Research Note

COMPARISON OF THE CASAGRANDE AND DROP-CONE PENETROMETER METHODS FOR MEASURING THE LIQUID LIMIT IN PUERTO RICAN SOILS[1,2]

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The liquid limit (or upper plastic limit) of a cohesive soil is defined as the minimum gravimetric water content (percentage) at which a small sample of soil will barely flow under a standard treatment (McBride, 2002). Tests have indicated that the liquid limit corresponds to the soil water content where shear strength resides between 1.7 and 2.0 KPa, the soil water matric potential is about – 6 KPa, and the saturated hydraulic conductivity is about 2.5 x 10^{-9} m/sec (Mitchell, 1993). The liquid limit, together with the water contents at the *lower plastic limit* and the *shrinkage limit,* represent the three major points in transition of soil behavior between solid, semi-solid, plastic and liquid states (McBride, 2002).

Two major methods are currently used to measure the liquid limit: the Casagrande method (ASTM, 2000) and the drop-cone penetrometer method (BSI, 2000). The Casagrande method is the method most used in the United States of America. A pat of wet soil slurry is placed in the metal cup of a standard American Society for Testing and Materials (ASTM) liquid limit device (Figure 1), and a groove of specified depth, width and side slope is cut through the slurry. The cup is cyclically raised and dropped onto a hard surface, and the liquid limit is taken as the water content at which the edges of the groove flow together for 1.3 mm under the impact of 25 blows.

The drop-cone method (Figure 2) is most widely used in Europe and Asia (Das and Sobhan, 2014). A standard 30° cone is placed in contact with the soil surface and allowed to sink freely into the soil in a standard size tin for a period of five seconds. The liquid limit is taken as the water content at which the cone penetrates to a depth of 20 mm into the soil.

The objective of this study was to compare the Casagrande and drop-cone methods for measuring liquid limit on a set of 126 soil samples from Puerto Rico. The study formed part of a Collaborative Agreement between the University of Puerto Rico Agricultural Experiment Station and the Natural Resources Conservation Service (NRCS) of the US Department of Agriculture (USDA), with the goal of comparing estimates of Atterberg Limits published in Soil Survey Reports with values measured in the laboratory (Snyder, 2015).

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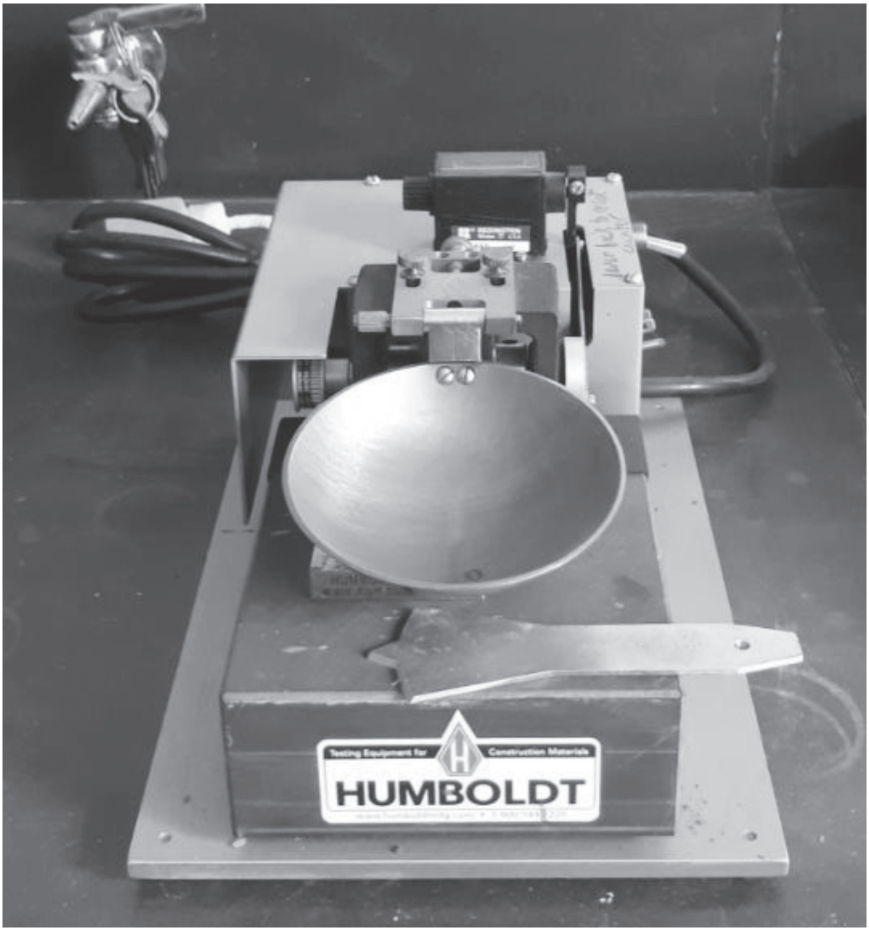

FIGURE 1. Photo of the Casagrande liquid limit device used in the study

Soils and Sampling locations

Soil samples were taken from A_p and B horizons of seven major soil series of Puerto Rico representing a wide range of clay mineralogy classes. The soil series and corresponding classifications according to the USDA Soil Taxonomy system (Soil Survey Staff, 1999) are shown in Table 1 (Muñoz et al., 2018). Three sampling sites corresponding to each soil series were identified with use of soil maps. A map of Puerto Rico showing the locations of the sampling sites is shown in Figure 3.

