Mechanical Characterization of MSW Using the Pressuremeter.

Détermination des propriétés mécaniques des déchets solides urbains avec le pressiomètre.

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ABSTRACT : The behavior of MSW is usually studied using models derived from soils, mainly the Mohr-Coulomb failure criterion. Due to the special characteristics of wastes, that make a clear difference between MSW and soils in terms of behavior and testing conditions, new methodologies for studying them have to be developed.

Geotechnical approaches to study the behavior of wastes can be through either laboratory tests or field tests. Notwithstanding the realization of some laboratory tests, the aim of a new study undertaken by the University of Cantabria Geotechnical Group is to find a method to characterize MSW using field tests, and more specifically with the usage of pressuremeter and cone penetration tests. It will cover several landfills, with conventional MSW, together with wastes subjected to mechanical and biological pre-treatment (MBT), introduced in Spain in the last years.

A first test survey has been accomplished in a landfill near Barcelona (Spain) made up of 16 pressuremeter tests carried out in different points of the landfill with depths ranging from 4 to 20 meters. Preliminary results and conclusions are submitted in this paper.

RÉSUMÉ : L'étude du comportement des déchets solides urbains est faite couramment avec des modèles envisagés pour les sols, tel que celui de Mohr-Coulomb. Cependant, à cause des singularités du comportement de ces matériaux par rapport aux sols, des nouvelles approches ont été envisagées.

Il est possible d'utiliser des essais de laboratoire ou in situ. Cependant, le principal but de l'étude entreprise par le Groupe de Géotechnique de l'Université de Cantabrie est l'usage des essais sur le terrain, et plus précisément, des essais pressiométriques et de pénétration statique. Plusieurs décharges ont été choisies avec des déchets conventionnels et aussi avec des déchets soumis à des prétraitements mécaniques et biologiques (MBT), introduits en Espagne et en Cantabrie il y a quelques années.

Une première campagne a été faite dans un dépôt à Barcelona (Espagne) avec 16 essais pressiométriques à des profondeurs de 3,8 à 20 mètres. Cette communication présente les résultats préliminaires et leur interprétation.

KEYWORDS : stiffness, MSW, pressuremeter, PBP (pre-bored pressuremeter) test

MOTS CLES : rigidité, déchets solides urbains, pressiomètre, pressiomètre en forage (PBP)

INTRODUCTION

The behavior of a landfill relies, among many other parameters, on the mechanical properties of the waste disposed in it. There are several factors influencing the mechanical characteristics such as composition, age, confining pressure, details of landfill operation, existence of soil layers as waste cell coverage, etc.

Shear strength determines the inclination to be given to the landfill slopes for a safe operation of the landfill, which is a key parameter in landfill design.

Besides that, the stiffness of the waste mass governs the settlement of the different layers making up a landfill and their horizontal movements. This is also a key parameter in landfill design, because it has to be used both to obtain the capacity of the landfill and to design all the drainage, gas piping and isolation systems inside the landfill according to the expected deformation to prevent failures.

Because of the nature of waste (great variability on particle size, heterogeneity of the mass, variability on the properties over time due to degradation, etc.), the achievement of a full mechanical characterization is not possible. Because of that, usually only ranges for the parameters are given (Sánchez et al. 1993, Cañizal et al. 2011).

Due to the similarities between soils and wastes, the behavior of MSW (Municipal Solid Wastes) is usually studied using models derived from soils, mainly the Mohr-Coulomb failure criterion. However, the special characteristics of wastes make it necessary to adapt the existing methodologies used in soils to their application in MSW. Although using equipment designed to test in soils is possible, some adjustments need to be done to test procedures and data analysis taking into consideration the special features of wastes.

Prior work has shown that although both using laboratory tests and field tests are possible geotechnical approaches to study the behavior of wastes, field tests have some clear advantages in terms of safety and representativeness (Cañizal et al. 2011). Therefore, a new research project of field testing in landfills is being undertaken by the University of Cantabria Geotechnical Group. The aim of the project is to find a method to characterize MSW using field tests, and more specifically with the usage of pressuremeter and cone penetration tests. It will cover several landfills with conventional MSW together with wastes subjected to mechanical and biological pre-treatment (MBT), introduced in Spain in the last years.

