Field test to assess the influence of a geomembrane liner in a landfill on soft clays

Parra-Piedrahita, N. P., Ovando-Shelley, E.
Instituto de Ingeniería, Universidad Nacional Autónoma de México, Ciudad Universitaria, circuito escolar, Edificio 4, Cubículo 112, Delegación Coyoacán, C.P. 04510, Mexico City, Mexico, NParraP@iingen.unam.mx

Cabrera-Velázquez, M. C.
Formerly Instituto de Ingeniería, Universidad Nacional Autónoma de México, Mexico City, Mexico

Trigo-Lara, M., Contreras, R.
TGC Geotecnia,Geotechnical consultants, Mexico City, Mexico

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ABSTRACT: This paper is about the long-term performance of a geomembrane installed as a liner at the base of a municipal solid waste landfill. This landfill was built on very soft and highly compressible lacustrine clay which is also being subjected to the effect of regional subsidence caused by water-pumping from an underlying aquifer. The paper describes the setting up and the results of a large scale field load test that was performed in the waste fill. Based on the behavior observed during the load test, a 3D finite element model was established to replicate the consolidation process in the underlying soil in order to describe the long-term performance and future stability of the totality of the solid waste landfill, taking into account the geomembrane properties and changes in the waste fill's height. The study disclosed the consequences of having the geomembrane, on the general stability of the landfill.

1 INTRODUCTION

Solid waste landfills are usually constructed on foundation soils which are neither too soft nor too compressible. Landfills should also be constructed away from water bodies that can potentially be contaminated during their lifetime.

In this paper are describe a landfill, the Bordo Poniente Landfill, BPL, that was built on very soft and highly compressible lacustrine clay which is also being subjected to the effect of regional subsidence that is produced by water-pumping from an underlying aquifer (Ovando-Shelley, et al, 2007). Another peculiarity of this structure is the presence of an HDPE geomembrane liner which influences the long-term behavior of the soft soil foundation, a very important aspect which we will discuss in this paper.

Nowadays, Mexico City produces 12,500 tons of MSW per day and for the time being it lacks another place to dispose them (SOS, et al, 2004). Hence, it was necessary to extend the operation time of BPL. In order to study the possibility of placing additional volumes of waste, a large scale field load test was performed, from June to December of 2003. In what follows, we analyze the results of the test, taking into account the influence of the geomembrane.

2 LOCAL CONDITION

The BPL is located on the Texcoco Lake over lacustrine soils that involve rather thick layers of very soft and highly compressible clay, interspersed by sandy layers with various contents of silt and clay (Contreras et al. 2000), as illustrated in figure 1. BPL it is being subjected to the effect of regional subsidence which produces reduction of pore pressures starting at a depth of 38 m.

A HDPE geomembrane 1.0 mm thick was installed to separate the natural soil from the MSW (JICA, et al, 1999). In our analyses the geomembrane was characterized in terms of its hydraulic conductivity. Its strength is not relevant for the analyses since it can only be mobilized when reaching rather large deformations (700%, equivalent to 7.0 m), a situation that did not arise in this case.

3 DESCRIPTION OF THE FIELD LOAD TEST

The large scale field load test involved the placement of nine layers of compacted sandy clay over an area of 150 m x 150 m, 4.85 m high. The compacted sandy clay was placed on top of a pre-existing solid waste fill 5.7 m high (Contreras et al. 2000).

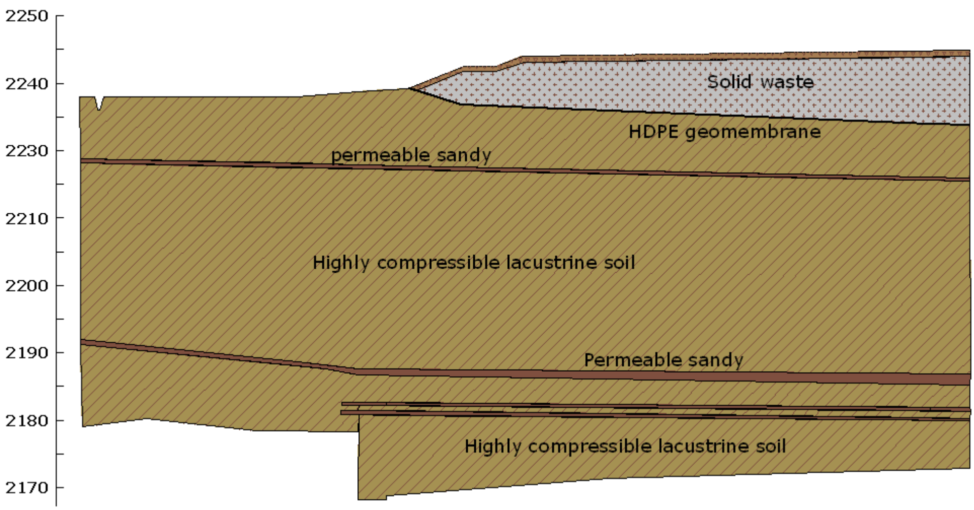

Figure 1 Soil strata in the subsoil of the Bordo Poniente Landfill.

