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On the choice of appropriate sieves and diffusor sieves for air pluviation based on sand grain properties

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ABSTRACT: Air pluviation is a widely used method in geotechnics for creating sand samples for physical modelling purposes. The benefit of this method is the wide range of possible bulk densities to be reached and, with the right equipment settings, homogenous samples. This leads to high quality experimental results.

However, to be able to achieve homogeneity, the set-up of the pluviation stand needs to be chosen carefully. Here, especially the sieve together with the diffusor sieves play an important role. The sieve is responsible for adjusting deposition intensity, which describes the mass of sediment per area and time falling on the sample surface. The diffusor sieves, which usually consist of a relatively coarse quadratic mesh, are generally attached below the sieve to uniformly distribute the sediment over the sample surface. If either the diffusor sieves or the sieves are not adjusted to the used sand, considering grain size as well as other grain properties, the resulting sample will not be homogenous.

To investigate this effect, an existing pluviation test stand is used for varying diffusor sieves and sieves, as well as the air pluviated sands. The resulting samples are examined regarding their density and grain size distribution by using directly collected sand samples as well as 3D-laser scanning. In addition, the properties of the sand grains, such as grain size distribution, roundness or shape, are determined by dynamic image analysis. From these results, the required geometries for the sieve and diffusor sieves to achieve homogenous samples are determined.

1 INTRODUCTION

Air pluviation is a method in geotechnics for creating uniform homogenous sand samples. It is a widely applied method with many different application fields. However, the main application is the creation of model soil samples for physical modelling due to the ability of reliably creating different sample densities. Here, uniformity and repeatability of the achieved sample is a main factor for soil sample quality, and the resulting physical experiments (Rad and Tumay, 1987).

Uniformity of sample density created with air pluviation depends on many factors. In this study, two influencing factors are investigated: the sieves and diffusor sieves chosen for pluviation. The sieve adjusts the deposition intensity of the pluviation set-up. The deposition intensity describes the mass flow per area on the sample and has been identified as one of the main factors affecting the resulting bulk density (Rad and Tumay, 1987) (Dastpak et al., 2021). Most set-ups use perforated plates as sieves, which can be classified by their opening diameters and the open surface in the sieve they create. The diffusor sieves distribute the sand homogeneously over the sample surface. The main construction methods here are quadratic meshes, which can mainly be classified by mesh size.

However, not only the geometries of sieves and diffusor sieves determine their effectiveness and therefore the properties of the received soil sample, but also the sand properties, like grain size and shape as well as grain size distribution (Dastpak et al., 1987).

Therefore, both need to be investigated as important aspects for the pluviation process. For this, deposition intensities of different sieves were investigated, and influences thereon identified. The goal is to be able to approximate the deposition intensities of future sands and sieves as the first step to predict pluviated sample densities. A further aspect is the size of the diffusor sieve meshes, and the resulting effect on the pluviation process as well as the achieved sample homogeneity. For this, both density distribution as well as particle size and shape distribution in the sample are investigated to determine which diffusor sieves result in the highest sample quality.

2 SAND PLUVIATION TEST STAND

For all experiments conducted in this study the same pluviation test stand was used, which can be seen in figure 1. The test stand consists of a silo, slide dampener, sieve, diffusor sieves, casing and sample container. The silo contains the sample before the tests. Below the silo, the slide dampener is attached, which opens at the beginning of the pluviation process.

Underneath the slide dampener the exchangeable sieve as well as the exchangeable diffusor sieves are located. For these investigations, only two diffusor sieves were used, which are attached 60 mm and 110 mm underneath the sieve, which is assumed to be sufficient to uniformly distribute the sand over the sample surface (Rad and Tumay, 1987). Underneath the diffusor sieves, a 300 mm casing is attached. The main pluviation apparatus, containing the silo, slide dampener, sieve, diffusor sieves and casing can be lifted with different speeds. This ensures that the casing is always slightly above the sample surface, and a loss of sample material, which would influence deposition intensity, can be avoided. Underneath the pluviation apparatus, a sample container is attached. This container is removable, which allows for a closer investigation of the sample. The container has a height of 200 mm and an internal diameter of 140 mm. For all tests in this study the falling height of 305 mm measured from the lowest diffusor sieve was held consistent during the pluviation process.

