DMT tests for compaction control purpose

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ABSTRACT: DMT was intensively used for compaction control during the landfill execution for a logistic site close to São Paulo – Brazil. The volume involved at the earthwork is around 1,000,000 m³ and 65 boreholes were done in the compacted fill, accumulating more than 1,000 m of DMT results. The rigorously controlled landfill was evaluated during its construction process, as it gained height, with monthly DMT campaigns. The results of these tests showed that the first 1.5 m of the landfill height is more susceptible of deformations, even with a rigorous compaction control. The results also indicated that an adequate compaction control can reduce the deformability of the compacted fill by half, when compared to another results of DMT performed in a near site, at the same city, but without rigorous compaction control on the landfill.

Keywords: DMT; compaction control; compacted fill; deformability.

1. Introduction

For the implementation of a logistic distribution park in the city of Cajamar, located near São Paulo, Brazil, the cut volume and fill volume estimated in the earthwork project was around to 1,000,000 m³.

Figure 1 presents a 3D model of the site in question, obtained by drone during the earthwork services.

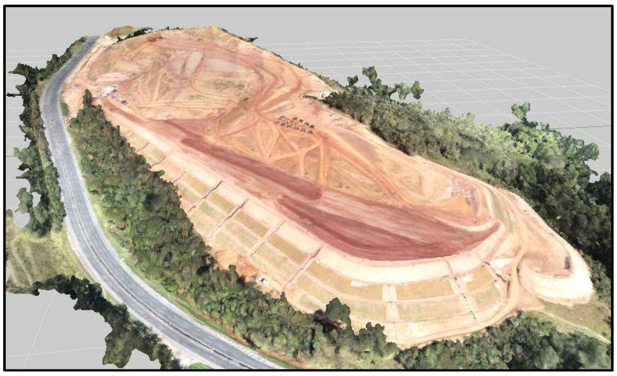

Figure 1. 3D model by geodrone during the earthwork services.

Considering landfills height up to 25 – 30 m and the future implementation of heavy structures over them, it was required a rigorous compaction control of the soil to be launched over the natural ground, in order to avoid excessive deformations possibly caused by the overloads from the building operating.

Therefore, all along the construction, the landfill was executed in layers of only 20 – 25 cm. The acceptance criteria for each layer was degree of compaction superior to 98% of standard Proctor, measured by Hilf tests performed in different points of the compacted fill.

Complementarily, this landfill was evaluated during its construction process, as it gained height, with monthly DMT campaigns. The intention was to verify its behavior based on the variation of “P_0”, “I_D”, “K_D” and “M” obtained in compacted soil layers. At the end of the job 65 DMT boreholes were executed and around 50 of them, in the fill area, were used in this research.

Those tests were compared to another results of DMT performed in a near site, at the same city, using the same type of soil for the landfill execution. Its compaction, however, was done without a rigorous compaction control.

2. Dilatometer test - DMT

2.1. General features

The dilatometer is a stainless steel blade equipped with a circular membrane on one side. The blade is driven vertically into the soil and in every 20 cm a test is perfomed by inflating the membrane and taking pressure readings at prescribed displacements.

The penetration is done with the aid of pushing rigs adapted from those used in the CPT and it’s compatible with a wide variety of soils (clay, sand, silt and hard formations).

After the readings corrections, related to the equipment calibration, the test provides the pressures P_0 (at which the membrane starts to expand) and P_1 (pressure required to move the centre of the membrane by 1.1 mm against the soil), as shown in Fig. 2.

These pressures (P_0 and P_1) are subsequently used for interpretation of DMT results in the assessment of soil constitutive parameters.

