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A comparison of sieve-hydrometer and laser diffraction grading curves

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ABSTRACT: Particle size distributions obtained through sieve and hydrometer analyses were compared with those obtained through laser diffraction for silty sand and sandy clay samples. The effect of ultrasonication duration in the laser diffraction method was also evaluated. For the silty sand there was reasonable agreement between the laser diffraction and sieve-hydrometer grading curves, with the former marginally underestimating the fraction smaller than 0.03 mm diameter. In the case of the sandy clay, the laser diffraction underestimated the fraction smaller than 0.02 mm and overestimated the fraction larger than 0.02 mm. The effect of ultrasonication duration on the silty sand was limited, whilst the sandy clay sample showed significant increase in the volume of the finer fractions. For the sandy clay the incremental increase in the finer fraction after each ultrasonic impulse was of similar magnitude, indicating that the ultrasonic application was possibly too short to disperse all the agglomerated particles. For the sandy clay particles between 0.15 mm and 1mm, whilst there was close agreement between the laser only curves and the sieve analysis, a volume increase in finer fractions after ultrasonication was observed, indicating either particle disintegration or that the agglomerations were not effectively dispersed during the sieve analysis.

1 INTRODUCTION

The particle size distribution of a soil is one of its fundamental properties related to composition and the determination thereof is part of most laboratory testing programmes in geotechnical investigations. Various methods can be employed to determine grading curves: these include the classical procedures of wet or dry sieving, sedimentation techniques such as the hydrometer or pipette methods (Gee & Bauder 1986) and the use of X-ray attenuation, electrical resistance and laser diffraction methods (Eshel et al. 2004). Amongst these the sieving, hydrometer and laser diffraction methods are more frequently used and are of relevance to the topic under discussion in this paper.

1.1 *Sieve and hydrometer analysis*

With a sieve analysis, carried out on the larger than 0.075 mm diameter portion of the sample, the intermediate "calliper" diameter of the individual soil particles is measured and is expressed in terms of the total mass for a specific range of particle diameters. The analysis is affected by the particle density and the results are effectively rather a measure of the weight distribution than the size distribution (Blott et al. 2004). It should be noted that the sample is not treated with a chemical dispersant for the sieve analysis and aggregated particles will skew the results accordingly.

The hydrometer test can be used to approximate the grading curve for particle diameters smaller than 0.075 mm. According to Allen (1990), and Konert & Vandenberghe (1997), the hydrometer method "defines a particle diameter as equivalent to that of a sphere settling in the same liquid at the same speed as the unknown sized particles" being tested, based on Stokes' law. In essence, the measurement is based on the difference in density of the particles and of the suspension, assuming spherical particle shapes (Wen et al. 2002). To overcome the difficulties of aggregated particles, the sample is chemically dispersed to separate individual silt and clay particles. As silt sized particles are often irregularly shaped and clay particles tubular or platy, the assumptions of Stokes' law are not satisfied leading to an overestimation of the fine size fraction of the soil (Di Stefano et al. 2010). In addition, Stott et al. (2016) found that the agglomeration of the fine silt or clay particles in the hydrometer test can lead to the overestimation of the silt fraction and underestimation of the clay fraction.

Different types and concentrations of dispersing agent lead to different particle size distributions from the hydrometer test. Different types of soils also react differently to the same dispersing agent.

1.2 *Laser diffraction*

With the laser diffraction method, a laser beam is passed through a suspension containing the sample. The diffracted light is focussed onto detectors which measure the light intensity. Based on the principle that the angle of diffraction is inversely proportional to the particle size, the particle sizes in the sample are back calculated from diffracted light measurements. Two optical models are commonly used in the calculation – being either the Fraunhofer diffraction model or Mie theory (Eshel et al. 2004). The resultant particle size distribution is expressed in terms of volume, and not in terms of mass as in the case of the classical methods described above. Laser diffraction can typically size sample from a maximum particle size of 2 000 micron down to 0.1 micron.

Loizeau (1994), Buurman (2001) and Eshel et al. (2004) all found that the laser diffraction method underestimates the clay fraction of the soil when compared to the pipette method (with the pipette results regarded as comparable to hydrometer results). In addition, Di Stefano et al. (2010) concluded that laser diffraction overestimates the silt fraction. With regard to the sand fraction, the sand size grading from laser diffraction methods was found to be similar to the sieve analysis results.