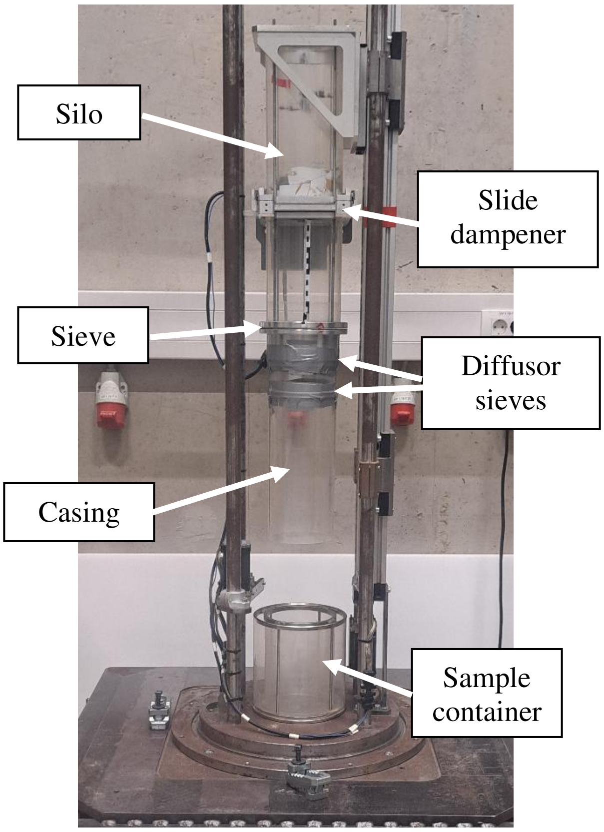

Figure 1. Pluviation test stand.

3 SAMPLE SANDS

To allow for a wide applicability of the results of this study the chosen sands have properties often used in physical modelling: (I) a poorly graded, medium to coarse sand (sieved sand), (II) a fine sand with small fines content (melt water sand) and (III) a medium, graded sand (sand box sand). The grain size distributions of these sands, determined by sieving (DIN EN ISO 17892-4, 2017), are shown in figure 2.

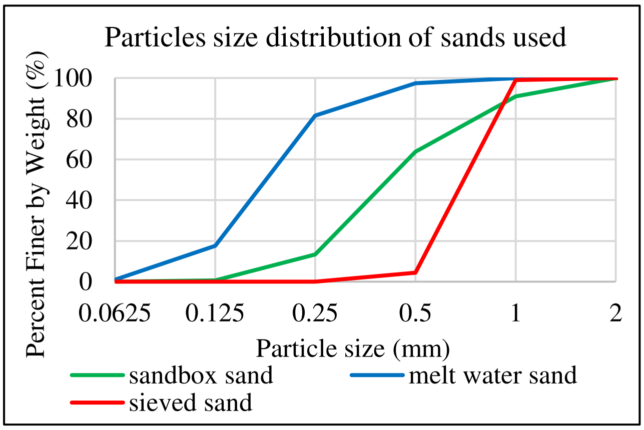

Figure 2. Particle size distribution of sands used.

The sands were further investigated using dynamic image analysis. This allowed for an additional determination of grain shape properties, which in combination with those determined by from the particle size distribution, are summarized in table 1. Based on the measurements, the chosen sands mostly differ in particle sizes and grading, while they share very similar grain shape properties. This allows for comparison of the later described experimental results.

Table 1. Particle properties of sands used.

property	sandbox sand	melt water sand	sieved sand
d_{10} [mm]	0.24	0.11	0.53
d_{50} [mm]	0.42	0.18	0.70
d_{90} [mm]	0.95	0.29	0.91
C_U [-]	2.0	1.8	1.4
width/length b/l [-]	0.719	0.711	0.714
sphericity	0.899	0.902	0.879
symmetry	0.905	0.897	0.903

4 SIEVES AND DIFFUSOR SIEVES

4.1 Sieve geometries

All sieves in this study consist of a perforated, 3 mm thick plate. To investigate the factors affecting deposition intensity, different sieve geometries were used. These geometries are defined by the opening ratio (ratio of open area to the total sieve area) and the diameter of the sieve openings. The planned opening ratios were 3 %, 10 % and 20 %, while the opening diameters ranged from 3 mm to 7 mm. However, after closer investigation, these intended diameters were not always achieved by the manufacturing process, which influences the behaviour during the flow through the sieve. Therefore, both the intended as well as real opening diameters are shown in table 2.

