Design, Manufacturing and Testing of Biaxial Mechanical Travelling Pluviator

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Abstract. This paper includes design, manufacturing, operation and testing of a special device for preparation of granular or sandy soil (cohesionless soil) models that widely used as a part of the physical modelling in geotechnical engineering which is a main part of the civil engineering. To achieve a desired and uniform relative density of sandy soil models during preparation, air pluviation technique using pluviator is more suitable as the sand particles can be dandified through falling of sand grains from different heights and may even reaches to very dense state. Steel materials from local markets are used in the design of mechanical pluviator manufacturing. The mechanical pluviator consist of main steel frame, movable bench that can be moved up and down mechanically, crane lever to control on the pluviator container, pulleys and wheels. CPT tests are conducted at different prepared sandy models to investigate the skin resistance at different densities and the results shows great agreement. Different steel sections materials with different light steel plates which reduce the device weight available in the local markets were used in the manufacturing of the pluviator machine. The machine was provided by crane lever and gear box that can be controlled mechanically to achieve the desired height for the falling sand grains. The maximum height that can be attained is 120 cm and 40 cm is the minimum value. The machine contained also a v -shape container provided with 4 reels or pulleys that can be moved back and forth along two parallel steel tubes girders which the filled sandy model is located below it. The v shape container has two plate sides; the first one is fixed while the other is movable to achieve the desired opening depth or slot width and can be changed easily. The container with its carried frame can be controlled via mechanical rode that can be move up and down using multi- coil wire. The machine is verified using cone penetration test at results at different soil relative densities.

Keywords: Container, CPT, Pluviator, Relative density, Sand

1. Introduction
One of the main important steps in most of the geotechnical laboratory tests is the model preparation technique whether these model tested under 1-g (i.e. shaking table models) or N-g (i.e. geotechnical centrifuge models). The model preparation is mainly depends on the type of the soil. For cohesive soils (i.e. clayey soils), the model preparation is complex as due to the consolidation considerations which is not simulate easily in the model scale. In contrast, the cohesioless soil in prototype scale is widely simulated and prepared in model scale using tamping, vibration or air pluviation technique [1]. The pluviation is widely used by geotechnical researchers because a wide range of the relative densities (i.e. loose to dense state) can be obtained [2-5]. Large and small scale models have been widely prepared last few decades to investigate different geotechnical phenomena and testing different
foundations, footing and piles models [6], geotechnical centrifuge tests [7-9], 1-g shaking table tests [10] and Triaxial tests [11-12].

The word pluviation is Latin origin “pluvial” and means “rain”. To obtain a uniform density for sandy soil layers during the model preparation process, it was appeared clearly from the art-of-literature that the falling of sand grains from different heights and different falling rate can achieve the desired densities and may even reaches to very dense state. This can be achieved by the pluviator apparatus using air pluviation technique.

Many trials have been done at different research centres and universities around the world to fabricate the pluviator for cohesionless soil preparation. Hussein and Ansary, 2018 [13] designed and manufactured simple pluviator as a funnel (like a hopper) and has different perforated disks and different size of holes each that can be replaced to achieve the desired relative density. Chains, levers and crane to change the height of the funnel pluviator are used in the design. Presti et al.1993 [1] designed small travelling pluviator for small sandy soil models preparation. Moayedi and Mosallanezhad, 2017 [14] manufactured mobile pluviator and it was tested at different heights and different sand grains falling rate using different slots. It was observed that the relative density of the prepared models is strongly influenced by the falling height and the size of the slot (i.e. the rate per time). Carvalho et al. 2015 [15] developed new pluviator and it was more modern compared with the previous designed machine and it was tested and verified during sandy soil preparation to investigate the behaviour of retaining walls stabilized by anchors. Four main support are provided and the contained moves easily but the height of the container was limited. Lauder, 2011 [16] manufactured small v- shape pluviator that can moves personally but the height changing is very difficult as it needs two person to change the structural parts of the main frame (add or remove elements to change the height). Al-Baghdadi 2017 [17] developed new pluviator when sandy soil models were prepared to investigate how the screw pile models behave under compression and tension loads in geotechnical centrifuge. Khari et al. 2017 [18] designed travelling pluviator and the height of falling grains-relative densities are investigated and the slot opening-relative displacement as well.