At each sampling site shown in Figure 3, three sub-sites were established in a roughly triangular pattern with apices separated by approximately 20 m. At each sub-site approximately 2 kg of soil were taken from the A_p and B horizons and stored in plastic bags for transport to the laboratory.

The total number of soil samples, corresponding to seven soil series, three sampling sites per series, three sub-sites per site and two soil horizons at each sub-site, added

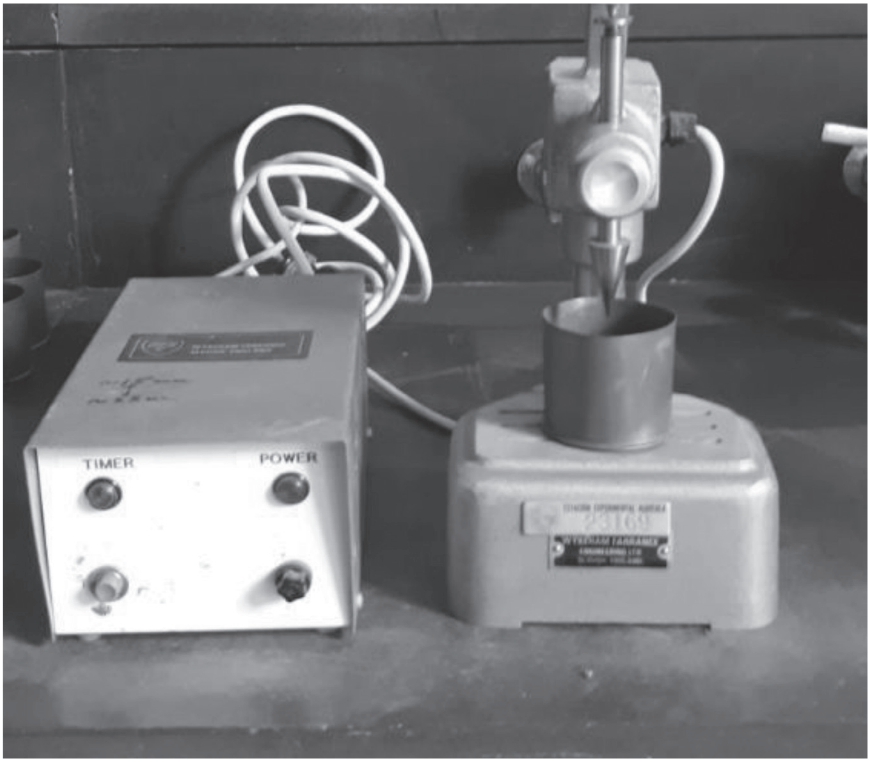

FIGURE 2. Drop-cone penetrometer apparatus used in the study (right) with timer on the left.

up to 126 samples. Soil textures, determined by the pipette method (Gee and Or, 2004), ranged from coarse-loamy to clayey.

Sample processing procedures

As specified by methods ASTM D-4318 (2000) and BS-1377 (2000) for the Casagrande and drop-cone techniques, respectively, only the soil fraction passing through a 0.425 mm sieve was retained for analysis. A wet-sieving procedure was used, as described in ASTM D-4318. Approximately 2 L of disturbed field-moist soil was placed on a sieve that was submerged under approximately 2 cm of distilled water in a large pan containing approximately 8 L of water. The soil was gently rubbed across the sieve surface until all particles <0.425 mm in diameter passed through the sieve. The soil and water suspension in the pan was then transferred to a 20-L bucket, and excess water was removed from the suspension using porous suction cups connected to a vacuum pump. The resulting soil pastes were stored in 1-L plastic containers in a refrigerator until use.

Near the time of liquid limit testing, the soil pastes were placed on large, fritted glass plates in the laboratory and allowed to dry to a moisture content slightly lower than the liquid limit. Distilled water was then added in small increments, and after each increment the depth of drop-cone penetration and the number of blows necessary to cause 12.5 mm groove closure in the Casagrande cup were determined. After

TABLE 1.—*Classification of soils sampled.*

Soil series	Classification according to USDA Soil Taxonomy[1]
Bayamón	Very-fine, kaolinitic, isohyperthermic Typic Hapludox
Fraternidad	Fine, smectitic, isohyperthermic Typic Haplusterts
Humatas	Very-fine, parasesquic, isohyperthermic Typic Haplohumults
Múcara	Fine-loamy, smectitic, isohyperthermic Vertic Eutrudepts
Nipe	Very-fine, ferruginous, isohyperthermic Typic Acrudox
San Antón	Fine-loamy, mixed, superactive, isohyperthermic Cumulic Haplustolls
Toa	Fine, mixed, active, isohyperthermic Fluventic Hapludolls