One of the techniques used to disperse agglomerated soil particles in the laser diffraction procedure is ultrasonication. The duration of ultrasonic application can influence the resulting particle size distribution. Over exposure may lead to the disintegration of quartz particles (Di Stefano et al. 2010 and Blott et al. 2004) or even the aggromation of particles if used with chemical dispersants (Ryżak & Bieganowski 2011) or in the absence of chemical dispersants (Blott et al. 2004). Different authors have also recorded varying durations of ultrasonic application: Di Stefano et al. (2010) found no change in the particle size distribution when ultrasonication for 1, 2 and 3 minutes and used a duration of 2 minutes in their investigations. The data presented is for a clay fraction of 20 %. Blott et al. (2004) found that a 2-minute ultrasonication altered the particle size distribution significantly due to the disintegration of coarser particles and used a 90 second duration in their testing. Ryżak & Bieganowski (2011) applied ultrasound for 4 minutes at a maximum power of 35 W.

When compared to the sieve-hydrometer method, laser diffraction uses a small sample and the test can be completed in a few minutes (Di Stefano et al. 2010). In addition, the laser diffraction method is less operator dependent.

1.3 *Scope of current study*

As part of a broader research project, particle size distributions were determined for clayey and sandy soils using both the classical sieve-hydrometer methods and laser diffraction technology. This paper presents an evaluation of these results in light of the preceding discussion. Of specific interest is the comparison of the grading curves between the two methods for the sandy and clayey soil, respectively, and the impact of ultrasonication duration on the sandy and clayey samples.

2 EXPERIMENTAL PROCEDURE

Fourteen soil samples were obtained from test pits excavated on a farm near Sasolburg in the Free State province. The typical soil profile comprises a 0.5 m thick hillwash horizon overlying residual sandstone and soft rock sandstone at a depth of 3 m. The hillwash classified as a silty sand and the residual sandstone as a sandy clay. The plasticity index values for the silty sand ranged from non-plastic to 6 % and between 19 % and 27 % for the sandy clay. For the silty sand, liquid limit values between non-plastic and 16 % were recorded whilst the sandy clay's liquid limits ranged from 39 % to 62 %. Six silty sand samples and eight sandy clay samples were evaluated in this study.

The sieve analysis and hydrometer tests were carried out by a SANAS accredited commercial geotechnical laboratory according to the TMH1 A1 and A5 methods (Committee of State Road Authorities 1986) and ASTM D422 (ASTM 2007).

The laser diffraction was done using a Mastersizer 2000E particle analyser at the civil engineering laboratory of the University of Pretoria. After oven drying the samples, the particles were gently crushed and sieved to obtain the smaller than 1mm diameter fraction. Samples were suspended in distilled water (no chemical dispersant was used) and then analysed. At first, the samples were scanned with the laser twice, after which two ultrasonic impulses, each with a duration of 15 seconds, were applied to the suspension. A reading was taken after each of the impulses (Doman 2019). Thus, a total of 4 particle size distributions were recorded for each of the samples: two with the laser only and two with the laser and ultrasound. The particle size distributions were calculated using Mie theory (Truter 2019).

3 RESULTS AND DISCUSSION

3.1 *Laser diffraction vs. sieve-hydrometer analysis*

In general, the particle size distribution of the silty sand samples (hillwash) showed reasonable agreement between the laser diffraction and sieve-hydrometer analysis, with the laser diffraction marginally underestimating the fraction smaller than 0.03 mm. This is evident from the grading envelopes for all the hillwash samples in Figure 1 and the individual results for sample TP02-2 in Figure 2. In Figure 2 "Laser" refers to the laser only measurements and “L&U” refer to the addition of the ultrasonic impulse.

As the laser diffraction was only done on the smaller than 1 mm diameter fraction of the sample, the results from the sieve-hydrometer analysis were normalised to 1 mm for comparison purposes. It must also be kept in mind that the sieve-hydrometer curves are expressed in terms of mass percentage and the laser diffraction curves based on volume percentage. A direct comparison of the distributions assumes that the particle densities (specific gravity) of the two samples are the same for the entire range of particle sizes. It is for this reason that SANS 3001 now requires a separate SG to be determined for the sub 75 micron fraction to be used for the hydrometer analysis.

The results are similar to the observations recorded in Section 1.2, in that agreement is found between the sieve-hydrometer and laser diffraction methods when applied to a silty sand sample.