Table 2. Sieve geometries.

Sieve number	Opening ratio	Opening diameter	
		intended	real
1	3 %	3 mm	2.90
2	3 %	5 mm	4.90
3	20 %	5 mm	4.85
7	20 %	3 mm	2.80
8	20 %	4 mm	3.90
14	10 %	6 mm	5.90
15	10 %	7 mm	6.80
16	3 %	7 mm	6.75
17	20 %	7 mm	6.70

4.2 Diffusor sieves geometries

The diffusor sieves are all made of quadratic meshes, with a height of 5 mm and a thickness of 1 mm. In total 3 sets of diffusor sieves were created with distances between the centre of the meshes of 5 mm, 7 mm, and 9 mm. All diffusor sieves were 3D-printed, to avoid inconsistencies, which would affect sample homogeneity. An image of the diffusor sieve model used for 3D printing is shown in figure 3. For the experimental set-ups two diffusor sieves with similar geometry were used, with one being turned by 45°, to ensure the best possibly distribution of the sample material.

Figure 3. Model used for 3D-printing of diffusor sieves (7 mm mesh size).

5 INVESTIGATION ON DEPOSITION INTENSITY

5.1 Experimental set-up

To investigate the achieved deposition intensity DI, both the pluviation time t_p as well as the mass m_s in the sample container were measured. The resulting deposition intensities could then be calculated using equation (1)

$$DI = \frac{m_s}{t_p \cdot \frac{\pi}{4} \cdot d_s^2} \quad (1)$$

where d_s is the diameter of the sample. These preliminary experiments were conducted without diffusor sieves, as they do not affect mass flow if properly sized.

5.2 Flow behaviours

During this process, three different flow behaviours through the sieves could be observed: (I) no flow, (II) unsteady flow and (III) steady flow. During no flow all or most sand particles could not pass the sieve. Here, particle bridging over the opening developed and stabilized over time. During unsteady flow, particle bridging is not stable and constantly developed and collapsed over time or only developed for some sieve openings. This can lead to varied deposition intensities, changing both the average density as well as the homogeneity of the sample. This flow state is not always immediately visible, due to the fast nature of building and breaking of the particle bridging. However, certain results such as occasionally clogged sieve openings, varying sample densities or visible unsteady flow out of the sieve indicate this behaviour. Only during steady flow, deposition intensity stays consistent over time.

The development of the different flow behaviour was mainly defined by the ratio of sieve opening to particle size and the particle size distribution. While for the sieved sand, particle bridging with no flow was only observed for the 3 mm sieve openings and no unsteady flow could be observed, the sand box sand did show no flow for both sieves with 3 mm openings. Further a very unsteady and a still partially unsteady flow could be observed for the 4 mm and 5 mm openings respectively. While these sands have a similar d_{50} the sand box sand has a higher grading and therefore higher diameters for the larger particle sizes. For the melt water sand only steady flow could be observed for all sieve opening diameters. Here, the smaller d_{50} and d_{90} seem to be the main factor for this difference.

Comparing when the different flow behaviours occur, both particle sizes as well as particle size distribution need to be considered. Reported in other investigations, the ratio between sieve opening and mean grain size d_{50} was the main influence on this behavior (Dastpak et al., 2021). However, considering the results from these investigations, grain size distribution also seems to be an important factor. To show this, different ratios were examined in table 3. None of these ratios, except using both d_{90} and the coefficient of uniformity C_U, show good accordance between the sieved sand and the sand box sand, however not the meltwater sand. However, for this sand the diameter at which the flow becomes unsteady or stops could not be determined, so the given values are mainly assumptions. Thus, more investigations are required, especially using different particle size gradings, but also different particle shapes. However, it is generally recommended to choose the pluviation sieve with caution to avoid an unsteady flow, especially an unsteady flow that may not be easily recognized.

