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Effect of Dynamic and Static Methods of Compaction on Soil Strength

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Abstract: *The effect of static (hydraulic press) and dynamic (Proctor) methods of compaction on the strength of soils was investigated in the laboratory. Soil samples of different densities were obtained by incorporating peat into three agricultural soils at 0%, 4%, 8% and 12%, air-dry mass basis. The soils were dynamically compacted using 5, 15 and 25 blows of the Proctor hammer at moisture contents which varied from 5% to 55%, after which bulk density and penetration resistance were measured. The soil was then loosened and repacked to the same bulk densities using static compaction imposed via a hydraulic press and penetration resistance was again measured. Peak strengths of soils achieved from the two compaction methods were compared and the two sets of values were highly correlated (P = 0.001). Results indicate that as long as the same soils are compacted statically or dynamically at the similar moisture contents to same bulk densities, similar strength values are expected. The effect of method of soil compaction on soil strength is not important.*

Keywords: *Static, dynamic, soil, compaction, strength, impact*

1. Introduction

Soil compaction refers to the method of mechanically increasing the density of a soil by reducing the volume of air. Soil compaction has direct effect on soil physical properties such as bulk density, strength and porosity; therefore these parameters are normally measured and used to quantify soil compactness (Ohu, 1985). The commonly used laboratory methods for measuring compaction include the impact, static, kneading and vibratory ones (Seed, 1954). The impact test commonly adopted is the Proctor test (Lambe, 1951) while the static laboratory compaction tests involve the use of hydraulic press or pump (Amani et al., 2011; Garcia et al., 2012) to press soils to given bulk densities.

Some researchers (Seed, 1954; Asmani et al., 2011; Crispim et al., 2011) compared the effects of static and impact methods on soil compaction and noted different results. Seed (1954) observed that at equal densities and water contents, soil samples compacted by static pressures exhibited higher stabilities (strengths) than those compacted by Proctor impact methods. Crispim et al. (2011) noted similar results for a silty sandy clay soil they tested. They, however, noted a reverse result for the clayey-silty sand soil in that the strength of the dynamically compacted soil exceeded that of the statically compacted one. Asmani et al. (2011) found that statically compacted soils achieved greater bulk densities and strengths than those compacted with the dynamic Proctor impact test although the Proctor test impacted greater energies in compacting the soils. Asmani et al. (2001) did not, however, compare the strength of their soils at the same water content and bulk density. It is possible that the soil strength achieved will depend on whether static or dynamic methods are utilised in compacting the soil. These authors only measured few soils with few moisture contents and densities. There is need to perform more comprehensive number of experiments to investigate this hypothesis further.

This paper compares the effect of static (hydraulic press) and dynamic (impact) methods of compaction on the strength of soils compacted at the same moisture content to the same bulk densities. Several soil samples with different bulk densities were obtained using soils amended with organic matter in form of peat. Results will determine whether methods of soil compaction have a significant effect on soil strength and will generally increase the understanding of how the common laboratory methods utilised for compacting soils affect soil strength.

2. Materials and Methods

Three soils: Piarco sandy loam, Maracas clay loam and Talparo clay (see Table 1) were selected and used to represent some of the major agricultural soils in Trinidad. They were collected from the 0 to 20 cm depth of the soil profile, air-dried and ground to pass a 5 mm sieve. Particle size distribution was performed using the hydrometer method (Lambe, 1951). Organic matter content in the samples was measured using the Walkley-Black (1934) method. Organic matter content in the samples was increased by adding air-dry sphagnum peat moss (0.08 Mg m^{-3} air-dry density) at 4%, 8%, and 12%, air-dry mass basis.

Table 1. Classification, organic matter, and the particle size distribution (%) of the soil

Soil Series	Classification*	Organic Matter Content (%)	Sand (0.06-0.002) mm	Silt (0.06-0.002)mm	Clay (<0.002)mm
Piarco	Aquoxic Tropudults **	1.7	64.9	17.0	18.1
Maracas	Orthoxic Tropudults	4.7	44.7	24.7	30.6
Talparo	Aquentic Chromuderts	2.7	25.4	28.3	46.3

* - Classification according to the Soil Taxonomy System (soil survey Staff, 1999).
** - All values are means of three replicates

To determine the bulk density and strength of the soils after compaction, two replicate soil samples were compacted using the Proctor method (Lambe, 1951). Compaction was carried out at different moisture contents (varying from 5 to 55%) using 5, 15 and 25 Proctor hammer blows applied in three layers on soils put in cylindrical moulds of 10.2 cm diameter and 11.8 cm height. The moisture contents for compacting the soils were chosen according to the soil consistency limits, which were determined from an earlier experiment by Ekwue and Stone (1995).

