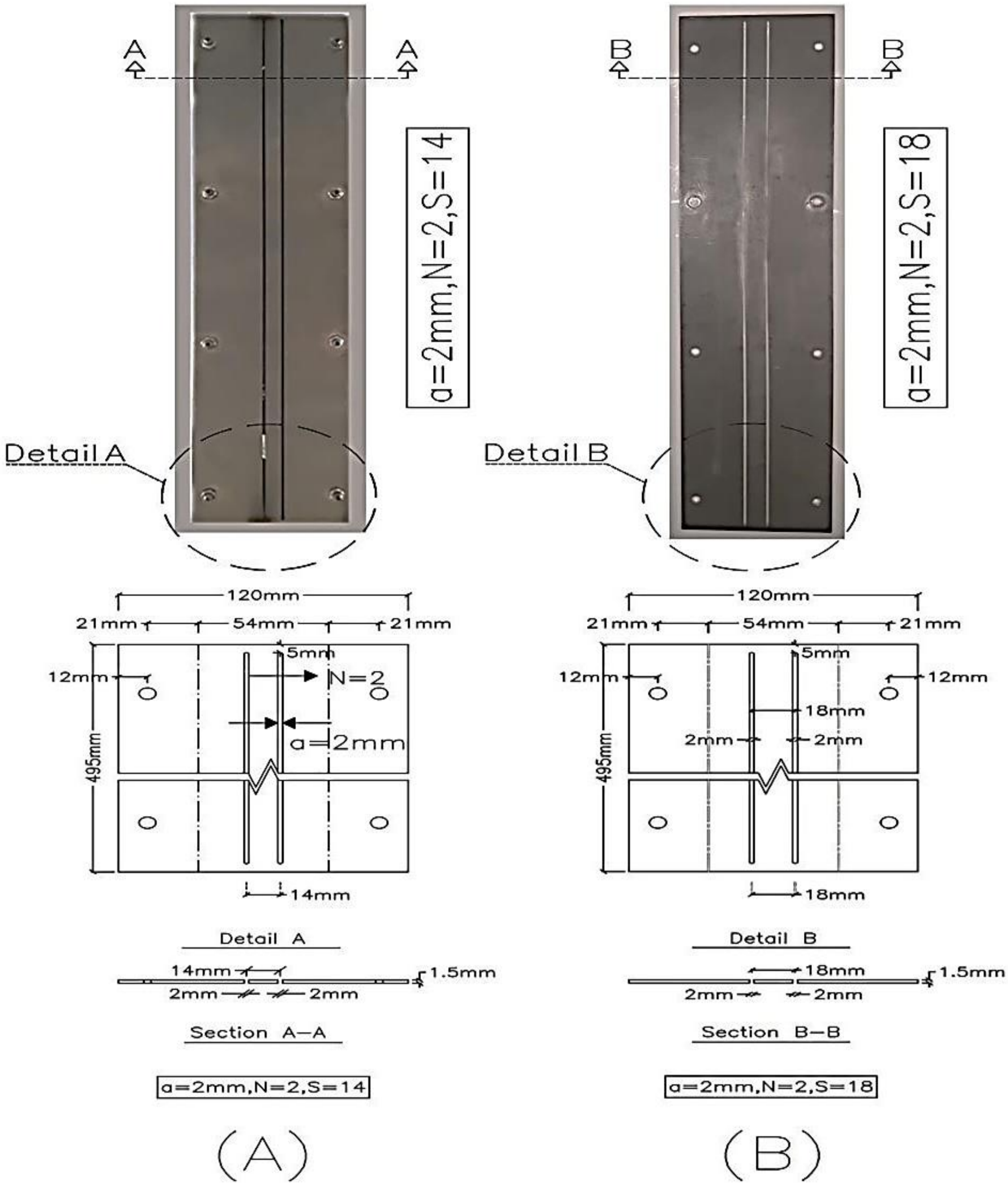
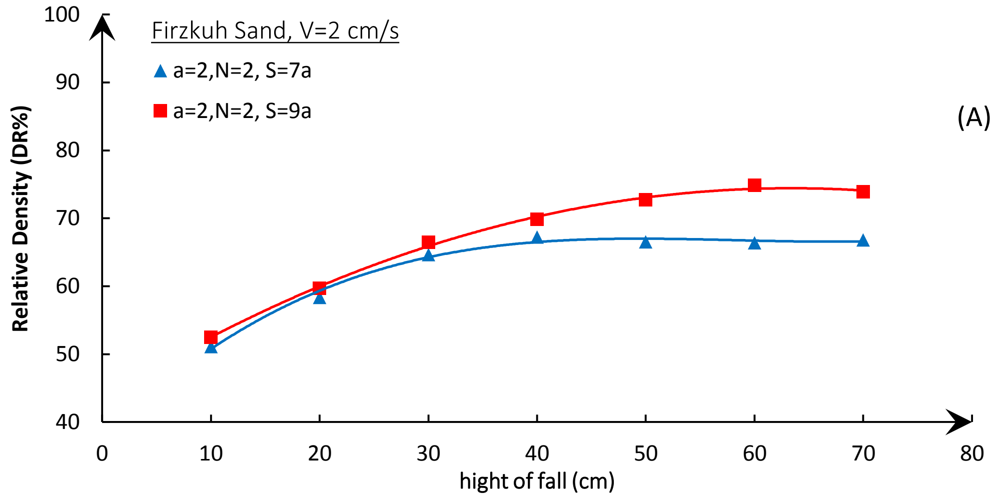