Table 3. Minimum ratios for full flow through the sieve openings.

ratios	sand box sand	melt water sand	sieved sand
$\frac{d_{\text{sieveopening}}}{d_{10}}$	25.0	27.3	7.5
$\frac{d_{\text{sieveopening}}}{d_{50}}$	14.3	16.7	5.7
$\frac{d_{\text{sieveopening}}}{d_{90}}$	6.3	10.3	4.4
$\frac{d_{\text{sieveopening}}}{U \cdot d_{50}}$	7.14	9.3	4.1
$\frac{d_{\text{sieveopening}}}{U \cdot d_{90}}$	3.2	7.2	3.1

5.3 Achieved Deposition Intensities

When investigating deposition intensities, examining the different sieve openings ratios separately is not sensible. This would limit the applicability to other scenarios, where different opening diameters may be used. Therefore, the mass flow per sieve opening was calculated using equation (2)

$$m_o = \frac{DI \cdot A_{sample}}{n_{opening}} \quad (2)$$

where DI is the deposition intensity after equation (1), A_{sample} the surface area of the sample and $n_{opening}$ describes the number of sieve openings. The number of sieve openings can be calculated after equation (3)

$$n_{opening} = RO_{sieve} \cdot \frac{d_{sieve}}{d_{opening}} \quad (3)$$

where RO_{sieve} is the opening ratio of the sieve, $d_{opening}$ the intended diameter of the opening and d_{sieve} the sieve diameter, which in the current pluviation test stand is equal to the sample diameter d_{sample}.

With respect to the afore described conditions, the diagram in figure 4 could be created depicting mass flow over sieve opening diameter.

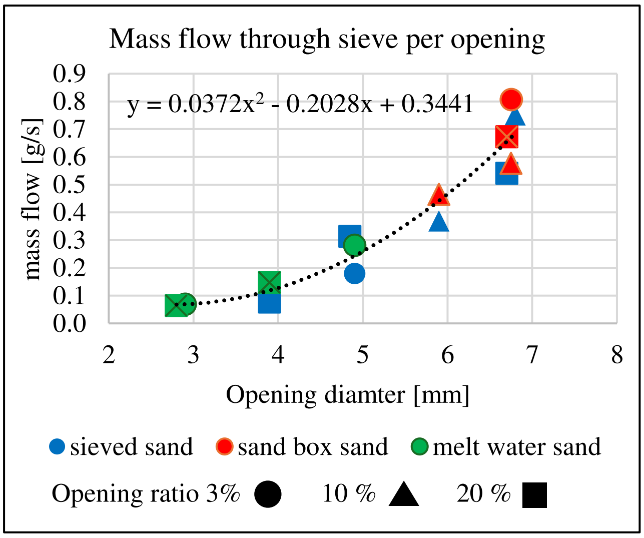

Figure 4. Mass flow over sieve openings.

Here, a correlation can be seen, which, at least for the here investigated sands, is not strongly influenced by the sand properties, such as particle size. However, there also seems to be uncertainty regarding mass flow, even when using the same openings ratio or opening diameter with the same sand as no definite pattern could be established. However, considering this and the formulas given above, an approximate deposition intensity can be determined, which is helpful in selecting a suitable sieve for future pluviation tests. Nevertheless, further investigations are also required, especially concerning different particle shapes and gradings.

6 INVESTIGATIONS ON DIFFUSOR SIEVES

6.1 Experimental set-up

To investigate the influence of the diffusor sieve, two approaches were taken. First, visual flow was observed. If inhomogeneities or unsteadiness are remarked, the resulting sample will not become homogenous. Second, for all flows showing similar flow behaviour, both particle size and density distribution in the sample were analysed. With this, suitable diffusor sieves for air pluviation of the different sands could be determined. As sieves with smaller opening ratios provide greater challenges for the diffusor sieves due to unequal mass distribution underneath the sieve, sieve 2 (5 mm – 3 %) was chosen for the melt water sand and the sieved sand, whereas sieve 16 (7 mm – 3 %) was chosen für the sand box sand.

6.2 Visual flow behaviour

The homogeneity or inhomogeneity of the flow underneath the diffusor sieves is one of the main factors affecting sample homogeneity. Therefore, visual observation of the flow is the first step in determining suitability of the applied diffusor sieves.

