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The Impact of Ultrasonic Waves on Soil Classification through Hydrometer Testing

Influencia del empleo de ondas ultrasónicas en la clasificación del suelo con el ensaye de hidrómetro

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ABSTRACT: This study investigates the use of ultrasonic dispersion in hydrometer testing for soft soils in Mexico City and tailings. The procedure consists of preparing a suspension with sodium hexametaphosphate and shaking it with ultrasound before transferring it to a sedimentation cylinder. The results show that ultrasonic agitation causes a change in the gradation curves, decreasing the silt content and increasing the clay content. The ultrasonic process can cause a significant change in clay content, suggesting that the usual deflocculation process may be ineffective in some cases. Although the use of ultrasound increases the clay content, it generally has a limited effect in the cases studied when the full particle size distribution curves are considered. It was also observed that the changes in clay content were not dependent on whether the fine-grained soil was natural or artificial.

KEYWORDS: Ultrasonic, hydrometer, clay content, size distribution curve.

1 INTRODUCTION.

The plasticity diagram is used to determine the type of soft soil that makes up the deposits in Mexico City, as well as its degree of plasticity. However, it is common for some of the soils in these deposits to be exactly on line A (Fig. 1), making it difficult to determine whether the soil is clayey or silty, and therefore it is convenient to carry out additional laboratory tests such as the conventional sedimentation method, the hydrometer test, or other modern techniques such as the laser diffraction method and digital imaging (Arriaga *et al*, 2006; Edizer, 2006).

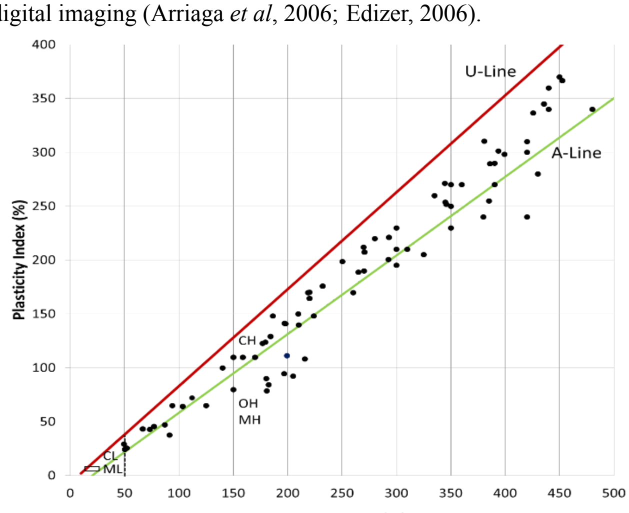


Figure 1. Plasticity chart with soil data from Mexico City.

It would seem that there have been a number of papers published which have compared different methods for determining the size distribution curve for fine soils (*i.e.* Fisher *et al*., 2017, Makó *et al*., 2017, Bieganowski *et al*., 2018, Makó *et al*., 2019, Igaz *et al*., 2020, Goraczko and Topolinski, 2020; Bittelli *et al* 2022).

The results of the comparisons were sometimes inconsistent. However, the main conclusion from most authors was that sedimentation techniques may overestimate the clay fraction, while laser and digital methods, which produce similar results, may tend to underestimate the clay fraction.

1.1 *Hydrometer test*

The hydrometer test is used to determine the particle size distribution curves of a soil with equivalent diameters less than 75μm (Fig 2), *i.e.* the size distribution of fine-grained soils, by measuring the density of a fluid (water, soil, and a dispersing agent) with a hydrometer. In this test, the sedimentation process is represented by Stokes' law, therefore, it is established that particles are spherical, the sedimentation process of the suspension is free and continuous, and that there is a relationship between the equivalent diameter of a particle in a liquid medium and its sedimentation rate, and from the sedimentation time observed, the percentages of fine sand, silt and clay are determined.

1.1.1 *Hydrometer test limitation*

When determining the particle size distribution in fine soils by hydrometer analysis, especially in clayey soils, it is common for soil particles to agglutinate and form lumps, artificially increasing the percentage of fine sand or silt and decreasing the percentage of clay, so that the particle size distribution curve is inadequate under these conditions. Therefore, an important aspect of the test is to ensure that all particles are separated. This is achieved by using a dispersant, which is usually a sodium metaphosphate solution, $(NaPO_3)_{13}\cdot Na_2O$, also known as sodium hexametaphosphate.