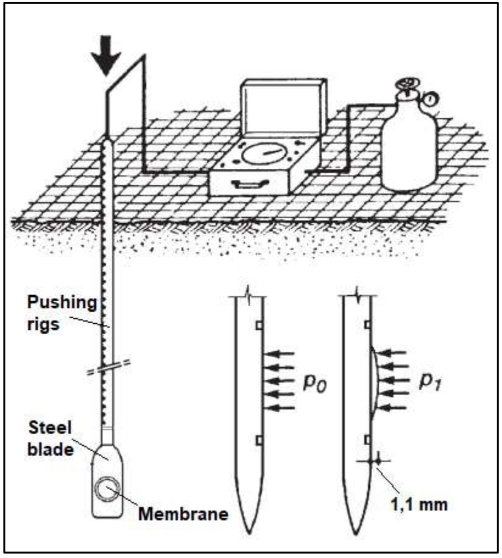

Figure 2. Schematic representation of the dilatometer test (Marchetti el al., 2001 [1]).

2.2. Intermediate DMT parameters

Based on the pressures P_0 and P_1, Marchetti [2] defined three index parameters to interpret the test: material index, horizontal stress index and dilatometer modulus.

2.2.1. Material index – I_D

Marchetti [2] observed that the difference between P_0 and P_1 is small for clay and large for sand.

So he expressed the material index by Eq. (1).

$$I_D = \frac{P_1 - P_0}{P_0 - \mu_0} \tag{1}$$

Where μ_0 is the hydrostatic porewater pressure.

According to Marchetti [2], the soil type can be identified as follows:

- Clay → $0.1 < I_D < 0.6$
- Silt → $0.6 < I_D < 1.8$
- Sand → $1.8 < I_D < (10)$

The material index provides a reasonable estimate of soil type, but not exact. Therefore, the parameter I_D is about the granulometric behavior of the soil and not its real grain size.

2.2.2. Horizontal stress index – K_D

The horizontal stress index (K_D) can be regarded as the coefficient of earth pressure at rest (K_0) amplified by the penetration of the blade. It's expressed by Eq. (2).

$$K_D = \frac{P_0 - \mu_0}{\sigma'_{v0}} \tag{2}$$

Where σ'_{v0} is the in situ vertical effective stress.

According to Marchetti [2], in genuinely NC clays (normally consolidated clays) the value of the horizontal stress index is $K_{D,NC} \approx 2$.

2.2.3. Dilatometer modulus – E_D

The value of ($P_0 – P_1$) can be converted into a modulus of elasticity of the soil using the theory of elasticity. Marchetti [2] declares that a solution for this problem is posible assuming that the space surrounding the dilatometer is formed by two elastic half spaces, in contact along the plane of symmetry of the blade.

For an elastic half space with Young's modulus E and Poisson's ratio υ, when zero settlement is computed externally to the loaded area, it has Eq. (3).

$$S_0 = \frac{2D\,(P_1 - P_0)}{\pi}\frac{(1 - \upsilon^2)}{E} \tag{3}$$

For the membrane diameter D = 60 mm, displacement S_0 = 1.1 mm and ratio $\frac{(1-\upsilon^2)}{E}$ defined as E_D, it has Eq. (4).

$$E_D = 34.7\,(P_1 - P_0) \tag{4}$$

2.3. Interpretation of results

2.3.1. Constrained modulus - M

The constrained modulus is a parameter related to the soil deformability: the higher the value of M, the higher the stiffness of the soil, so, the less its deformability.

Marchetti [2] and Lunne et al. [3] have already explored a correlation between constrained modulus M and dilatometer modulus ED in the form of Eq. (5).

$$M_{DMT} = R_M E_D \tag{5}$$

Where:

If $I_D \leq 0.6$ → $R_M = 0.14 + 2.36\,logK_D$
If $0.6 < I_D < 3$ → $R_M = R_{M0} + (2.5 - R_{M0})\,logK_D$
$R_{M0} = 0.14 + 0.15\,(I_D - 0.6)$
If $3 \leq I_D < 10$ → $R_M = 0.5 + 2\,logK_D$
If $I_D \geq 10$ → $R_M = 0.32 + 2.18\,logK_D$

In the equations above, if $R_M < 0.85$ → set $R_M = 0.85$.

3. Results

3.1. Initial thoughts

The horizontal stress index (K_D) provides values from 1.8 to 2.3 in case of normally consolidated (NC) soils. In case of over consolidated (OC) soils, the values of K_D are superior to that and decrease in depth.