Here, two aspects to the flow behaviour were considered: (I) homogeneous distribution of material and (II) steadiness over time. Variability in either decreases sample quality. The results of the visual observation are summarized in table 4. The 5 mm diffusor sieves were not investigated for the sand box sand, because plugging of the openings, like for the sieve openings, was likely to occur. An example for the inhomogeneous and homogeneous flow is shown in figure 5.

Figure 5. Examples of inhomogeneous flow (left) and homogeneous flow (right) after diffusor sieves.

Table 4: Results of visual flow behaviour observation

Diffusor sieves	Sand box sand	Melt water sand	Sieved Sand
5 mm	-	Unsteady Inhomogeneous	Steady Homo-geneous
7 mm	Steady Homo-geneous	Unsteady Inhomogeneous But improvement	Steady Homo-geneous
9 mm	Unsteady Homo-geneous	Slightly unsteady Slightly inhomogeneous	Steady Homo-geneous

Based on these observations, the 5 mm diffusor sieves for the melt water sand and the 9 mm diffusor sieves for the sand box sand were not further investigated. For all other set-ups, sample quality was investigated by means of density and particle size distribution.

6.3 Density determination by Laser-Scanning

To determine the density distribution of the sample, small parts of the sample at different depths had to be excavated, and then both the mass of the material as well as the volume of the removed material had to be measured. To excavate the material without disturbing the bulk density of the sample, a suction tube was used. This method was also used to excavate between different depths. During this process, the sample container was placed on a scale, such that the weight before and after excavation could be determined. The resulting hollow, an example of which can be seen in figure 6, then was scanned using a laser scanner of the type HandySCAN BLACK Elite (Creaform, 2025).

Figure 6. Excavated hollow for density sampling (melt water sand, 5 cm depth).

The resulting scan (example in figure 7) then was further edited so that the hollow of removed material can be isolated. The resulting shape can is then virtually filled (figure 8), allowing for determination of the shapes volume.

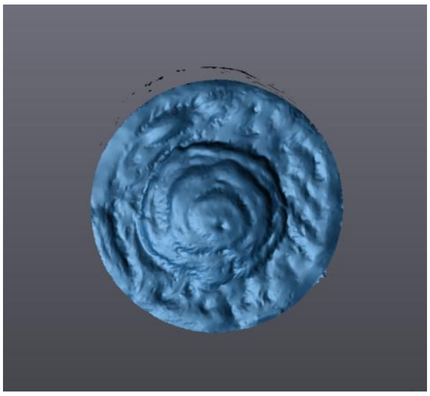

Figure 7. 3D scan of excavated hollow (melt water sand, 5 cm depth).

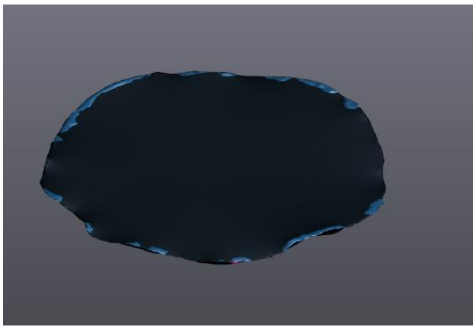

Figure 8. Processed 3D scan for volume determination.

The sample density was determined for sample depths (under the surface) of 0 cm, 5 cm, 9.5 cm, 14 cm and 17.5 cm. The given depth is always measured to the flat surface from which the hollow was created. Because the hollow requires a certain depth, this measurement technique cannot reach the sample bottom.

Because the sample container is constructed using transparent acrylic glass, the scanner did not record the side of the container. This had the benefit that, especially for lower depths, the hollows could not only be measured from the sample top but also from the sides. Without this, the hollows would not have been properly recorded. This, however eliminated the possibility of using a non-transparent container side, and therefore also the measurement of the density distribution on the outside of the sample. Therefore the density measurement could only be conducted in the sample middle.

6.3.1 Sieved sand

For the sieved sand the flow was steady and homogeneous for all diffusor sieves. However, the density distribution, which is depicted in figure 9, showed a certain variation over depth for all investigated samples. This variation was smallest for the 7 mm diffusor sieves, though not by a significant amount.