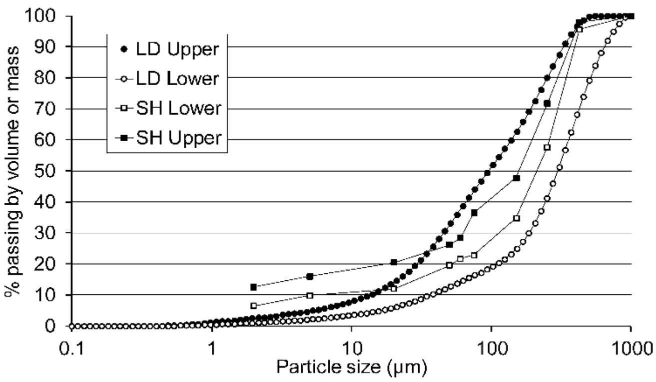

Figure1. Laser diffraction (LD) and sieve-hydrometer (SH) grading envelopes for silty sand.

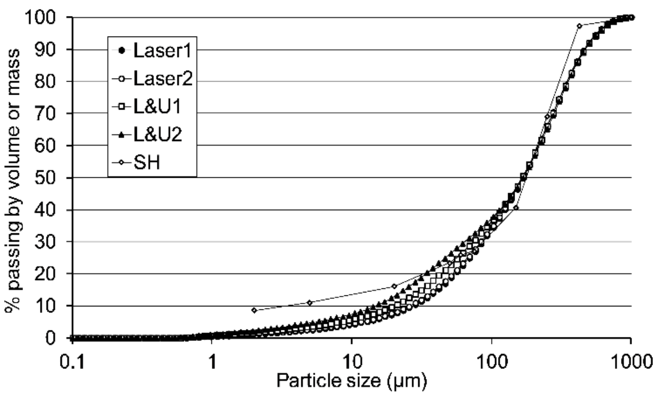

Figure 2. Laser diffraction and sieve-hydrometer (SH) grading curves for TP02-2.

For the sandy clay (residual sandstone) there is significant discrepancy between the sieve-hydrometer and the laser diffraction results. As shown in Figure 3 and Figure 4, for the fraction larger than 0.02 mm diameter, the laser diffraction shows a greater volume percentage whilst for the fraction smaller than 0.02 mm diameter the laser diffraction underestimates the distribution.

The results correspond to the findings reported in Section 1.2 where the laser diffraction overestimates the silt fraction and underestimates the clay fraction.

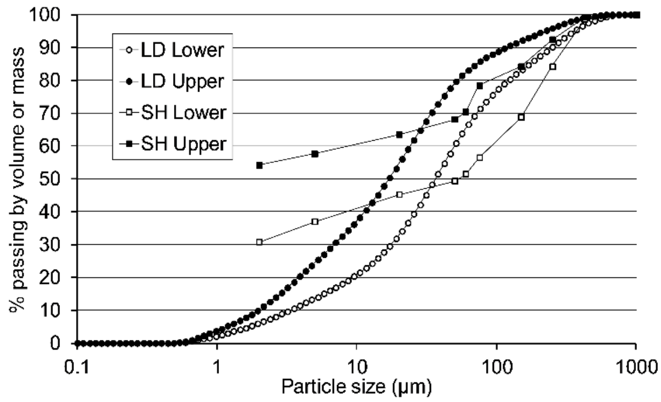

Figure 3. Laser diffraction (LD) and sieve-hydrometer (SH) grading envelopes for sandy clay.

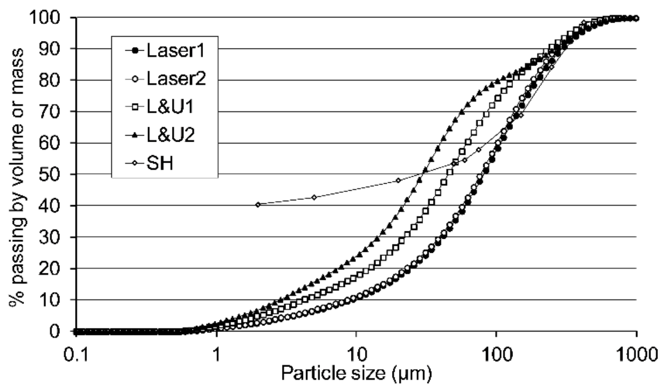

Figure 4. Laser diffraction (LD) and sieve-hydrometer (SH) grading envelopes for TP05-1.

3.2 *Effect of ultrasonication*

In general, the application of the ultrasonic impulse had a greater impact on the sandy clay samples than on the silty sand samples.