After compaction at given moisture content, the mould with the compacted soil was weighed to determine the bulk density. Soil strength was measured on the samples using penetration tests conducted using a hand-pushed spring-type Proctor penetrometer (ASTM, 1985). The soil was then removed from the mould, loosened and then repacked into the same Proctor mould using a hydraulic press configured to facilitate the compression of soil. A flat circular metal plate with 2 mm clearance which allowed it to fit into the 10.2 cm diameter Proctor mould, was used as the interface between the piston arm of the hydraulic press and the soil. The compression process was carried out until the same bulk density of the Proctor test was gained. This was achieved by gauging the depth of the piston as it descended into the mould.

The same penetrometer was again used to measure soil strength. The dynamic (impact) Proctor and the static (hydraulic) compaction methods were then continued for the other moisture contents following the same procedure each time. The optimum moisture contents and the maximum densities from the Proctor test for each soil, as well as the peak resistance from both methods of compaction were noted for each soil.

3. Results and Discussion

Figure 1 shows the bulk density-moisture content plots for the three soils each with four peat contents and compacted with 25 Proctor blows. The nature of the graphs follows typical soil behaviour (De Kimpe et al.,1982; Ohu et al., 1985) The plots for the 5 and 15 Proctor blows were similar except that the values of the maximum bulk density and the optimum moisture contents were different as shown in Table 2.

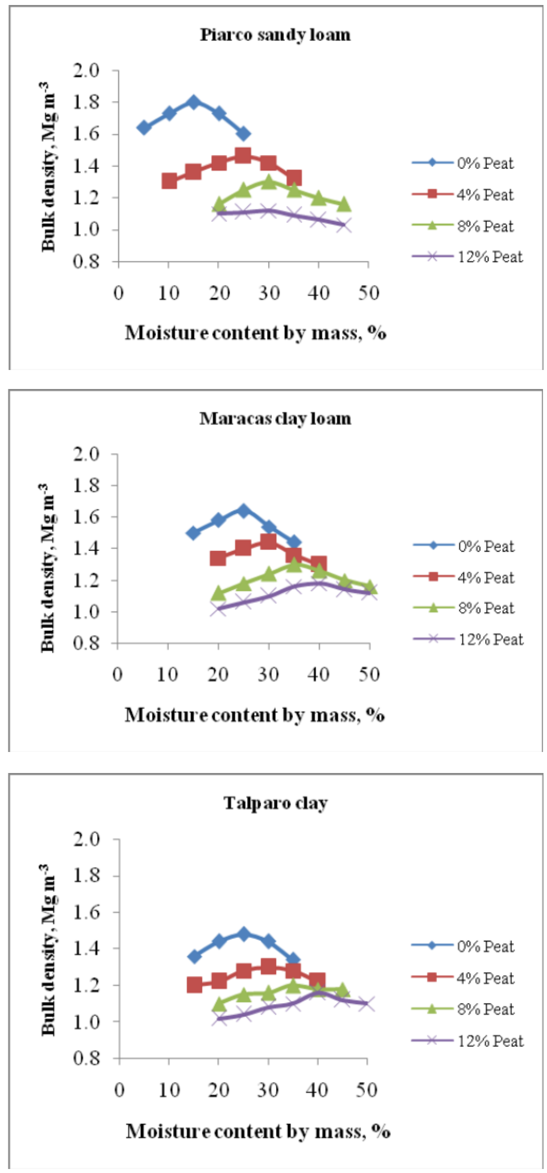

Figure 1. Bulk density and moisture content for the three soils at the compaction level of 25 Proctor blows

As was expected, the bulk densities declined, while the optimum moisture contents increased with increasing peat contents from 0% to 12%. This was attributed to the lower bulk density of the peat incorporated into the soils. This occurred for all the three soils and all the three compaction levels. Maximum bulk densities increased while the optimum moisture contents declined with increasing levels of soil compaction.

Figure 2 shows the penetration resistance-moisture content plots of the three soils using the 25 blows of the Proctor method compared with the same plots obtained using the hydraulic press to compact the soils at the same moisture contents to the same bulk densities achieved during Proctor test. The nature of the graphs for the two compaction methods followed typical soil behaviour fully described by Ekwue and Stone (1995) and were similar in values and shape. Generally as was obtained in previous studies by Ohu (1985) and Ekwue and Stone (1995), for each soil and compaction method, peak penetration resistance occurred at lower moisture contents when compared with the optimum moisture contents for maximum compaction.