In this paper, new biaxial mechanical v- shape pluviator is developed in the geotechnical laboratories at Wasit University. The relative densities from the prepared models have been measured at different heights of sand grains falling with different slot size. The results have been verified at three main relative densities (i.e. loose, medium and dense state) using the cone penetration tests to investigate the cone resistance with depth.

2. Parts of the pluviator

The pluviator is consisting of many parts that were mainly designed and manufactured from the local market like the main frame, the v- shape container, the crane lever, movable bench, pulleys and wheels.

The main frame

The main frame of the pluviator device consists of different sizes and different sections from local steel. Four main legs of 5cm x 7.5 cm cross section with 2.25 m length comprised the main four supports of the frame. Four wheels are used (one for each leg) to ensure the device movement in the laboratory in a smooth way. The four legs are connected from the top with the main movable bench and welded perfectly. Both the guide rails and the chain pulleys are welded with the main frame. The total height of the device is 2.5m and the movement vertical limits is ranged between 0.4m to 1.2m with large space below the v- shape container for giving a wide area for the model below the device during pluviation. Figure 1 shows the details and dimensions of the main frame.
The movable bench
To ensure that the v-shape container moves horizontally back and forth and vertically up and down to cover whole the model underneath, the movable bench is designed and attached with the main frame. The guide rails are welded with the bench to allow the containers moves easily with minimum the friction using four steel pulleys.

The mechanized crane lever
In order to change the height of the movable bench to achieve the desired depth and subsequently, the desired relative density of the prepared model, Mechanical crane lever is provided. To reduce the difficulty of the researchers during the model preparation due to expected heavy weight of the pluviator, gear box is added to the crane lever to transfer the load to achieve ease of movement up and down. Multi-coil wire is used to connect the movable bench from both sides for equilibrium to the crane lever. Figure 3 shows the full details of the crane lever.
Figure 3. The mechanical crane lever

**Pulleys of the container**

Four stainless steel frictionless Pulleys are used for the V-shape container and welded. The pulleys were moves along steel guide rails back and forth that were welded along movable bench. The pulleys were chosen in small size to decrease the total weight on the bench and giving easy movement for the container particularly when filled with sand. Figure 4 shows full details of the pulleys with the dimensions.

Figure 4. The main pulley dimensions

**Wheels of the main frame**

As the designed and manufactured mechanized pluviator is large to prepare large models, It was expected that the weight of the machine is too much (i.e. around 150 Kg). Thus, four smooth rubber wheels are connected at the end of each leg of the main frame. (one for each leg). In this case, the
movement of the pluviator from position to another in the lab is very easy even of the weight is too much. Figure (5) shows picture of the wheel.

![Figure 5. Wheels of the main frame](image)

3. **Final configuration of the mechanized pluviator.**
After connection and welding all the device parts, the final configuration of the biaxial mechanized pluviator appeared to be as shown in figure. Two pictures are shown in the figure, the right one (i.e. figure 6a) is an actual picture in the laboratory while the left one (i.e. figure 6b) is 3D drawing. All parts of the mechanized pluviator and even the filled with sand v- shape container are appeared.

![Figure 6. Final configuration of; (a) real biaxial mechanized pluviator and (b) 3D sketch.](image)

Figure (7) shows the full details of the biaxial mechanised pluviator.
4. The model preparation procedure.

