F.E.M. Modelling of the Behaviour of a Vertical Composite Lining System

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ABSTRACT: The behavior of a composite synthetic lining system placed on a landfill with vertical rock slopes has been modeled through F.E.M. The composite synthetic liner has been considered fixed to the top of the rock and anchored along the rock face with a group of bolts. The stresses induced in the system have been analyzed. These were:
- thermal actions;
- self consolidation of the waste;
- combined effect of temperature and waste settlement.

The length, the strength and the arrangement of the anchorage have been defined by a trial and error process. Allowable stress/strain condition for the composite synthetic lining system have been defined. The F.E.M. study has been carried out in *Plane-Strain* condition in order to assess the forces induced by self consolidation of the waste mass, and in *Plane-Stress* condition in order to assess the stresses and strains induced in the system by the external forces.

1 INTRODUCTION

Landfilling abandoned quarries is a common practice in Italy and in several european Countries as well as it is becoming an increasing practice in Far East.

Particularly in the case of abandoned rock quarries, very often the designer has to face the problem of vertical rock walls to be properly lined.

Traditional solutions for vertical lining in landfills (see figure 1) implied the creation of artificial soil slopes against the rock face, to be covered with clay layers and HDPE geomembranes (see figure 1).

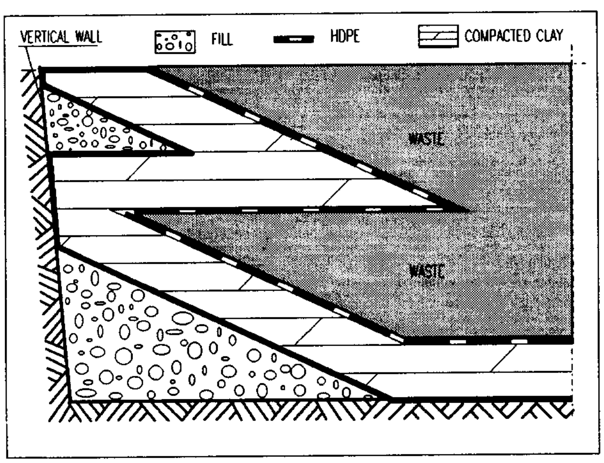

Fig.1 Christmas Tree lining system - Typical section

This solution is typically known as Christmas Tree.

In order to improve airspace management, different empirical solutions have been implemented at different sites, "hanging up" on rock faces different liners with different "nails".

The purpose of this paper is to propose a new design tool which models the behaviour of a vertical synthetic composite lining system (VSCLS) during the construction and the operation of a landfill.

2 THE VERTICAL SYNTHETIC COMPOSITE LINING SYSTEM (VSCLS)

The chosen VSCLS had the following layout (from the rock face to the waste mass):
- lining geocomposite, made of one HDPE geonet, 13 mm thick, one Geosynthetic Clay Liner (GCL), 10 mm thick, one HDPE geomembrane, 2 mm thick. The lining geocomposite is acting as a double composite liner, where the GLC provides mineral lining;

- HDPE geonet, 5 mm thick. The geonet has the purpose to collect and drain the leachate to the bottom drainage;
- protective HDPE nonwoven geotextile, 2.3 mm thick.

The geotextile has both the purpose to protect the liner and to avoid the clogging of the geonet.

The lining geocomposite was considered anchored to the top of the rock wall and bolted against it; the geonet and the geotextile were considered anchored to the top and to the bottom and left free to elongate when stressed by the settlement of the waste mass.

This to minimize the transfer of stresses from the garbage to the liner.

The VSCLS has been modeled in the following conditions through the Finite Element Method:
- self weight-induced stresses, particularly around the anchors;
- thermally-induced stresses, due to solar exposure;
- stresses by the self consolidation process of the waste mass against the face of the VSCLS;
- the combination of the above mentioned conditions.

3 THE FINITE ELEMENT METHOD

A method has been used which allows a general discretization of the continuum problem posed by the behaviour of the vertical liner, using the Theory of the Membrane.

In order to define the stresses due the to weight of the system, the thermal and frictional loads, the Plane-Stress case has been considered.

This implies that the displacement field is uniquely given by the displacements in direction of the cartesian, orthogonal x and z axes. The strain and stresses to be considered are the three components in the xz plane, all other contributes to stresses are zero and therefore do not contribute to internal work.

The Plane-Strain case has been considered to model the stresses induced by the self consolidation of the garbage.