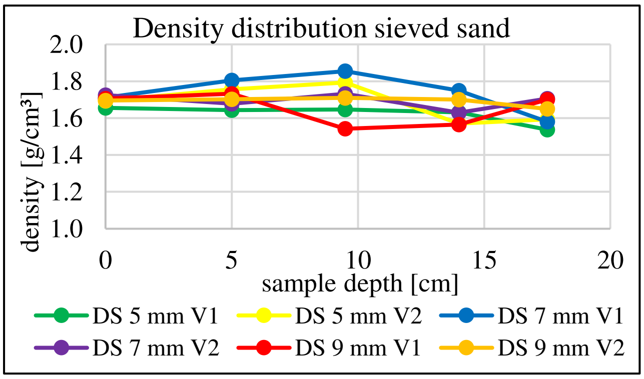

Figure 9. Density distribution over depth for the sieved sand samples.

6.3.2 Melt water sand

For melt water sand the density distribution (figure 10) is more homogeneous for the 9 mm diffusor sieves, which is in line with the observed flow (table 4). This can also be seen in the density variation between V1 and V2 for the 7 mm diffusor sieves, which was most likely caused by the unsteadiness and inhomogeneousness of the flow behaviour

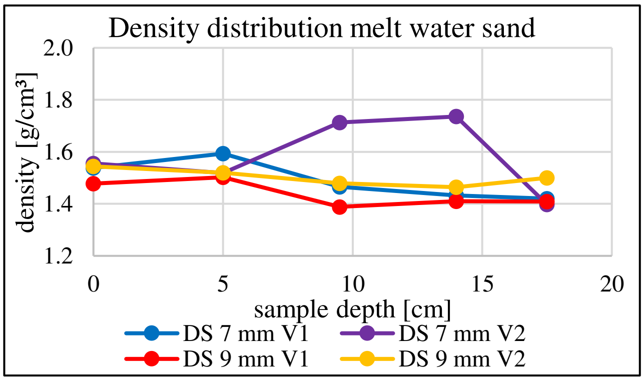

Figure 10. Density distribution over depth for melt water sand.

6.3.3 Sand box sand

For the sand box sand, only the diffusor sieves without uneven flow behaviour, with 7 mm mesh sizes was closer investigated. Therefore, a detailed evaluation of the influence of diffusor sieve mesh on the results is not possible at the moment. The here determined density distribution in figure 11 does however, still show significant variations, even with the observed homogeneous and steady flow.

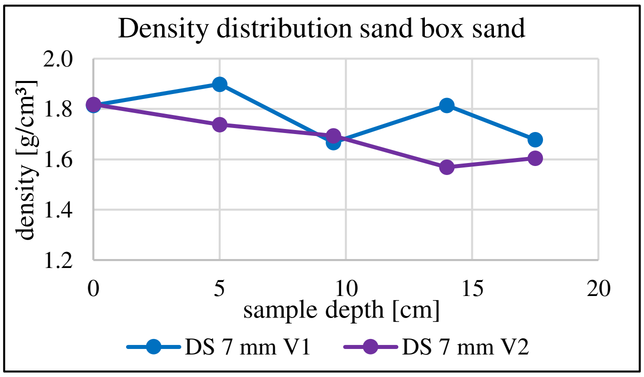

Figure 11. Density distribution over depth for sand box sand.

6.4 Particle size distribution determination with Dynamic Image analysis

To determine the particle size distribution, different samples were taken with a small scoop. For this, the same sample depths and excavation techniques as for density measurements were used. However, here, samples for both the middle and the sides of the pluviation sample were taken.

The samples were measured using the CamSizer X2 from microtrac. This allowed for measurement of both the particle size distribution as well as the distribution of the particle shapes in the sample.

To investigate the particle size distribution, the variation of d_{50} was used. While all particle size distributions showed a similar behavior over sample depth, variation was most significant for d_{90} and least for d_{10}. However, d_{90} showed more random behaviour, which could distort the results. Therefore, d_{50} is a good compromise between significance and reliability. An example of the differences between d_{10}, d_{50} and d_{90} for sand box sand and diffusor sieves 7 mm can be seen in figure 12.