Table 2. Values of maximum bulk density, peak penetration resistance, Tmax (MPa) and the moisture contents at which they occurred for the soils with peat content and compacted using Proctor blows and hydraulic press

Soil type	Proctor compaction blows	Peat content (%) 0			4			8			12		
		ρ_{max}	T_{max} (Proctor)	T_{max} (Hydraulic press)	ρ_{max}	T_{max} (Proctor)	T_{max} (Hydraulic press)	ρ_{max}	T_{max} (Proctor)	T_{max} (Hydraulic press)	ρ_{max}	T_{max} (Proctor)	T_{max} (Hydraulic press)
Piarco sandy loam	5	1.6/20[a]	3.0/13	4.0/12	1.3/31	2.9/20	3.6/18	1.1/44	2.7/30	2.8/30	1.0/34	2.1/31	2.7/34
	15	1.8/16	7.5/11	8.3/11	1.4/27	3.5/16	4.4/16	1.3/37	3.6/26	3.9/27	1.1/32	2.8/30	3.0/30
	25	1.8/14	9.0/10	10.0/10	1.5/25	8.3/15	7.2/15	1.3/30	6.0/25	5.0/25	1.1/30	5.7/28	4.8/30
Maracas clay loam	5	1.6/32	8.0/21	8.8/21	1.3/37	2.1/29	2.1/27	1.2/45	2.2/30	2.1/29	1.1/58	1.9/32	1.9/32
	15	1.7/26	8.5/20	9.3/20	1.4/30	5.9/26	5.0/25	1.2/39	4.6/28	4.8/28	1.1/42	3.6/31	1.2/31
	25	1.6/25	12.0/20	11.0/20	1.4/29	6.0/25	7.0/25	1.3/36	5.6/26	5.0/26	1.2/40	4.2/30	4.9/30
Talparo clay	5	1.2/30	5.1/23	4.9/25	1.2/32	4.0/28	4.2/30	1.1/38	3.4/30	4.0/31	1.0/52	1.4/37	1.4/35
	15	1.4/27	6.3/21	6.0/21	1.4/30	4.9/27	5.0/27	1.2/36	4.2/28	4.4/30	1.1/43	3.3/36	3.3/33
	25	1.5/26	7.4/20	7.2/20	1.3/28	6.7/25	6.8/25	1.2/35	5.5/27	6.0/30	1.2/41	4.2/35	4.6/32

[a] Maximum values and the moisture content at which they occurred.
ρ_{max} is maximum bulk density (Mg m^{-3})