A first test campaign, made up of 16 pressuremeter tests carried out in different points of the landfill with depths ranging from 4 to 20 meters, has been accomplished in a landfill near Barcelona (Spain). Preliminary results and conclusions are shown in this paper alongside the problems found.

1 TEST METHOD

The degree of degradation of the materials ranged from very low for recently disposed wastes to almost fully degraded for the oldest ones. The waste used to arrive to the landfill in trucks from the Barcelona metropolitan area. However, nowadays prior to the disposal in the landfill, the wastes are subjected to several process both to valorize the residues (classifying them to be sent to a recycling facility or making compost using the organic fraction) and to reduce the contaminants sent to the landfill. These operations are carried out in a nearby facility, and the residue of this processes is what is actually sent to the landfill together with some municipal-like industrial wastes that are directly sent to it.

An initial series of tests has being conducted using a 76 mm diameter mono-cell pressuremeter in a pre-bored test pocket with the same nominal diameter (PBP tests). In order to achieve the desired depth, an access borehole was drilled prior to each PBP.

The device used was an Elastometer HQ manufactured by OYO. Although this device is not recommended for very soft soils, its usage was necessary due to the higher resistance of its membranes to be cut by sharp particles found inside the waste mass. Other authors have reported the usage of different types of pressuremeters designed for soft soils using a Chinese lantern to protect the membrane, but with no clear increase in membrane durability (Dixon 2006). Besides that, the addition of a metallic protection produces a considerable rise in the membrane strength, making it not desirable for testing soft materials, such as MSW. The maximum achievable increment in radius for the used device with standard membranes is 16 mm, and hence the maximum increment in volume that can be produced is about 100% of the original volume of the membrane.

As for the drilling process of both the access boreholes and the test pocket, most of the work was made using a widia boring crown. It was only necessary to use a heavy-duty diamond tool to drill some thin layers with high contents of metals. All the drilling was made using water flush. High drilling rates were achieved except when the diamond crown was necessary. The main problem found on the execution of the access boreholes was the instability of its walls, making it necessary to case them even for shallow excavations (less than 5 meters). The casing used was 123 mm in diameter when a 116 drilling tool was used, and it was pushed into the borehole both with rotation and water flush. Because of the instability of the walls and the high friction between the waste and the casing pipe, it was impossible to extract the casing from the waste for pipe lengths over 20 meters. Due to that, for depths over 17.5 m, a 101 mm in diameter drilling tool was used, allowing the installation of smaller casing (113 mm in diameter) inside the previously installed and with no mechanical link to it, reducing the pipe surface in contact with the waste to the part not covered by the pre-installed casing and making it possible to reach depths over 20 meters without losing the pipe (see Figure 1).

When the desired depth was reached using the system described above, the test pocket was executed using a crown

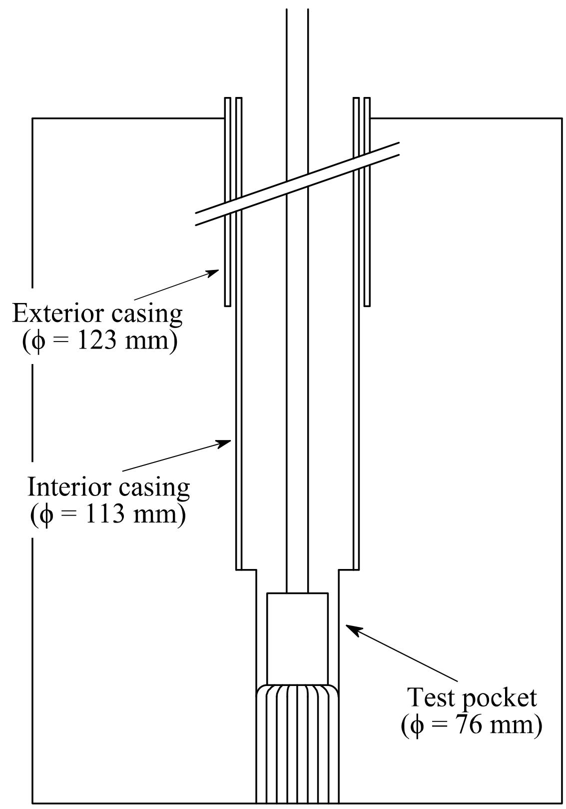


Figure 1. Deep borehole schematic drawing.

with the same nominal diameter of the pressuremeter's membrane, 76 mm. The process for drilling it was basically the same used for the access borehole, that is widia drilling and water flush were used. As it was mentioned before, the borehole's walls turned out to be quite unstable, so small to moderate force was needed to push the pressuremeter into the test pocket prior to the beginning of the test due to the reduction in diameter of the borehole during the pressuremer insertion maneuver.