Thus, it's possible to identify the transition between the compacted fill (OC soil) and the natural soil (NC) looking at the results of DMT in an isolated way.

From there, it was noted in the isolated tests results that the material index (I_D) and the constrained modulus (M) do not suffer much variation along the landfill.

The DMT-308 was taken as example to illustrate the situation above. It reached a total depth of 15 m, being 6.2 m in landfill and 8.8 m in natural soil. Its results are shown in Fig. 3.

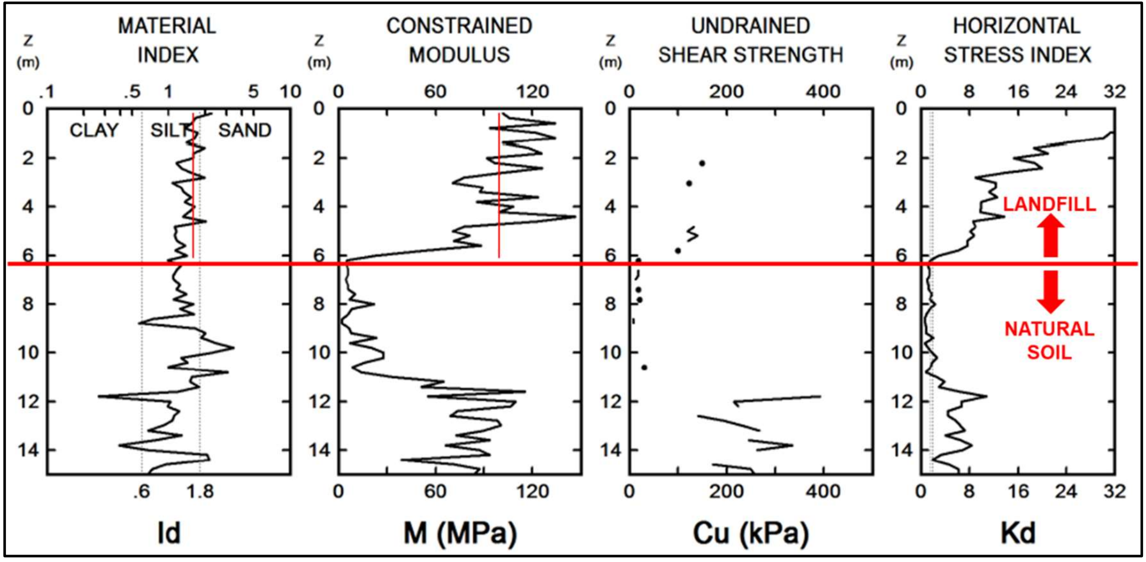

Figure 3. Example of a DMT result (DMT-308), indicating the transition from landfill to natural soil.

The results of I_D (granulometric behavior) and M (deformability) presented in the graphs seems to indicate similar characteristics of the soil along the landfill height.

Therefore, it is expected that the values of P_0 (pressure at which the membrane starts to expand) do not present wide variations in landfill, either. This situation can be noted in Fig. 4.

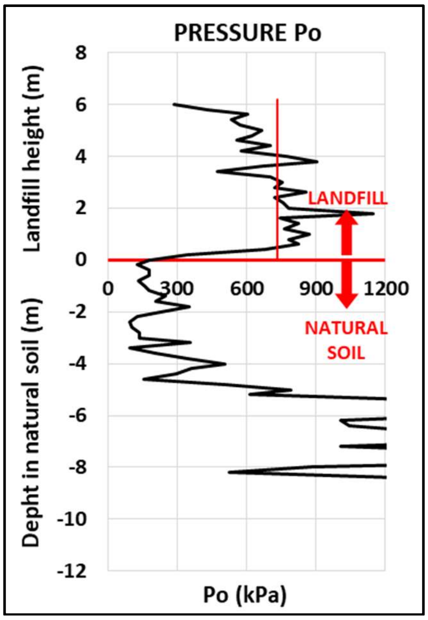

Figure 4. Results of Po in the DMT-308

3.2. Results overlap

It was found at the previous item that the values of I_D, P_0 and M do not present wide variations along the landfill height for an isolated result of DMT.