The sandy clay transmits an average contact pressure of 89.5 kPa, on the underlying soil, equivalent to 10.5 m of MSW, whilst the solid wastes apply 60 kPa.

The test area was instrumented with five vibrating wire piezometers, two open head piezometers, and three inclinometers; precision leveling surveys were also carried out (Contreras, et al, 2001).

The load test took place from June to December, 2003 and at the end of it, failure of the embankment did not occur, as predicted by limit equilibrium analyses performed before, albeit some cracking of the waste cover was observed and excess pore pressure did not dissipate.

4. ANALYSES WITH THE NUMERICAL MODEL

Figure 2 shows the geometry of 3D model and the relative location of the load test. The soil is modeled as an elastic-plastic Mohr-Coulomb solid (Brinkgreve, et al, 2007) and effective stiffness parameters are considered. In the numerical model, a waste fill was placed over the natural soil to produce the initial conditions of the test.

First, an undrained effective stress analysis was made, in order to give rise to excess pore pressure after each load increment. Afterwards, the consoli dation process in the underlying soil was replicated, to describe and analyze the long-term performance. Soil parameters for the 3D model were taken from several sources: effective stiffness parameters of the highly compressible soft soil were obtained from an earlier laboratory research (Giraldo-Sierra, 1996), and the other parameters from laboratory and cone penetration tests carried out during this project (Contreras, et al, 2000). Table 1 shows the properties of soft soil from Texcoco Lake in contrast to the other layers. A drained condition was set for soils above the water table.

Table 1 Soil parameters of 3D model

Parameters	HCS-1	HCS-2	PSL-1	HCS-3	PSL-2	HCS-4	DD	MSW
Soil condition	Drained	Undrained	Undrained	Undrained	Undrained	Undrained	Undrained	Drained
Final depth (m)	-1.30	-9.50	-10.50	-39.00	-41.30	-56.50	-100.00	5.72
e_0	3.20	3.20	0.50	8.68	0.50	6.20	0.50	0.50
γ_{nat} (kN/m^3)	12.30	12.30	16.00	12.80	18.00	13.40	17.00	10.00
$k_h = k_v$ (m/s)	8.64E-04	8.54E-05	1.00E-03	1.00E-06	1.00E-03	8.64E-05	1.00E-03	1.16E-07
E' (kN/m^2)	130	100	130	1700	2000	40000	350000	5550
ν	0.30	0.35	0.30	0.35	0.25	0.35	0.25	0.33
c' (kN/m^2)	27.00	2.00	75.00	3.00	85.00	6.00	1000.00	5.00
ϕ'	1°	44.52°	35°	45.5°	35°	53°	35°	20°
PSL: Permeable sandy lent, HCS: highly compressible soil, DD: deep deposits, MSW: municipal soil wastes.								

The finite element model developed this way replicated fairly well displacements and pore pressures that were measured during the load test (Contreras, et al, 2003). According to these results, pore pressures increased considerably in the lacustrine soil down to 38 m under the area of the load test, figure 3. Furthermore, the analyses demonstrated that the loads applied during the test influenced the neighboring areas in the landfill as far as 33 m away.

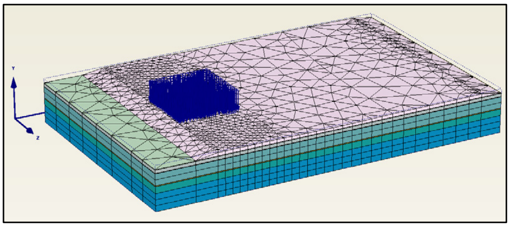

Figure 2 geometry of the 3D model, showing the load test area.