In this case the displacement field is given by the displacements in direction of y and z axes and the only strain and stresses to be considered are the three components in the yz plane. In Plane-Strain case the stress in a direction perpendicular to the yz plane is not zero. By definition, the strain in that direction is zero, and therefore no contribution to internal work comes from this stress.

4 DESIGN ASSUMPTIONS

In order to study the behaviour of the VSCLS, the following parameters have been chosen for each component:
- thickness,
- modulus of elasticity,
- thermal expansion coefficient,
- yield stress.

In each node of the discrete model the acting stresses have been kept 20% below the yield point, as to mantain the whole system into linear-elastic conditions Figure 2 is showing , for the different elements of the system, the frictional forces acting on the membrane plane.

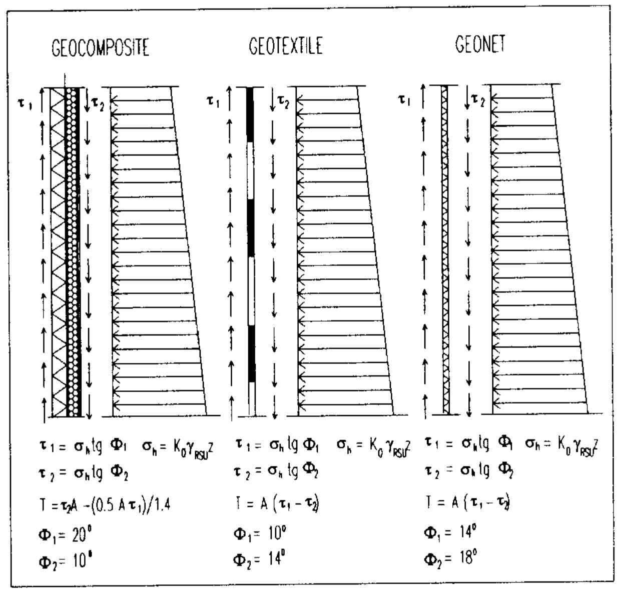

Fig.2 Frictional forces mobilized at the membrane plane

One of the most critical aspects in assessing the stability of the VSCLS is the definition of the long-term behaviour of the membrane around the rock bolts anchoring it, being these points of concentration of the stresses acting along the surface of the system.

For each bolt it has been verified that the stresses acting around it were lower than the yield strenght of the vertical liner, following this formula:

$$\sigma_{RIF} <= 2 * 0.9 * \sigma_y \quad (1)$$

where σ_{RIF} is the maximum stress around the anchorage, without damaging the HDPE components of the geocomposite, given from

$$\sigma_{RIF} = F/A \quad (2)$$

F = force on the anchorage,
A = two times the area of contact between bolt and geocomposite (is negliged the area of bentonite).

The frictional parameters of the elements of the system have been chosen from the avalaible literature;

- HDPE geonet, 5 mm thick. The geonet has the purpose to collect and drain the leachate to the bottom drainage;
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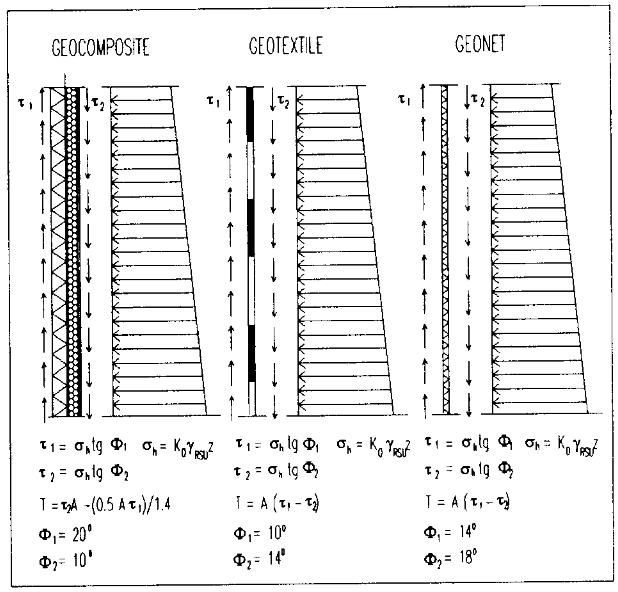

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F = force on the anchorage,
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The frictional parameters of the elements of the system have been chosen from the avalaible literature;

the stress distribution comes from plane strain analysis, applying a k_0 defined as follows:

$$k_0 = 1 - \sin \Phi \quad (3)$$

where:

- k_0 = coefficient of pressure at rest of waste,
- Φ = internal friction angle of the waste mass.

5 RESULTS OF THE STUDY

Making use of the geometry described above, in order not to exceed the yield strength on the components of VSCLS and the maximum resistance at the anchorage points, the layout reported in figure 3 has been defined.