Bearing in mind the landfill was executed with the same type of soil and the same compaction control criterion in each point of the construction (theoretically homogeneous) , is was expected that the results of I_D, P_0 and M obtained in the compacted fill were constant (or similar) between each DMT performed.

However, the overlapping results of 50 tests showed that this behavior is not verified.

In relation to the pressure P_0, for example, it can be noted a wide variation of its results even in the landfill, as shown in Fig. 5, in which each color represents a different DMT.

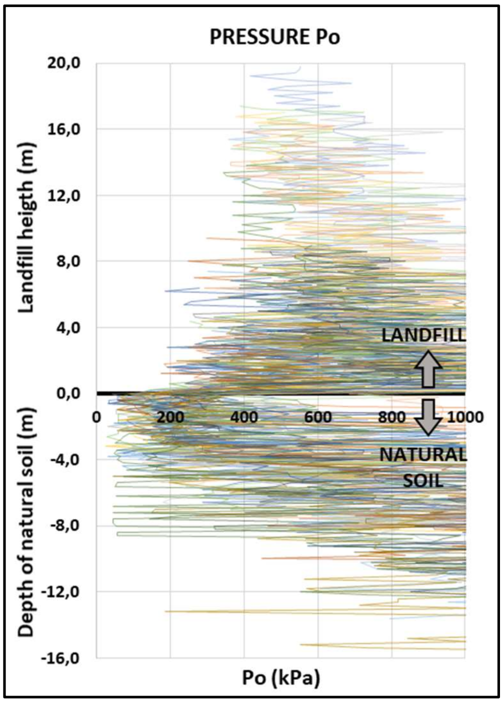

Figure 5. Po results overlap (approximately 50 different tests)

Going on with the analysis of the overlapping results, it was observed that the majority of the tests indicated soils with granulometric behavior (I_D) of sand.

Nevertheless, a good part of the tests also indicated soils with granulometric behavior (I_D) of silt.

To verify the difference of P_0 and M variation between the two "types of soil", the results were separated in two groups:

- Fig. 6 → $0.6 < I_D < 1.8$ ("Silt");
- Fig. 7 → $I_D > 1.8$ ("Sand").