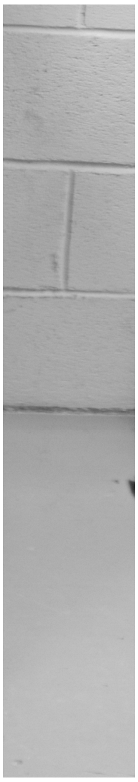
The tests were conducted following the recently published ISO 22476-4. The aforementioned code does not cover the realization of unload-reload cycles, because of that, the NF P 94-110-1 was used for those parts. Minor adaptation was done to the procedures described in the codes in order to work with waste instead of rocks or soils. Only one cycle was carried out at the end of each test and, in despite of the recommendations of the code for the cycles, pressure was set to 0 after the unloading process, because using recommendations either for sands or clays have not been validated for their usage in MSW studies, and it is not clear how the waste behaves in comparison to them.

2 MEMBRANE SELECTION

Usually the membrane selection is based on previous experience with the material to be tested and the used testing device. In this case, the amount of work carried out with mono-cell pressuremeters in MSW landfills is very limited, and hence the initial membrane choice was made using only the data available on waste characteristics and previous experiences using different types of pressuremeters. As it was said before, among the waste mass there are particles of all size, material and shape. As far as the membrane selection is concerned, sharp metallic particles are very likely to damage the membrane during the inflation.

Because of that, the membrane used for the first tests had medium strength, although a weaker membrane could has been more suitable for a material as soft as waste, it was supposed to be less resistant. The medium membrane turned up not to be suitable for the work, as the resulting curves representing pressure against cavity displacement were erratic, making it impossible to obtain the shear modulus from them. This could be caused by the small difference between the data read in field tests and the calibration curve obtained for the device. Some authors suggest that the strength of the membrane is not important in regular soils but it could have an influence in very soft soils (Elton 1981).

A soft membrane was tried, producing better results with almost no difference in terms of membrane durability. Although the soft membrane turned up to be more suitable for its usage on MSW, it showed an unusual behavior during the calibration process. The point obtained for maximum deformation was not aligned with the previous ones as expected (see Figure 2). On subsequent calibrations, it was found that exceeding a radius increment of 12 mm causes the membrane to lose its cylindrical shape adopting an "S" shape (see Figure 3). To prevent this behavior, it is better not to exceed the aforementioned deformation during the calibration. During the tests this is not an issue due to the confining effect of the material surrounding the membrane.



3 DATA ANALYSIS

3.1 *Scope*

16 PBP test were carried out in the landfill, 5 of them using medium strength membranes and 11 using low strength membranes, with depths below ground level ranging from 3.8 to 20 m. Although the initial tests were carried out without cycles, 12 tests included an unload-reload cycle.

3.2 *Methodology*

Data shows that the tested material behaves non-elastically even for small strains. Due to that, the secant shear modulus ( ) was obtained for the loading part of each test, using the natural in-situ pressure before the execution of the borehole ( ) as starting point and the theoretical expression for a linear solution (see Eq. 1).

(1)

Several approaches can be used to obtain the natural pressure on the waste before the execution of the borehole ( ), in this case the unit weight of the waste was used to obtain the natural effective vertical pressure ( ) prior to the borehole execution, and from this value is obtained.