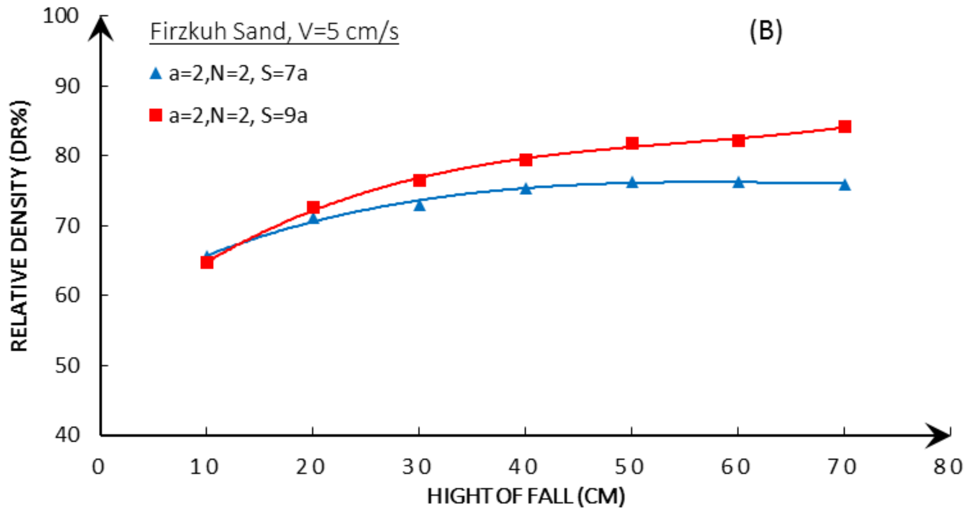