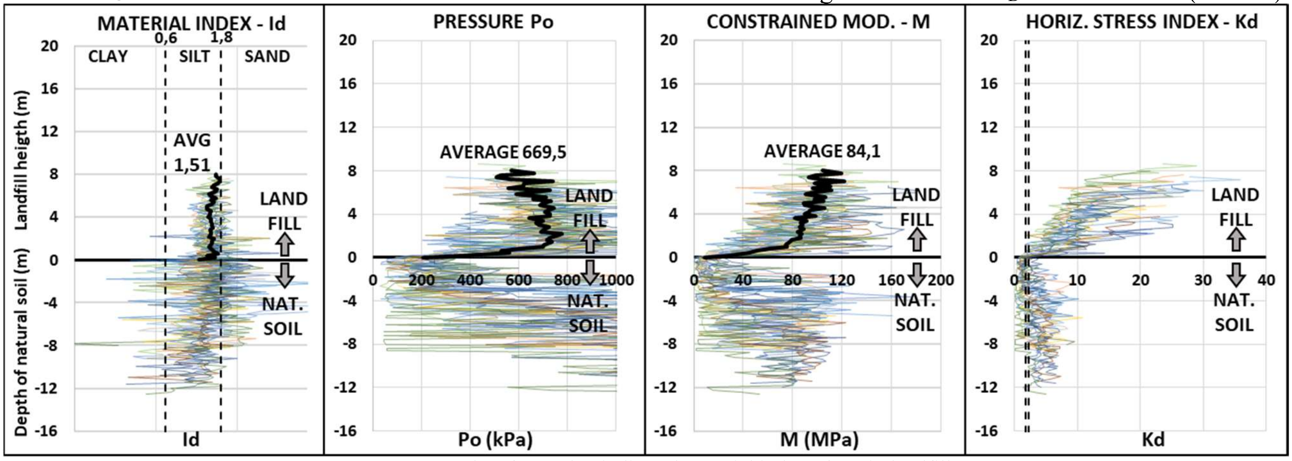

Figure 6. Results of tests that indicated material index of **silt** in landfill

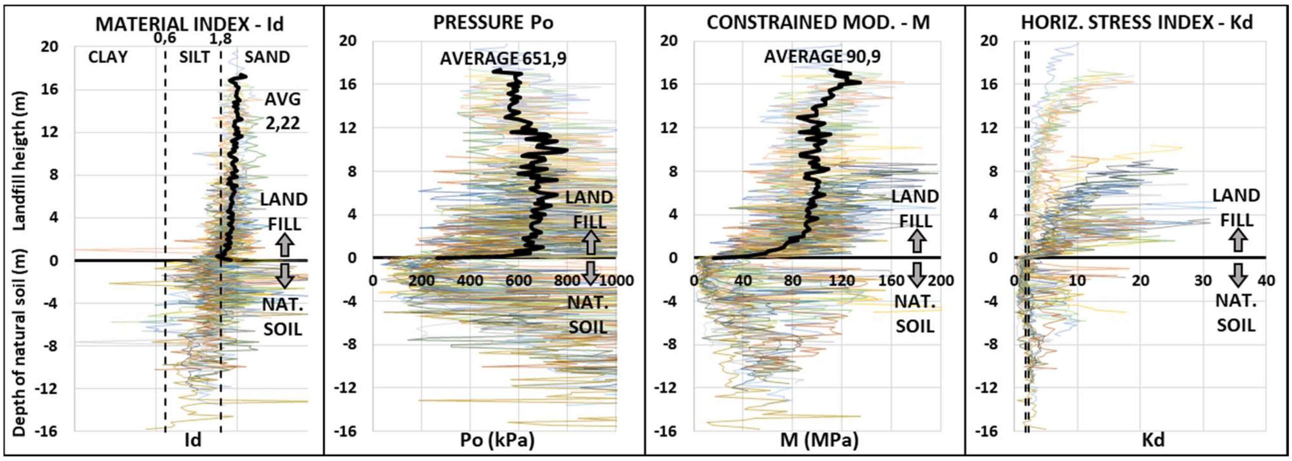

Figure 7. Results of tests that indicated material index of **sand** in landfill

Somewhat, it was expected that the group with material index of silt had presented lowers parameters of resistance when compared to the group with I_D of sand. In other words, it was expected that their values of P_0 and M had appeared to the left (x-axis) of the graphics.

However, the Fig. 6 and the Fig. 7 show that P_0 variation (from 300 to 1,000 kPa) and M variation (from 40 to 140 MPa) did not present a big difference between the two groups of distinct granulometric behavior.

The averages calculated to these parameters, inclusive, were very similar between the two groups.

The Fig. 8, therefore, illustrates all of the DMT results in an overlap, without separate the group of silt from the group of sand.

An important observation about the graphics of the Fig. 8 is that the first 1.5 m of landfill height presented lower values of the parameter M. It means that this part of the compacted fill is more susceptible to deformations, because it's supported on the first layers of natural soil, which, as a general rule, present worse characteristics of resistance.