Obtaining the unit weight of the residues is not an easy task, a comprehensive geotechnical investigation needs to be undertaken just to obtain an approximate unit weight profile, because of that the establishment of a certain introduces uncertainty on the test analysis. For this paper two approaches have been used: assuming a constant profile of 10 kN/m^3 (an average unit weight on the disposal) and using the unit weight model exposed by Zekkos et al. (2006) with an on-surface unit weight ( ) of 10 kN/m^3. The model supposes a hyperbolic relationship between unit weight and depth (see Eq. 2)

(2)

Values for parameters α and β are also provided for different compaction and amount of soil coverage, in this case the values for the typical scenario were chosen, and hence the values of the parameters are: $\alpha = 3$ m^4/kN and $\beta = 0.2$ m^3/kN. is obtained replacing the parameters on Eq. 2 and integrating from 0 to z (see Eq. 3).

(3)

Once σ'_{v0} is obtained it is necessary to assume a certain lateral earth pressure at rest (K_0) to obtain P'_0. Laboratory and field testing provide K_0 values ranging from 0.2 to 0.8 for MSW (Zekkos et al. 2006), according to that, the mean value was used (0.5). This assumption introduces an additional uncertainly in the obtained P'_0 value.

The secant shear modulus obtained corresponds to the initial part of the loading process, prior to first yield, so it is also necessary to obtain the point of the curve that corresponds with this situation. As in the selection of an appropriate unit weight model, determining the pressure corresponding to the first yield also introduces uncertainty to the test analysis.

Due to excessive discharge during the unloading part of the cycles, it is not possible to use the first step in the reloading part as the new origin for pressure, and hence P'_0, as it was calculated for loading, was used to obtain the modulus of the cycles.Results

For this preliminary work, shear modulus for small strains has been obtained as described in the methodology section. Only one value for G_l and G_r is presented for each test, due to the

Table 1. Summary of results.

Code	Membrane strength	Depth (m)	$P'_0\ (I)$ (kPa)	$P'_0\ (II)$ (kPa)	G_l (MPa)	G_r (MPa)	G_r/G_l
CM-04-PBP-01	Medium	7.5	37.5	41.05	1.53	-	-
CM-04-PBP-02	Low	13	65	74.09	-	-	-
CM-04-PBP-03	Low	19	95	111.81	2.69	-	-
CM-06-PBP-01	Low	4	20	21.14	0.80	-	-
CM-06-PBP-02	Medium	7.5	37.5	41.05	-	-	-
CM-06-PBP-03	Medium	10	50	55.84	-	-	-
CM-06-PBP-04	Medium	16.5	82.5	95.93	-	-	-
CM-06-PBP-05	Medium	19.5	97.5	115.02	-	-	-
CM-09-PBP-01	Low	3.8	19	20.03	0.61		
CM-09-PBP-02	Low	7.3	36.5	39.88	-	0.4288	-
CM-09-PBP-03	Low	10	50	55.84	2.17	3.14	1.45
CM-09-PBP-04	Low	16	80	92.78	3.71	5.64	1.52
CM-09-PBP-05	Low	20	100	118.23	3.64	3.06	0.84
CM-12-PBP-01	Low	7.2	36	39.30	2.29	2.49	1.09
CM-12-PBP-02	Low	10.7	53.5	60.06	0.95	1.93	2.04
CM-12-PBP-03	Low	13.2	66	75.33	1.43	5.13	3.60

$P'_0\ (I)$ = Estimated natural pressure using a constant unit weight.
$P'_0\ (II)$ = Estimated natural pressure using a hyperbolic model for unit weight profile (Zekkos et al. 2006).
G_l = Secant shear moduli obtained using the loading part of the curve
G_r = Secant shear moduli obtained using the reloading part of the curve