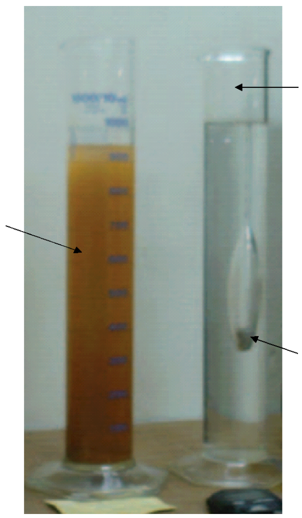


Figure 2. Hydrometer test.

However, in certain soil conditions it is necessary to apply additional procedures to ensure dispersion of all soil-forming particles. Some of the various dispersion methods include end-over-end, electro-magnetic mixers, mechanical mixers, air jet dispersers and ultrasound. Of these methods, mechanical mixers and air jet dispersers are the most used.

This phenomenon also occurs when the laser diffraction method is used, but in this case an ultrasonic destruction technique is applied.

1.1.2 *Effects of proper dispersion*

Various studies have compared the application of the various dispersion techniques, and it has been verified that the granulometric curves obtained are different. In Hall's study (NYSDOT 2015a), it was found that the difference between the granulometric curves varied between 20% and 30%, while the New York State Geotechnical Engineering Bureau (NYSDOT 2015b) found that for the soils studied, the variation decreased between 3% and 5%. Although the studies recommend the use of the air jet dispersion method, it is concluded that it is possible to use the mechanical mixing apparatus because the procedure is simple, fast and does not cause the soil degradation observed in the air jet dispersion method.

1.2 *Purpose of this research*

In the present work, the application of the ultrasonic dispersion method to the determination of the size distribution of fine-grained soils with the hydrometer is studied for two types of soil deposits: the very soft soils of Mexico City and the tailings.

2 PROCEDURE

The procedure used is the one described in ASTM D7928, but with the variant that before mixing the slurry using the cylinder tipping method, the saturated sample is agitated for 3 to 5 min with ultrasonic equipment (Ultrasonic Cleaner, Fig 3). In summary, the process is as follows:

1. *Sample preparation and deflocculant*. The sedimentation sample consists of 50 g of fine dry soil passed through a 200 mesh sieve and a deflocculant consisting of 5 g of sodium metaphosphate in 125 ml of distal water (1 day).
2. *Slurry*. Saturation of the sediment sample with the deflocculant solution and rest (16 hours).
3. *Stir the suspension* (3 to 5 minutes) using a mechanical mixer.
4. *Stir with ultrasound*. The slurry is additionally subjected to ultrasonic vibration for 3 to 5 minutes using the Ultrasonic Cleaner.
5. *Transfer the slurry to the sedimentation cylinder* by filling to the 1 L mark with distilled water.
6. *Mix the slurry* using the cylinder tipping method (1 minute).
7. *Read the hydrometer (152H) and temperature* at approximately 1, 2, 4, 15, 30, 60, 240, 1440, 2160 and 2880 minutes.

Figure 3. Ultrasonic Cleaner equipment used during the test.

3 RESULTS

In order to assess the importance of using the sodium metaphosphate solution (NaPO3)13·Na2O together with ultrasonic agitation in dispersing soil particles during the hydrometer test, sedimentation tests were carried out on different types of soil from different sites: natural soft soils (lacustrine and alluvial sites) and young artificial soils (tailings). Two hydrometer tests were carried out on each soil type, one with the sodium hexametaphosphate solution alone (normal procedure) and the second with the same dispersant plus ultrasonic agitation (ultrasonic procedure).

Fig 4 shows the results in terms of the grain size distribution curves of fine-grained soils using hydrometer analysis for two cases studied, sites 4 (lacustrine deposit) and 8 (tailings deposit), and for the two execution procedures: normal (blue line) and ultrasonic (orange line). In both cases it can be seen that the effect on the gradation curve of the fine-grained soil when using the ultrasonic equipment is to shift the curve upwards, mainly in the silt zone, causing the silt content to decrease and the clay content to increase by the same amount.

Fig. 5 shows the total results in terms of silt and clay percentages determined at each site with the two methods (normal and ultrasonic). The same effect can be observed in all the cases studied: a decrease in the silt content and an increase in the clay content.