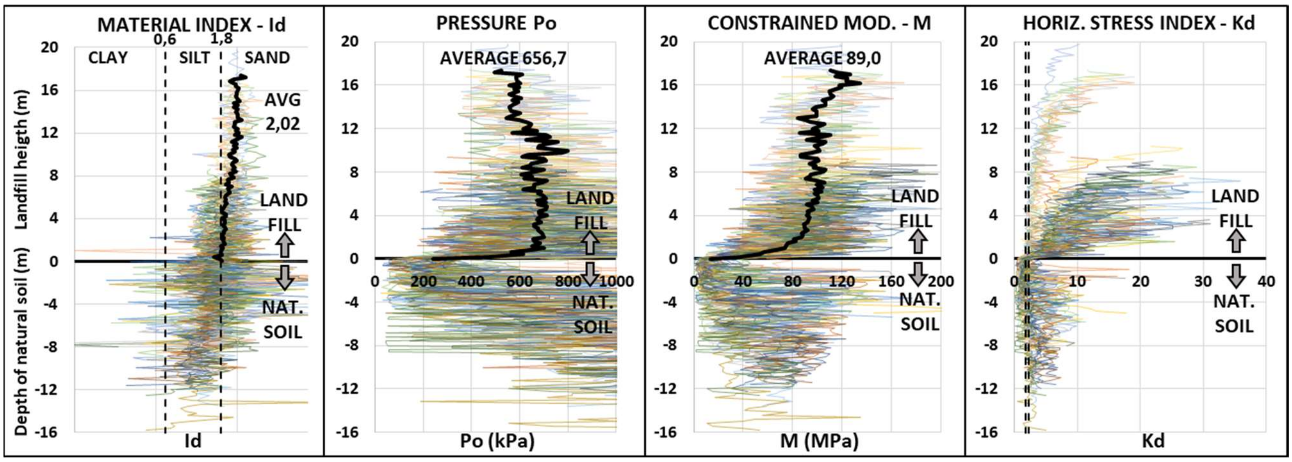

Figure 8. Results overlap of **all** DMT tests

3.3. Comparison between the rigorously controlled compacted fill and another landfill without rigorouscompaction control

The objective here is to compare the variation of P_0 and M in two different constructions located at the same city, in which the same type of soil was used to execute the landfill.

In the first construction (that one studied until here), it was required a rigorous control of the compacted fill, with degree of compaction 98% of standard Proctor.

In the second one, the landfill was executed without a rigorous compaction control.

The Fig. 9 presents the P_0 normal distribution in the rigorously controlled compacted fill.

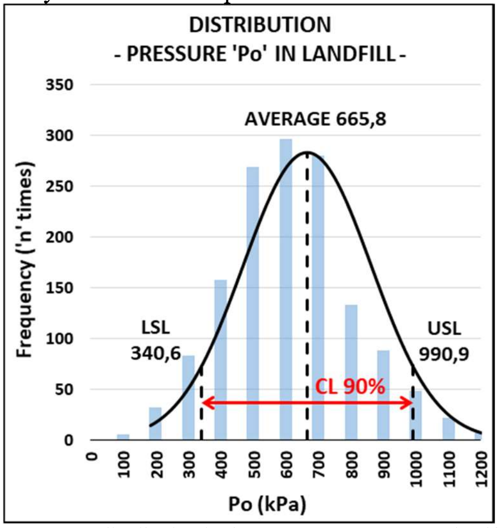

Figure 9. Po distribution in the **rigorously controlled** landfill

The Fig. 10 presents the overlapping results of P_0 in the rigorously controlled compacted fill.

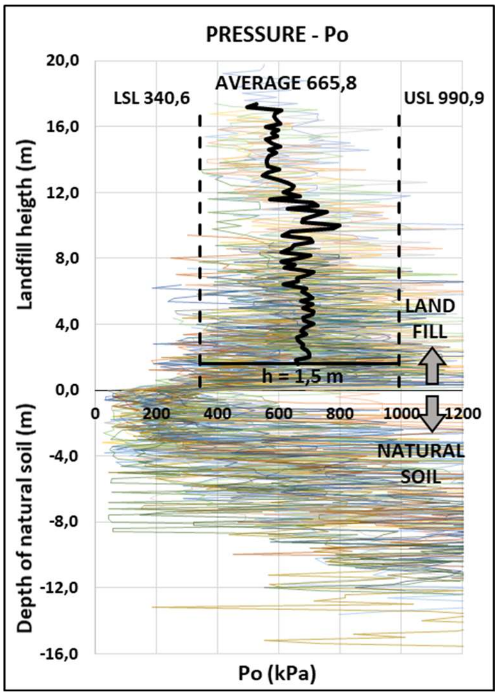

Figure 10. Po overlap in the **rigorously controlled** landfill

The values of P_0 and M obtained in landfill for each case were arranged in normal distribution patterns. The specification limits (upper – USL and lower - LSL) were determined to a confidence level (CL) of 90%.