Figure 5 and Figure 6 show the cumulative and non-cumulative changes in the particle size distribution for sample TP09-3 (silty sand) before and after each of the impulses were applied. It is evident that the increase in volume in the smaller particle ranges was limited and only affected the fraction smaller than 0.2 mm.

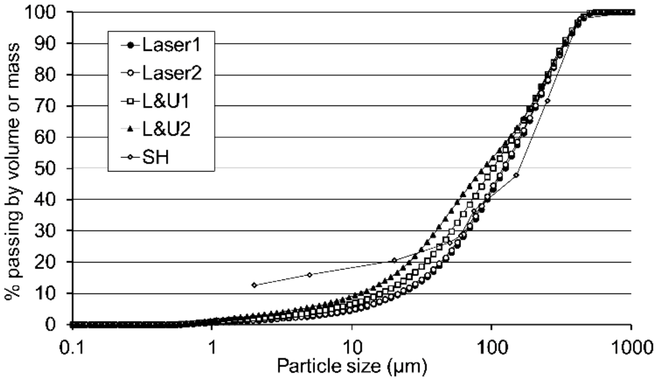

Figure 5. Incremental cumulative particle size distributions for laser diffraction stages of TP09-3.

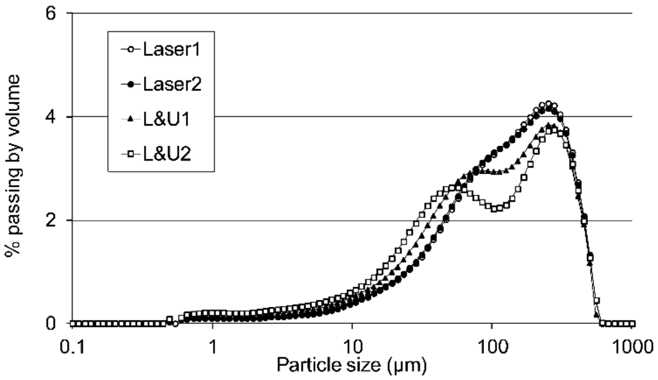

Figure 6. Non-cumulative particle size distributions for laser diffraction stages of TP09-3.

Figure 7, Figure 8, Figure 9 and Figure 10 show similar data as above for sandy clay samples TP10-2 and TP03-3. It is clear that although the laser only distributions show repeatability, the influence of the ultrasonic impulse is significant. For both samples, the change in magnitude of the distribution after the second ultrasonic impulse is similar to after the first impulse.

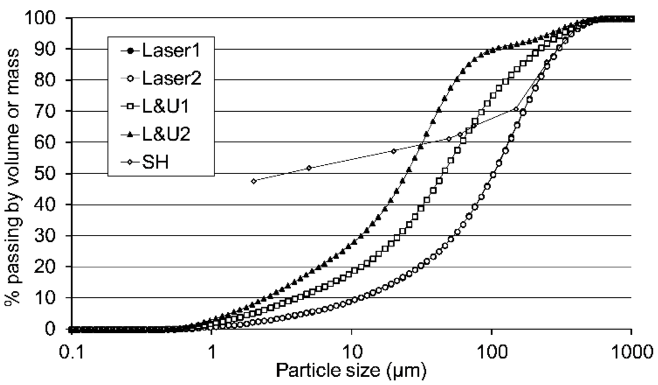

Figure 7. Incremental cumulative particle size distributions for laser diffraction stages of TP10-2.

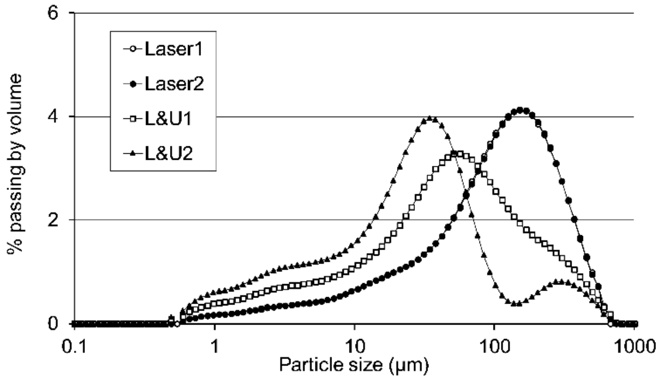

Figure 8. Non-cumulative particle size distributions for laser diffraction stages of TP10-2.