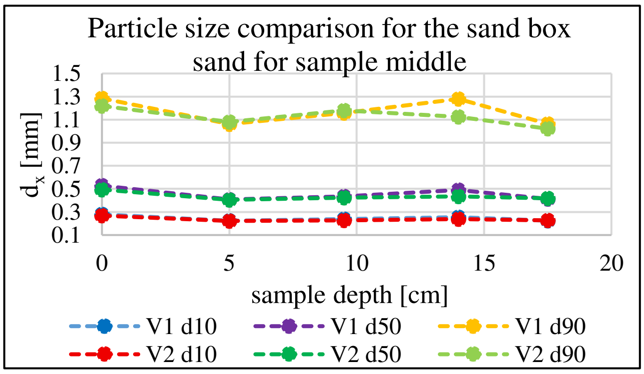

Figure 12. Particle size comparison of d_{10}, d_{50} and d_{90} for sand box sand for diffusor sieves 7 mm and sample middle.

Regarding the variation in particle shape, all measured parameters were investigated. However, none showed any significant variation for any of the regarded results such that all samples were homogeneous regarding particle shape.

6.4.1 Sieved sand

The distribution of d_{50} for the sieved sand can be seen in figures 13 to 15. Here, no significant differences between air pluviation using different diffusor sieves could be observed. Therefore, due to the improved density distribution, diffusor sieves with 7 mm mesh size are recommended for use with the sieved sand.

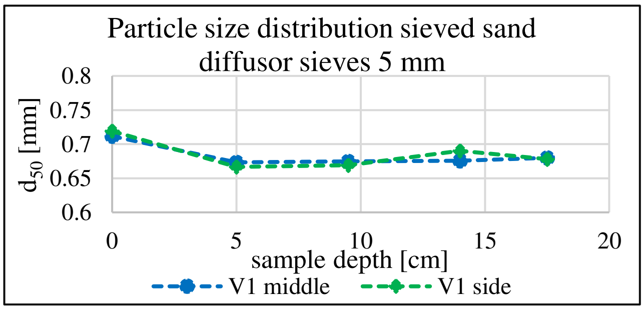

Figure 13. Distribution of d_{50} of sieved sand samples for diffusor sieve size 5 mm.

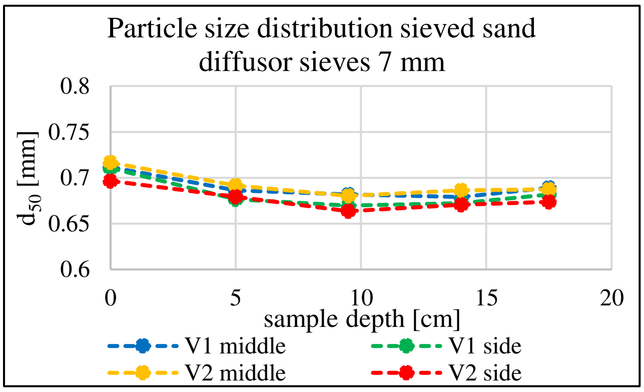

Figure 14. Distribution of d_{50} for sieved sand samples for diffusor sieves size 7 mm.

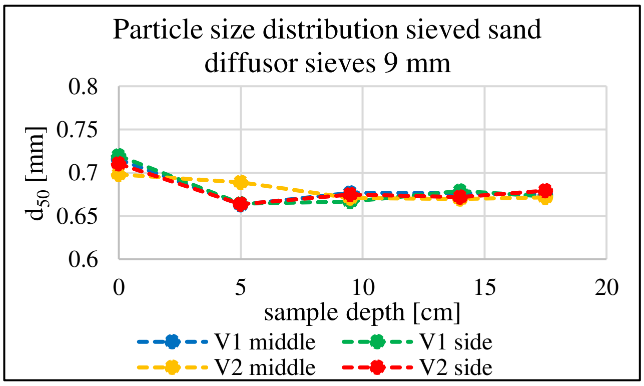

Figure 15. Distribution of d_{50} for sieved sand samples for diffusor sieve size 9 mm.

6.4.2 Melt water sand

The distribution of d_{50} (figure 16 and 17) for melt water sand is, contrary to the density distribution, less homogeneous for the 9 mm diffusor sieves. Here, the 7 mm diffusor sieves lead to better results. However, due to the improved results regarding density distribution and the more steady and homogeneous flow, the diffusor sieve with 9 mm mesh opening is recommended for this sand. However, further investigations with larger diffusor sizes should be conducted in future, to determine if the trend shown in table 4 leading to better results with larger mesh sizes can be justified.