It has already found that the first 1.5 m of landfill height presents higher deformability (lower values of P_0 and constrained modulus M), even with a rigorous compaction control. This occurs because this part of the fill is supported on the first layers of natural soil, which do not present good characteristics of resistance.

Thus, the first 1.5 m of landfill height was ignored (in the two cases). It means that its values of P_0 and M are not shown in the related distributions.

The Fig. 11 presents the P_0 normal distribution in the landfill executed without a strict compaction control.

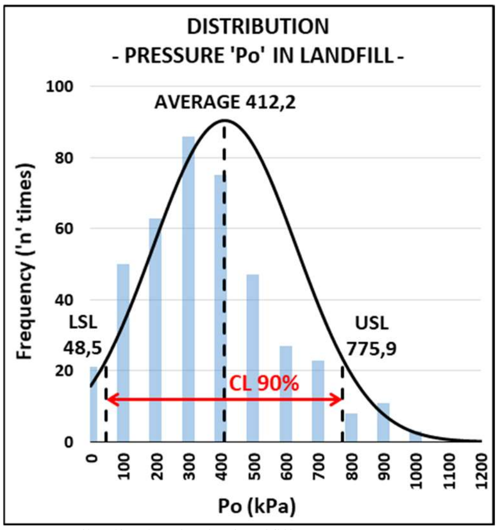

Figure 11. Po distribution in the landfill **without compaction control**

The Fig. 12 presents the overlapping results of P_0 in the landfill executed without a strict compaction control.

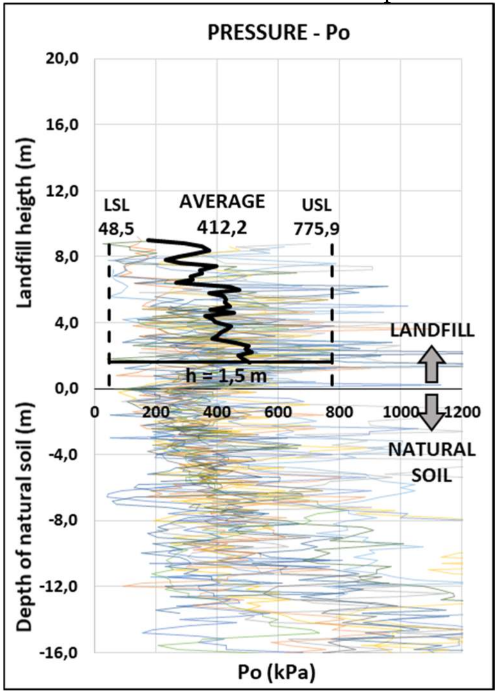

Figure 12. Po overlap in the landfill **without compaction control**

The Fig. 13 presents the M normal distribution in the rigorously controlled compacted fill.

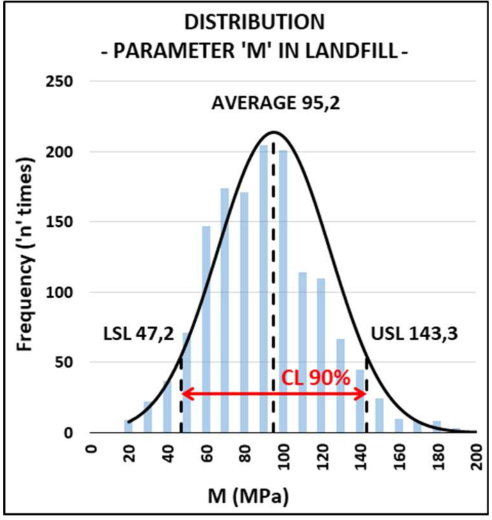

Figure 13. M distribution in the **rigorously controlled** landfill

The Fig. 14 presents the overlapping results of M in the rigorously controlled compacted fill.