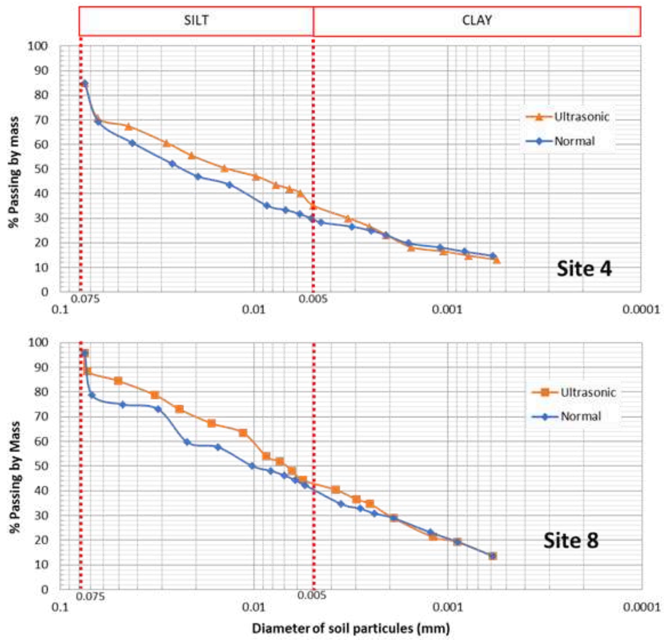


Figure 4. Particle size distribution curves of fine-grained soils using hydrometer analysis with deflocculant $(NaPO_3)_{13}\cdot Na_2O$ only (normal method, blue line) and deflocculant and ultrasonic agitation (ultrasonic method, orange line) for sites 4 and 8.

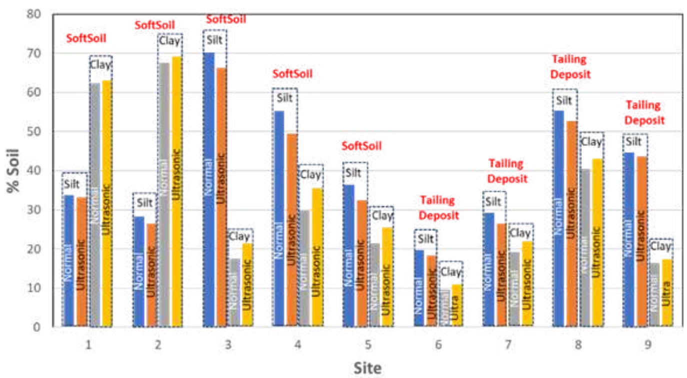
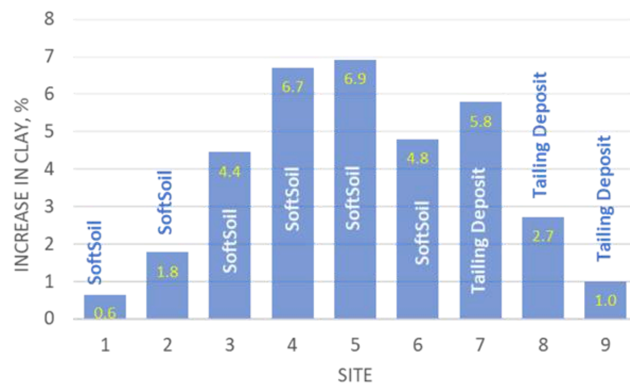


Figure 5 shows the silt and clay content obtained using the hydrometer for the studied cases, considering both the normal and ultrasonic dispersion procedures.

Fig 6a demonstrates that the ultrasonic equipment produces a change in the clay content of the soil, resulting in a variation between 1% and 22.3% across all cases studied. This indicates that while the change can sometimes be small, it can also be considerable. Importantly, the variations do not appear to depend on the type of soil. The ultrasonic procedure clearly demonstrates that the deflocculation process was inefficient in some cases. Fig 6b displays the percentage increase in clay content relative to the percentage of fines in the soil sample, which is equivalent to the decrease in silt content. This provides a comprehensive representation of the change in clay percentage, accounting for the granulometric composition of the entire soil sample. The increase in clay percentage ranges from 0.6% to 6.9%, regardless of whether the soil is natural or artificial, and is consistently lower than the previously mentioned values.

a) The clay content changes in proportion to the percentage of clay that is obtained from the normal process.



b) The clay content changes in proportion to the percentage of fines in the soil.

Figure 6 shows the increases in clay content achieved by using the procedure with a deflocculant agent and ultrasonic stirring for all the studied cases.

4 CONCLUSIONS

This work explores the impact of an additional slurry deflocculation step through ultrasonic stirring prior to mixing the slurry using the cylinder tipping method in the hydrometer test. The results indicate that the ultrasonic process does influence the determination of the clay content, *i.e.* it helps in the deflocculation of the slurry, but although it can be important in relation to the clay content determined with the conventional procedure (between 1 and 22.6%, for the cases studied), the effect on the particle-size distribution curves of fine-grained is limited (between 0.6% and 6.9%). The changes in clay percentages observed in the studied cases are independent of whether the fine-grained soil is natural or artificial.

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