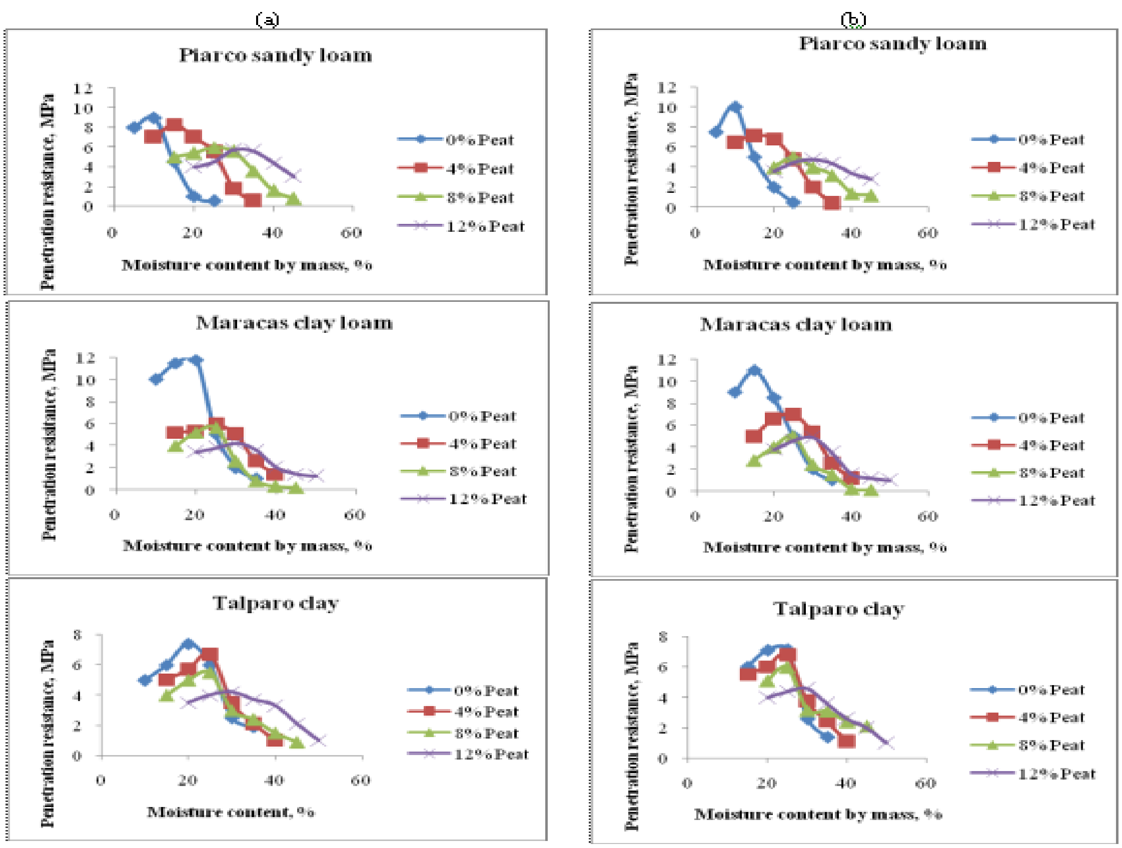

Figure 2. Penetration resistance and moisture contents of the soils compacted (a) with 25 blows with the Proctor Method and (b) at the equivalent bulk density using the hydraulic press

Table 2 details the values of peak penetration resistance and the moisture contents at which they occurred for the three soils at three compaction levels using the Proctor and the hydraulic press compaction methods. The trend in peak penetration resistance values was the same as was observed for bulk density in that penetration resistance declined with increasing peat content but increased with increasing compaction effort. Values of peak penetration resistance from the two compaction methods were close to each other (see Table 2) and were highly correlated, P = 0.001 (see Figure 3).

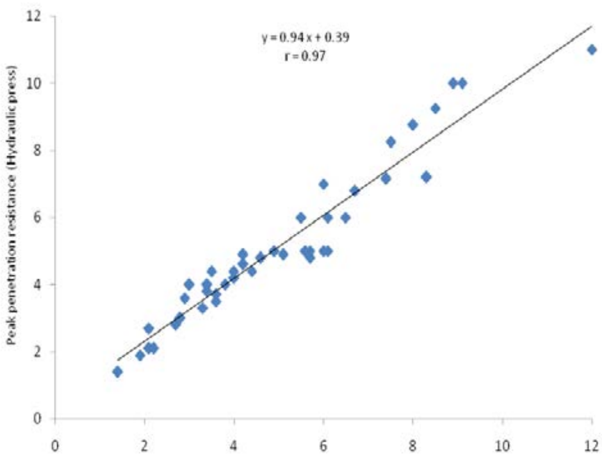

Figure 3. Comparison of peak penetration resistance (MPa) using the two compaction methods

The correlation coefficient (0.97) is close to 1.00 representing an almost perfect correlation. The value of the slope of regression line (0.94) and the intercept (0.39) were significantly close to 1.00 and 0.00 respectively, which showed that there was little or no bias in the prediction by the equation. As stated in the materials and methods section, the soils were compacted at the same water content to the same bulk densities as was obtained from the Proctor compaction test. Results show that once the soils were compacted at the same water content and bulk density, values of peak soil strength were almost the same irrespective of the method of compaction. This disagrees with the results of Seed (1954) which showed that statically compacted soils are more easily compacted to higher strength values than dynamically compacted ones.

Crispin et al. (2011) also observed the same trend for the silty sandy clay soil they studied. They observed that interparticle forces are destroyed by dynamic compaction producing structures with lower strength. Asmani et al. (2011) attributed this soil behaviour to the non-uniformity of the dynamically compacted soils using the Proctor test. They stated that since soils are compacted in three layers using the Proctor test, the bottom layer will normally have greater densities than the middle and the upper soil layers in the mould. Crispin et al. (2011), however, observed that dynamic compaction produced greater strength than static compaction for the clayey silty sand soil they studied. These authors used separate soil samples to perform the static and dynamic compaction of their soils and this may have contributed to the results they obtained.

In the present study, the same soils were compacted in the Proctor mold using the two methods of compaction. Moreover, these previous authors did limited soil tests. For instance, Crispin et al. (2011) only tested two soils each at less than 3% optimum, optimum, and 2% above optimum moisture contents. A more comprehensive soil test programme using three soils, four peat contents, three compaction efforts and several water contents were adopted in the present study.

4. Conclusion

This paper has demonstrated that the method of soil compaction utilised to achieve soil compaction does not affect soil strength as long as samples are compacted at the same moisture contents to same bulk densities.

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