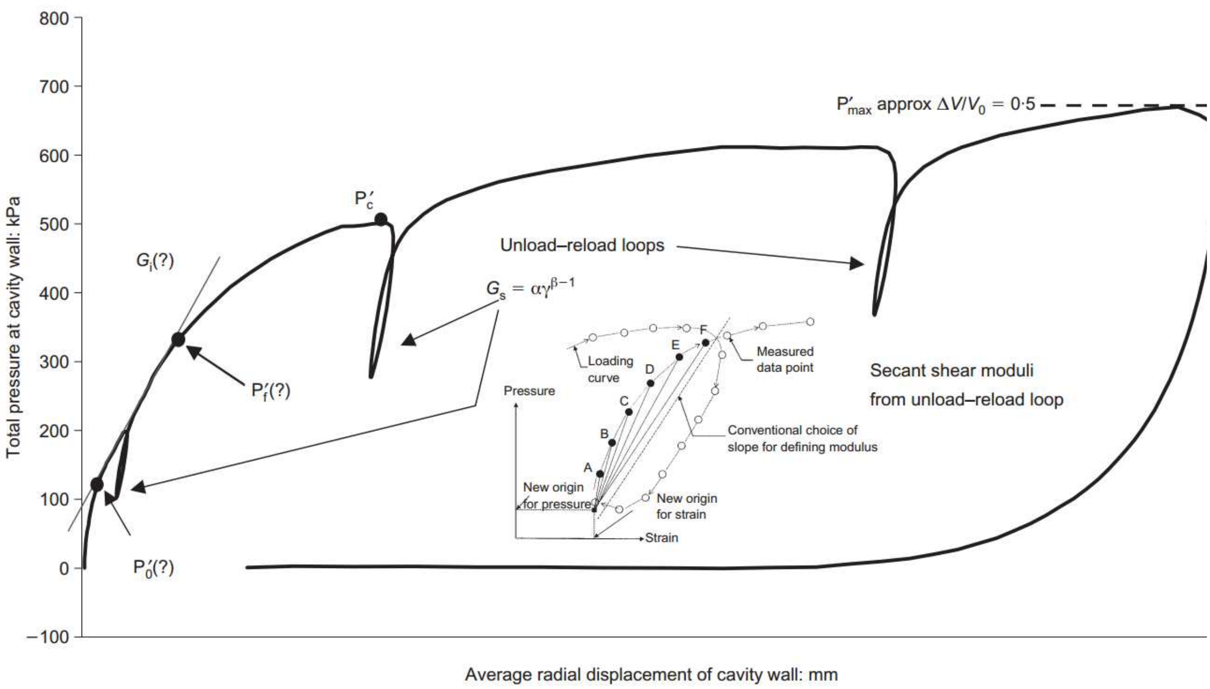


Figure 4. Plot of pressure against cavity displacement showing definition of key parameters and calculation of small-strain secant shear moduli from unload-reload loos. (?) denotes potential uncertainty in calculating values (Dixon 2006)

negligible difference on the values obtained using the two considered unit weight models.

Although the aim of the study is to obtain the shear strength of MSW, at this preliminary stage, it is only possible to obtain stiffness parameters.

A summary of the results derived from a preliminary analysis of the data is provided in Table 1.

4 CONCLUSIONS

A first batch of pressuremeter tests has been carried out in a landfill near Barcelona, Spain. Alongside the obtained results, the main purpose for this first contact was to find the appropriate way of performing PBP tests in waste, adapting the procedure provided in the ISO 22476-4 code to its usage in waste. After carrying out 16 tests, some conclusions about the procedure can be drawn:

- The usage of soft membranes is strongly recommended, due to their better performance and similar durability in comparison with stronger ones.
- Most membrane failures occur during the pressuremeter extraction maneuver. This is caused due to the instability of the test pocket's walls that allows the waste to get stick to the membrane during the deflating and to apply a considerable pressure, causing the membrane to burst due to excessive longitudinal deformation.
- Reaching the device's maximum deformation is possible without a noticeable decrease in the durability of membranes. Besides, due to the high deformability of MSW, it is necessary to achieve very large deformations to reach failure. This two considerations together, make it reasonable to say that tests have to be carried out until maximum deformation of the membrane is reached.
- A lower limit for the unload needs to be established to obtain valuable results from the unload-reload cycles.

With the conclusions obtained for this first test batch, new procedures have been established for its usage in next test campaigns.

As for the unit weight models used to analyze the tests, although the hyperbolic model produces a larger P_0', the influence in the obtained shear moduli is negligible.

As expected, large variability has been found on the obtained parameters at equivalent depths depending on the point of the landfill they were carried out.

Further analysis needs to be done to the gathered data alongside new data obtained from new test campaigns in different landfills in order to characterize MSW using field tests. Correlations between the data obtained using pressuremeters and CPTu for nearby points of study needs to be done to obtain strength parameters in addition to the stiffness parameters obtained using only pressuremeter tests.

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