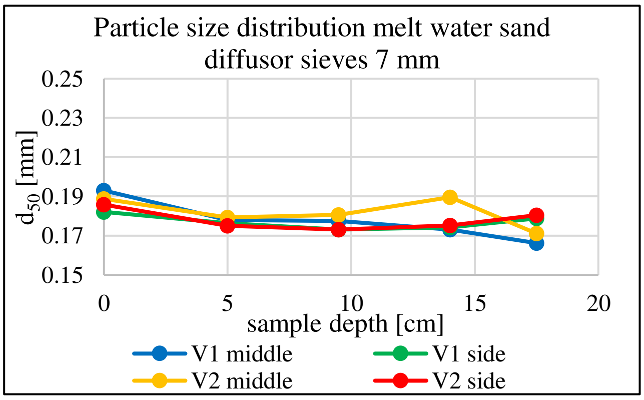

Figure 16. Distribution of d_{50} for melt water sand samples for diffusor sieve size 7 mm.

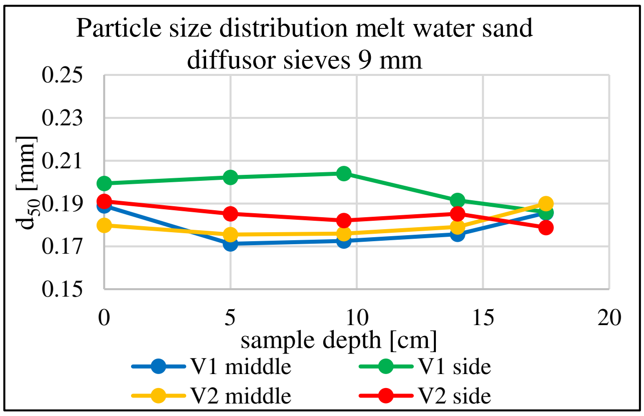

Figure 17. Distribution of d_{50} for melt water sand samples for diffusor sieve size 9 mm.

6.4.3 Sand box sand

Like for the density distribution, the distribution of d_{50} (figure 18), even with the steady and homogenous flow shows significant variations. Due to the best results during the visual flow, the 7 mm diffusor sieve is still recommended, however further investigations are needed with different mesh sizes to determine if an improvement is possible.

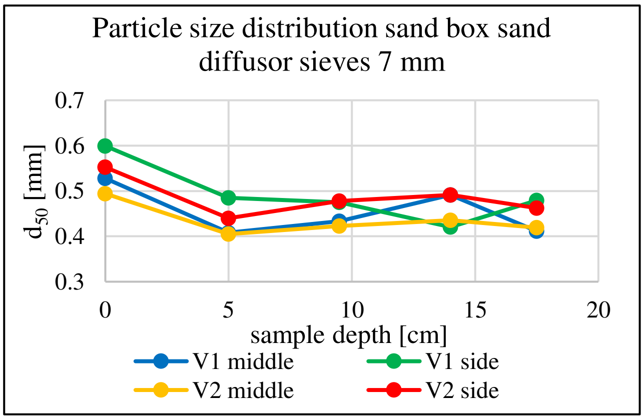

Figure 18. Distribution of d_{50} for sand box sand samples for diffusor sieve size 7 mm.

7 CONCLUSIONS

In this work, the influence of both the sieves and the diffusor sieves used during air pluviation was investigated regarding quality of pluviated samples.

For the sieves, a method for determination of the deposition intensity for future sieves was elaborated. This method should allow for easier selection of appropriate sieves for future testing. However, the effect of deposition intensity on sample density, but also on the sample quality still requires further investigation.

For the diffusor sieves, different geometries in form of mesh sizes were investigated, and the effect on the flow behaviour as well as density and grain size distribution of the sieved samples were investigated. Here, no clear pattern could be established concerning the size of the diffusor sieve in relation to particle sizes of the sands. Further investigations are required, especially as all sand samples, regardless of the used diffusor sieves, showed variety in density and particle size distribution. Therefore, this underlines the importance of proper choice of deposition intensity and diffusor sieve is significant during planning of air pluviation processes.

Finally, while no significant inhomogeneity regarding particle shape in the samples could be found, repeating the investigations using sands with different particle shape properties may lead to deeper understanding of the underlying processes, determining the quality of pluviated sand samples.

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