[1]In Muñoz et al. (2018)

each measurement, a small soil sample was extracted for moisture content determination by oven drying at 105° C. The range of water contents for each sample was such that approximately half the measured drop-cone penetration depths were below 20 mm and the other half above that value. Likewise, in the Casagrande method, the range of water content values was such that approximately half the samples required less than 25 blows to close the 12.5 mm groove and the other half required more than 25 blows. Cone penetration depths were plotted against water content, as were the number of blows measured in the Casagrande method. By least squares regression analysis, the water contents corresponding to 20-mm cone penetration and 25 blows in the Casagrande method were then determined, and taken as the liquid limit by the corresponding method. Details are specified in ASTM D-4318 (2000) and BS-1377 (2000).

A graph comparing liquid limit measured by the Casagrande method vs. that measured by the drop-cone method is shown in Figure 4. The regression coefficient was very high (R^2=0.98) and the best-fit regression equation deviated only slightly from the 1:1 line. For high liquid limit values the Casagrande method tended to give slightly higher values than the drop-cone method, a result also reported by Rehman et al. (2020) and other studies cited therein. The data in our study did not include

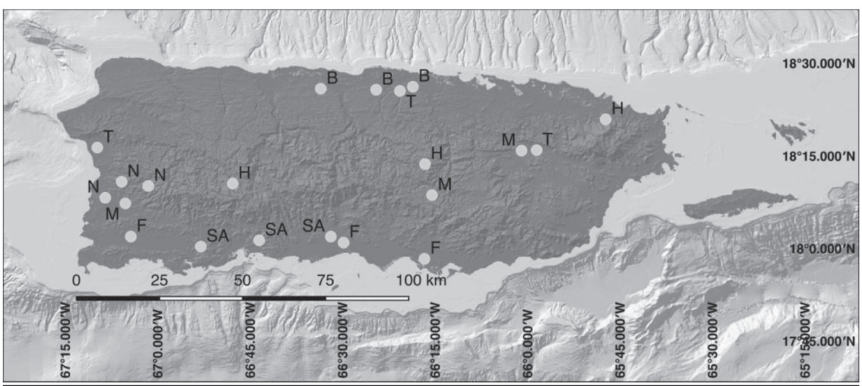

FIGURE 3. Map of Puerto Rico showing sampling locations of soils from different series. Letters indicate soil series as follows: B - Bayamón; F - Fraternidad; H - Humatas; M - Múcara; N - Nipe; SA - San Antón; T - Toa.

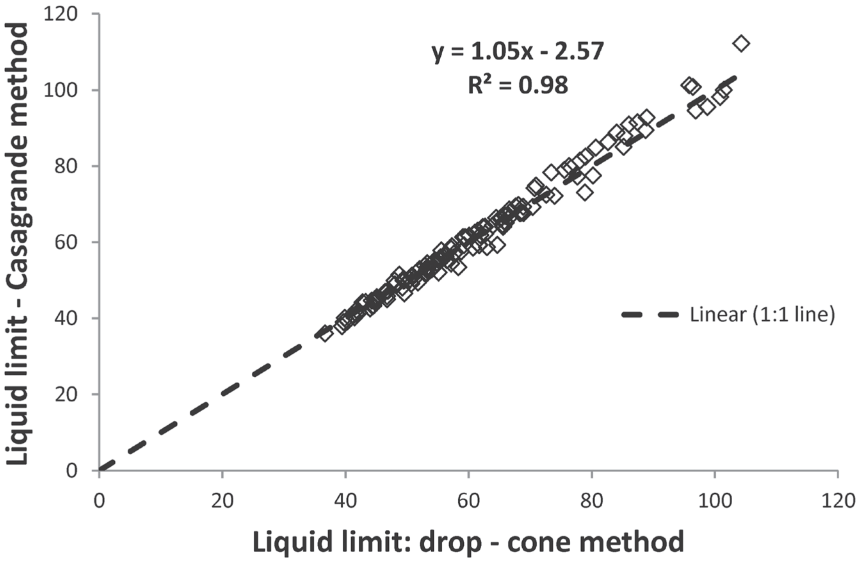

FIGURE 4. Relation between liquid limit measurements obtained by the Casagrande and the drop-cone methods.

soils with liquid limit values less than about 40, but the tendency of the regression line suggests that for liquid limit values < 40 the drop-cone produces values slightly higher than the Casagrande method, a reversal of the tendency at high values of liquid limit. This tendency was confirmed by Rehman et al. (2020). These authors noted, however, that liquid limit differences between the two methods never exceeded two to three percent, a result also supported by our data. Their conclusion, with which we concur, was that for routine testing purposes both the Casagrande and drop-cone methods can be considered equivalent provided the respective standard operating procedures are closely followed.

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