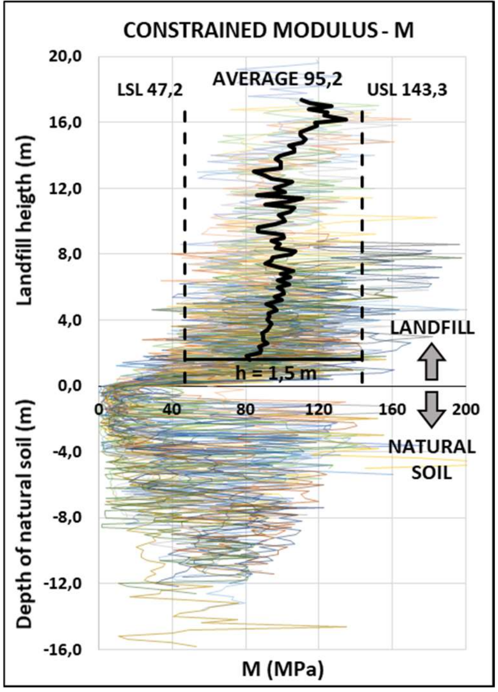

Figure 14. M overlap in the **rigorously controlled** landfill

4. Conclusions

The overlapping results showed that the values of I_D, P_0 and M were not constants between all DMT points of the construction, although it's a theoretically homogeneous landfill (same type of soil and compaction control).

The tests also indicated that the first 1.5 m of the landfill height are more susceptible to deformations, even in rigorously controlled compacted fill.

Finally, it was possible to conclude that a rigorous compaction control ($\overline{M} = 95.2\ MPa$) can reduce the landfill deformability by almost the half, when compared to another results of DMT performed in a near site, at the same city, with the same type of soil in the landfill, but without a strict compaction control ($\overline{M} = 52.3\ MPa$).

The Fig. 15 presents the M normal distribution in the landfill executed without a strict compaction control.

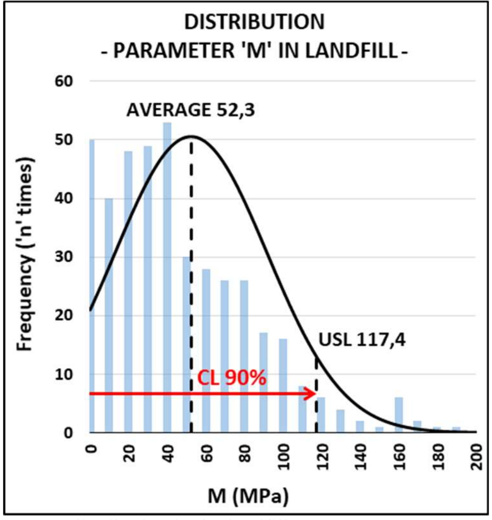

Figure 15. M distribution in the landfill **without compaction control**

The Fig. 16 presents the overlapping results of M in the landfill executed without a strict compaction control.

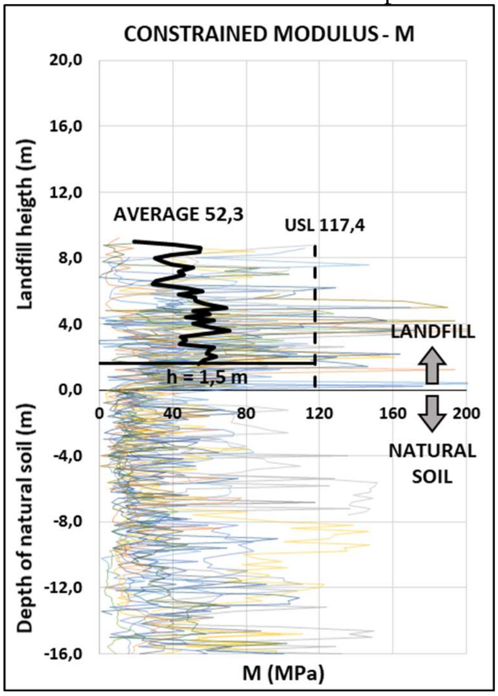

Figure 16. M overlap in the landfill **without compaction control**

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