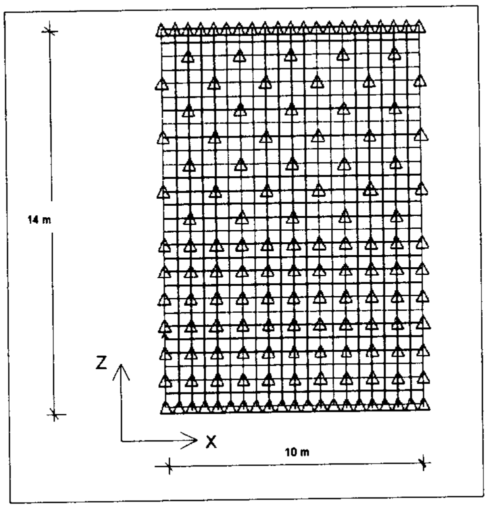

Fig.3 Layout of anchoring bolts

Each bolt of this layout had an allowable force of 3.9 kN; the required diameter of the bolt was found to be a minimum of 20 mm.

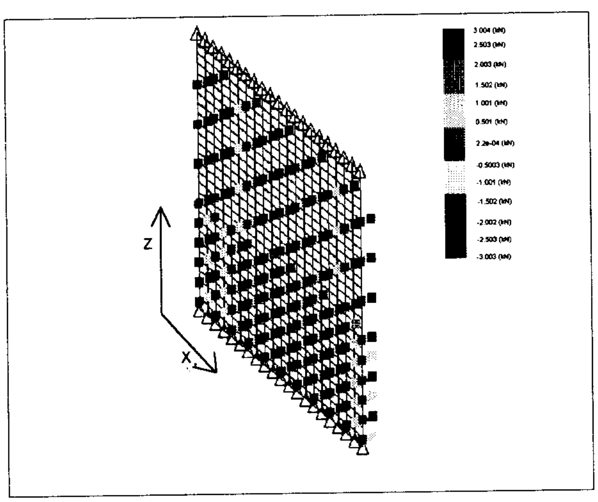

Fig.4 Mobilized force at the anchorages: thermal stress and self weight of system

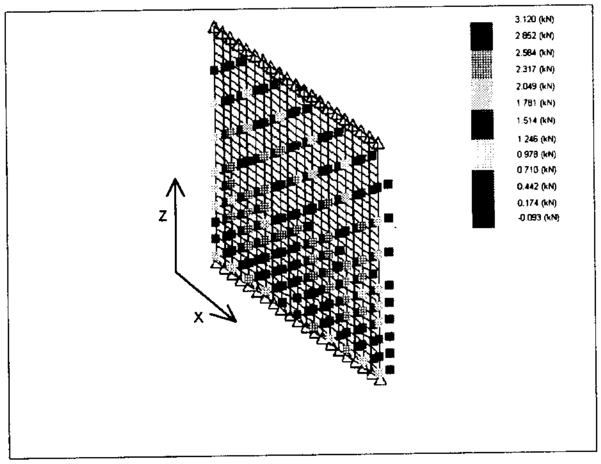

Fig.5 Mobilized force at the anchorages: settlement of the waste mass and self weight of system

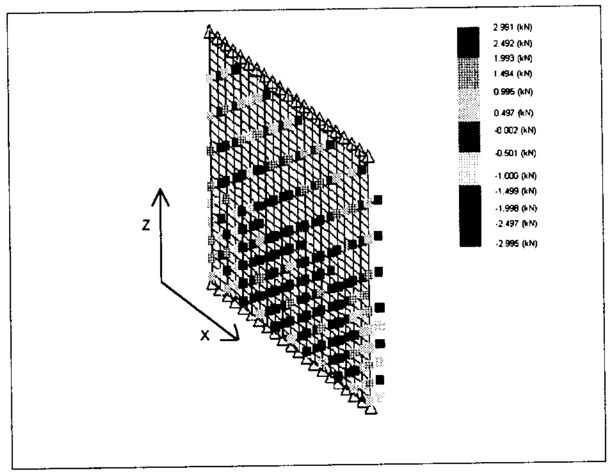

Fig.6 Mobilized force at the anchorages: combination of thermal stress, settlement of waste mass and self weight of system

Figures 4-5-6 show the mobilized force at the bolts in the following conditions:

- thermal stress and self weight of the liner;
- settlement of the waste mass and self weight of the liner;
- combination of thermal stress, settlement of the waste mass and self weight of the liner.

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