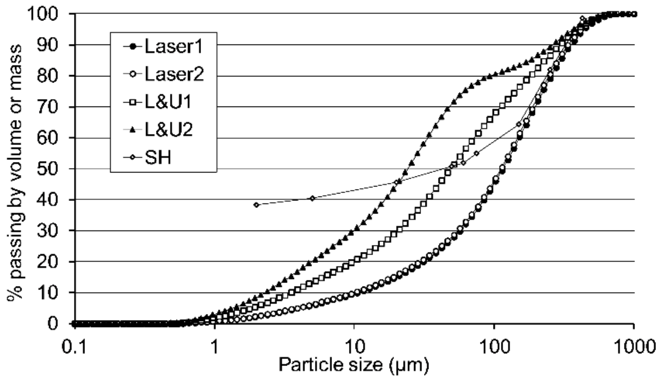

Figure 9. Incremental cumulative particle size distributions for laser diffraction stages of TP03-3.

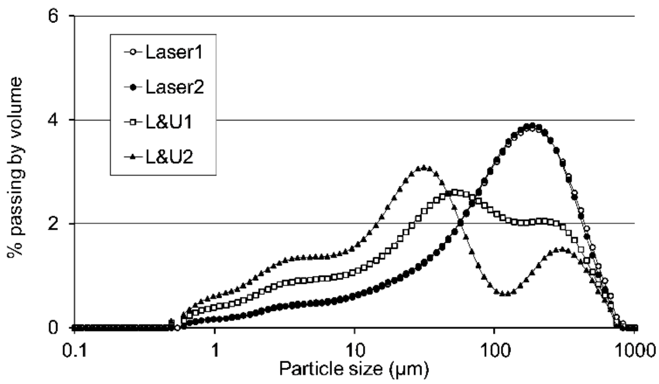

Figure 10. Non-cumulative particle size distributions for laser diffraction stages of TP03-3.

This is an indication that perhaps the application of the ultrasonic impulse for only two 15 second durations were not successful in dispersing the agglomerated particles sufficiently. The observation that all the ultrasonication durations mentioned in Section 1.2 were significantly longer than 30 seconds, further underlines the view that longer impulses may result in dispersing the agglomerated particles more successfully.

It needs to be kept in mind that even with the longer impulse durations referred to in Section 1.2, the laser diffraction still underestimated the clay fraction distribution. As such, the objective is not to keep increasing the duration until the distributions are aligned, but rather to increase the duration until the change in distribution is insignificant.

A further observation from Figure 7 and Figure 9 is that for the fraction between 0.15 mm and 1 mm diameter, there is close correlation between the sieve analysis and laser diffraction without the ultrasonication. However, once the ultrasonic impulse is applied, there is significant deviation from the laser only curves which will not be recovered by further ultrasonication. This deviation can either be due to the disintegration of some of the particles or the dispersion of agglomerations. The latter cause implies that both the sieve analysis and first laser scans of this fraction are incorrect.

4 CONCLUSIONS

The particle size distributions obtained through sieve and hydrometer analyses were compared with those obtained through laser diffraction for both silty sand and sandy clay samples. In the case of the silty sand there was reasonable agreement between the two grading curves with the laser diffraction marginally underestimating the fraction smaller than 0.03 mm. For the sandy clay, the laser diffraction underestimated the fraction smaller than 0.02 mm and overestimated the fraction larger than 0.02 mm.

The effect of ultrasonication on the silty sand was limited, while the sandy clay sample showed significant increase in the volume of the finer fractions. The observation that the incremental increase in the finer fraction after each ultrasonic impulse was similar, indicated that the ultrasonic application may not have been long enough to disperse all the agglomerated particles in the sample.

This study has confirmed the observations in literature that the particle size distributions for sandy soils as determined through laser diffraction, compare well with those determined through sieve-hydrometer analyses. For clayey soils, laser diffraction underestimates the clay fraction.

It is concluded that the laser diffraction method can be more readily used to obtain gradings curves for sandy soils. Not only due to the close agreement with the sieve and hydrometer results, but also due to the the small sample size required, the speed of testing and lower operator dependency. If clayey soils are to be analysed, care needs to be taken to evaluate if sufficient disaggregation of the soil particles was achieved by visual examination of the samples similar to Stott et al. (2016).

5 RECOMMENDATIONS

Further research to evaluate the influence of ultrasonic impulse duration on the sandy clayey samples is recommended. Of particular interest is the magnitude of dispersion achieved for each increment of ultrasonication. After each increment, the samples can be analysed photographically, similar to Stott et al. (2016), for analysis purposes.

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