First of all, the v-shape container is filled with sand; it may need to be downloaded to the minimum level so that the tester can fill the container easily. The size of the slot should be changed based on what the size that gives the required relative density which will explain later in this paper. Later on, the level of the bench that carry the v-shape container changes to the desired lever that gives the desired relative density (calibration of the pluviator is coming next section) using the crane lever. Back and forth movement of the pluviator along the guide rails handily by the researcher gives uniformly distribution of the fallen sand grains on the model container underneath the pluviator device. Figure (8) shows two images, one for small scale model preparation used in cone penetration tests to investigate the bearing resistance for the cone (i.e. figure 8a) while the other for preparation of large scale model on the shaking table to be used to investigate the seismic performance of gravity dam using shaking table.

5. Testing of the mechanized pluviator.

The designed and manufactured biaxial mechanized pluviator is tested and calibrated to investigate how the falling height of the sand grains and the slot size of the v-shape container effect on the
measured relative density of the prepared model. A 100cm x 80cm x 75 cm steel container is used in the calibration process. Different heights are used (0.5m, 0.7m and 1.1m) to cover the full height of the device. Full wide ranges are chosen also for the slot size (here between 2mm to 7mm) and repeatable tests are performed. The relative density was measured based on the maximum and minimum sand density. The sand is bought from the middle of Iraq and it was dried, then sieved and passed on #10 sieve and retained on #120 sieve. This procedure is followed to obtain particle size distribution of the used sand in this paper very close to the HST95 silica sand that was widely used in models preparation in the world [17, 19-21].

Figure 9a and b shows the relationship between the slot size and the falling height of the sand grains with the obtained relative density. The results are compared with those obtained from Lauder 2011 [16] and Aldefae 2013 [20].

![Figure 9. Calibration tests of the mechanized pluviator; (a) slot size- RD relationship and (b) Falling height- RD relationship](image)

6. Verification of the Pluviator using small scale CPT models tests.

It was clearly shown that the obtained relative density is strongly influenced by the falling height of the sand particles and the slot size of the v-container. The results of the calibration showed very good agreement with measured results from art-of-literature, figure 9a [16, 20] and great prediction in noticed with HST95 silica sand (figure 9b).

To verify the results of the pluviated sand model at wide range of relative density, small scale cone penetration tests (CPT) are conducted on three main relative densities (i.e. 38%, 52%, and 74%) and
these values are represent loose, medium and dense state. The penetrometer that was made by Aldefae et al. 2019 [20]is used for this verification which was 50 cm in length and small load cell is attached at the end of the cone to measure the load during penetration. It should be noticed from figure 10 that the variation of the core resistance in MPa with depth has great compatibility with the state of the soil strata density. Once the relative density of the prepared model increase, the cone resistance is increase with depth as this can be attributed to the densification of the layers and this leads to increase the skin friction along the cone surface. The results were compared also with the art-of-literature results [22] for both loose and dense state (see the legend of figure 10). I could be seen that the loose state is verified very well (black line) and the dense state is slightly under predicted and this can be attributed to the soil density that was used by Arshar et el. 2014 [22] (82%) is more than the value used in this test (74%).

![Figure 10. The measurement cone resistance models with depth](image)

7. Conclusions.
This paper included designing and manufacturing of new biaxial mechanized pluviator in the geotechnical laboratories at Wasit University, Engineering faculty to develop research skills and capabilities of both undergraduate and postgraduate students and researches. The main conclusions can be summarized as follows:

- The pluviator is great geotechnical tools to prepare the small and large cohesionless (sandy) soil models for testing different geotechnical problems.
- The new technique that used in this pluviator (i.e. the crane lever and gear box) provided distinguishable great facility and ease of model preparation particularly for large models.
- The calibration tests of the mechanized pluviator showed that the relative densities of the sandy soils are strongly influenced by the failing height of the sand grains and the slot size of the pluviator.
- It was clearly shown from the cone penetration tests that at all relative densities (i.e. loose, medium and dense) state have been well captured for the cone resistance and they have great agreement with what have been observed from other.
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