**Fig. 11. Details of pluviation plats with the double longitudinal slits with the separation distance of longitudinal slits 14 and 18 mm**


Firzkuh Sand, V=2 cm/s
a=2,N=2, S=7a
a=2,N=2, S=9a
(A)
Relative Density (DR%)
hight of fall (cm)


Firzkuh Sand, V=5 cm/s
(B)
a=2,N=2, S=7a
a=2,N=2, S=9a
RELATIVE DENSITY (DR%)
HIGHT OF FALL (CM)

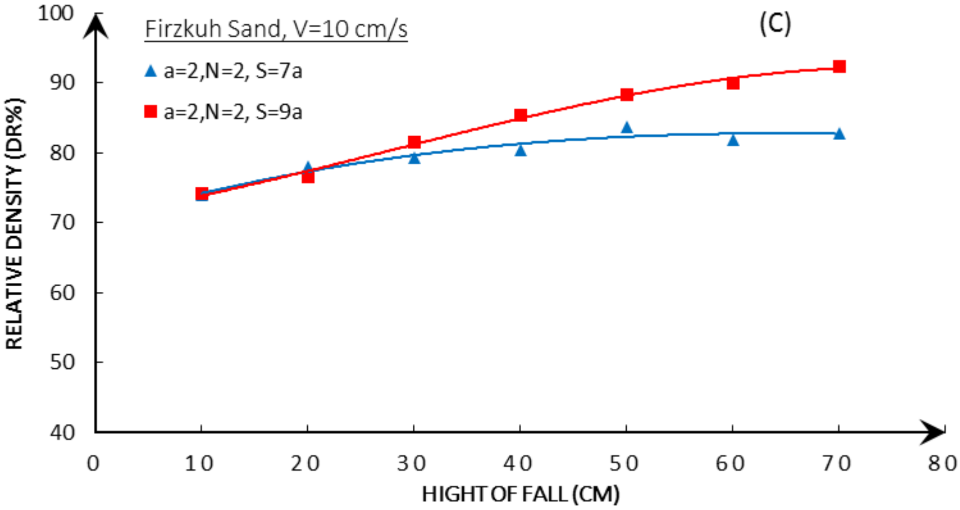



**Fig. 12. Effect of the center-to-center distance (14 and 18-millimeter) of longitudinal slits on pluviation plates, on relative density in the velocity of 2 cm/s. (A): V=2 cm/s, (B): V=5 cm/s, (C): V= 10 cm/s.**

For longitudinal slits spaced 18 mm it was obtained a higher relative density than the reached using the same pluviator speed and separation distance of longitudinal slits 14mm. The lower distance between longitudinal slits in the pluviator moving at the highest velocity, leads to collision of particles and reduction of their kinetic energy during the sedimentation. The comparison of the relative density of specimens reconstituted showed that pluviation plats with the separation distance of 18 mm has better performance than 14 mm. So that we can reach a higher relative density by enhancing the height of the fall and traveling pluviator speed. So, to achieve higher relative density, with a high speed of the pluviator, it is required to increase the distance between slits on the pluviation plate.

## 14. CONCLUSION

The present research deals with the preparation of a large-scale tests with a portable curtain pluviator. The equipment was used to investigate the effect of the number of slits, the falling height, and the speed of the pluviator moving over the modeling box on the relative density. Also, additional tests were performed to study the effect of the separation between slits. The following conclusions were drawn from this research:

1. It was observed that sand beds of target relative densities can be achieved by controlling the height of fall, and the speed of the pluviator moving over the modeling box. the time of modelingcould be controlled, by controlling the number of slits without making a change in the predicted density.
2. The increase in pluviator speed caused the enhancement of relative density and led to the preparation of a sand bed with an arranged surface. The significant effect of falling height on relative density had seen in the height of 10 to 40 cm. Moreover, the results showed an increasing trend of relative density from the falling height of 40 to 60 cm gently occurring. The higher values of falling height (more than 60 cm) have not affected the relative density. The increase in the number of longitudinal slits has caused an increase in deposition intensity. The

change in the number of slits has no impact on relative density, while the duration of modeling changes. At the high speed of the pluviator, the relative density of multi-curtain plates is less than the relative density of one curtain.

3. The lower separation distance of longitudinal slits of the pluviator moving at the highest velocity, leads to interferences between the grains and a reduction of their kinetic energy during the sedimentation. So, to achieve higher relative density, with a high speed of the pluviator, it is required to increase the separation between slits on the pluviation plate. This outcome has shown that each pluviation curtain behaves independently because of no interferences between the grains.

## 15. References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