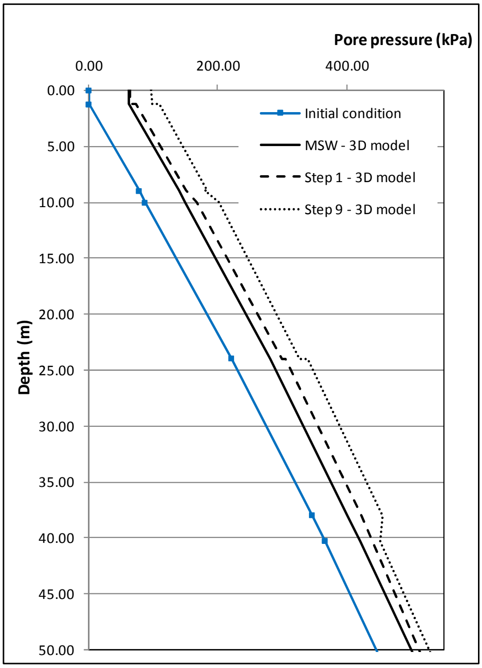

Figure 3 Pore pressure under the center of the load test.

In general, displacements and excess pore pressures predicted by the numerical model matched well instrumental observations.

Settlements due to the landfill and the load test were large and concentrated mainly in the edge of the loaded zone, reaching 5.15 m with an associated shear stress of 7.72 kPa which is 74% of the soils' shear strength. Deformations were calculated with respect to the condition existing before the test. Their very large magnitude is a consequence of the clays' extremely high compressibility. The relative settlements in different steps of the test are illustrated in figure 4.

As a consequence of the consolidation process, settlements increased slightly after each step and the geomembrane suffered a plastic elongation of about 33% at the last step. Assuming that deformations are mainly concentrated under the loaded area, this value is far from reaching elongation values at failure (700%) and the tension stress produced is far below the admissible stress.

It should be emphasized that the presence of the geomembrane precluded the dissipation of excess pore pressures during the test, a fact that was proven with the numerical analysis. In fact, consolidation happened at a much slower rate, just as expected a priori. However, this had the effect of temporarily reducing safety factors down to unacceptable values during the load process. Afterwards, the safety factors increased as effective stresses increased due to dissipation of excess pore pressures during consolidation of the soft lacustrine clays (Cabrera-Velazquez, 2009).

The following step in the study of the performance of BPL will be to determine the admissible maximum height of fill before failure and the evolution of safety factors with time, in order to assess the feasibility of enlarging its capacity and its operation time.

4 CONCLUSION

Landfills built on highly compressible soft soil benefit from the use of an impermeable barrier formed with a geomembrane because pore pressures dissipate slowly and the ensuing settlements also occur at low rates. However, care should be taken because safety factor will reduce considerably in the short term. Moritoring pore pressures in the subsoil are therefore necessary to assess the general stability of the fills as load accumulates in such fills.

The geomembrane worked adequately as an impermeable barrier during the load test according to the instrumentation records and the finite element model, and it behaved more than well regarding its plastic elongation. Piezometers reading suggest that the geomembrane has not been punctured or torn apart significantly since pore pressures have dissipated very slowly. Samples of pore water table taken below the fill show no evidence of leaching.

The use of a numerical model allowed us to study other features, such as the future evolution of pore pressures under the fill, as well as its implication for the general stability of the fill in the future.

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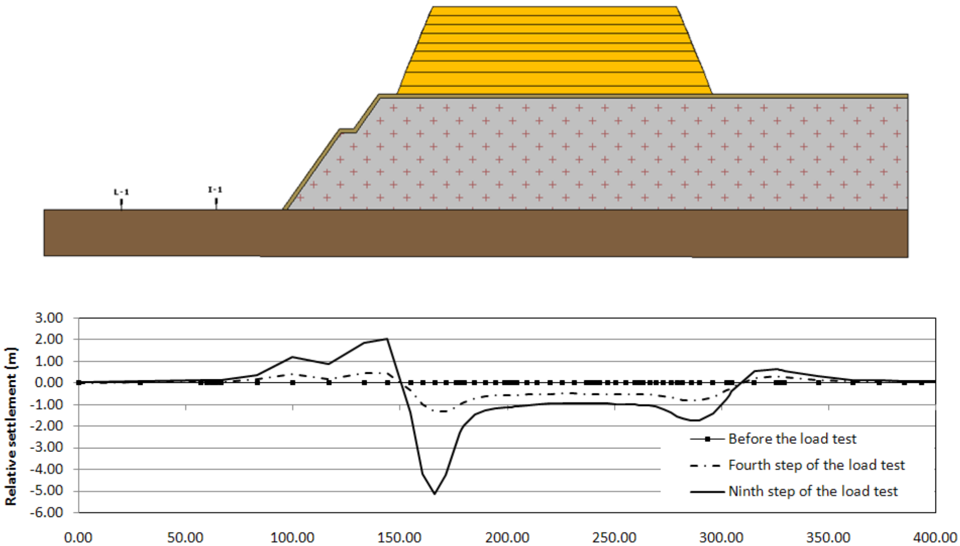

Figure 4 Relative settlements on account of MSW landfill and the load test.

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