Geosynthetics: Applications, Design and Construction, De Groot, Den Hoedt & Termaat (eds)
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Coastal embankment on bad soil: The port of Thessaloniki

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ABSTRACT: The improvement of soil behaviour of a coastal embankment constructed on bad and polluted soil with the use of geotextiles is examined in this paper. The foundation of embankment consists of soft compressive soil stratum. The use of the geotextile is to separate the unsuitable stratum from the landfill, to reduce the lateral and vertical soil movements and to strengthen soil resistance. The structure takes place at Port of Thessaloniki, Greece.

1 *The site of the project and soil mechanics considerations*

Geotextiles have been extensively and successfully used during the last 30 years in order to fulfill one or more of the following functions: separation, filtration, drainage, strengthening. Sensitivity of citizens in the protection of the environment has added in recent years the very important aspect of preservation of the environment for geotextile applications, (Rankilor 1981), (Profillidis 1995).

This paper analyzes a geotextile application which combines all classical functions of geotextiles but also the environmental aspect. In the port of Thessaloniki (Fig. 1) works of extension of the activities of the 6^{th} pier were necessary. However, the area of the works consist of bad soil with strong deposits of polluted materials, due to the operation of tanneries for many years at the surrounding area.

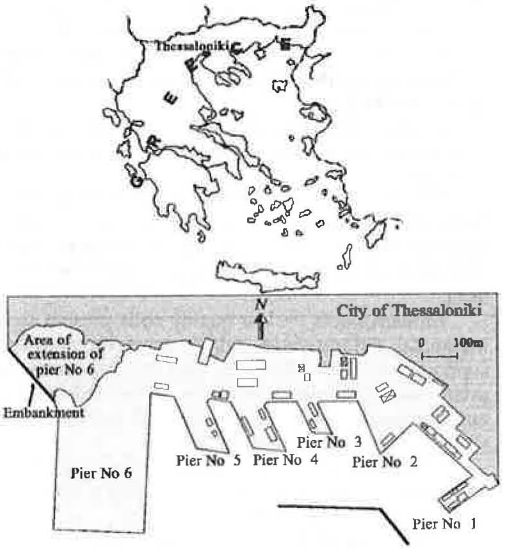


Figure 1. Site of the city and the Port of Thessaloniki.

Soil mechanics investigations gave the values of the undrained shear strength of the soil layers shown in Fig. 2. These are mean values deduced from an extensive series of investigations (Fig. 3). However, values of the liquidity limit LL and plasticity index PI have been also investigated (Fig. 4).

2 *Environmental data*

Investigations of the concentrations of the polluting materials in 4 points in the greater area of the Gulf of Thessaloniki gave the values of Table 1. As values are stronger for point 4, analysis of the concentrations of Cr in relation to depth has been

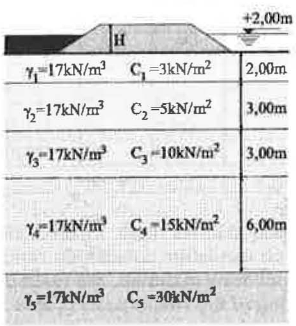


Figure 2. Values of the undrained shear strength of the soil layers.

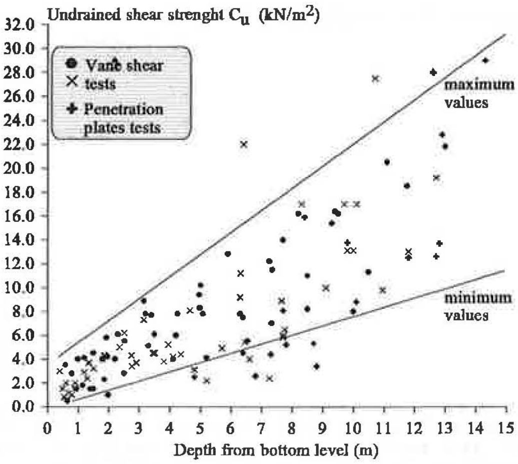


Figure 3. Results of the investigation for the undrained shear stress.

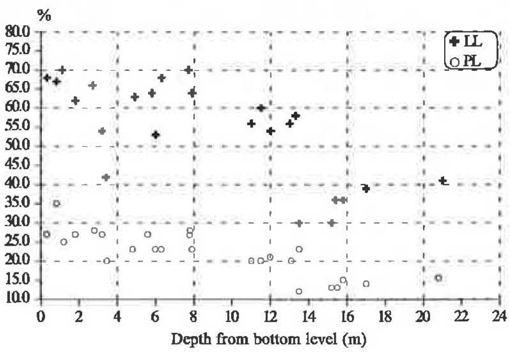


Figure 4. Variation of the liquidity limit and plasticity index from the bottom level.

Table 1. Concentrations (mg/kg) of polluting materials in the Gulf of Thessaloniki.

Point of investigation	Cu	Cd	Pb	Cr
1	35,0	1,5	25,0	72,0
2	43,0	1,5	93,0	167,0
3	108,0	4,0	195,0	1624,0
4	135,0	6,0	327,0	2647,0

conducted (Fig' 5). As both Greece and European Union have no regulation concerning concentrations of sea bottom polluting materials, we make a comparison with regulation of the Netherlands (Table 2).

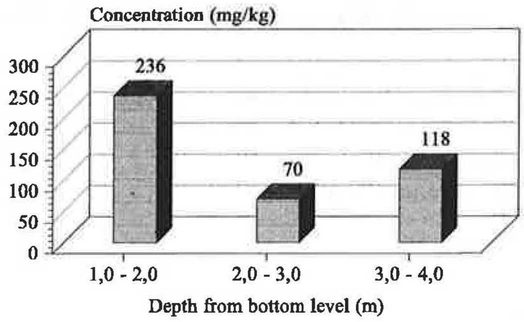


Figure 5. Variation of the concentrations of Cr in relation to depth.

Table 2. Values of the polluting materials in comparison to test values and warning values.

Polluting material	Concentration (parts per million)	
	Warning value	Values in the area of the project
Cu	30,0	5,4
Cd	1000	2136
Pb	400	122
Cr	1000	261

3 *What geotextiles can contribute*

The first idea to confront the problem, was to replace the polluted area of a total surface of 300000m^2 at a depth of 2m. This possibility was rejected for two reasons:

1. Principally for environmental risks: reduction of the oxygen in the sea water and increase of mortality of the small fishing beings and the flora; however the risk of propagation of the polluted materials during the replacement procedure, can not be fully controlled.

2. The technical problem and the cost of replacement at a great area, should not be under-estimated.

For the above reasons, it is preferable not to disturb the existing situation at the bottom. In order to safeguard the preservation of the environment and the strengthening of the soil quality, geotextiles have been used.

Embankments on low quality soils present strong horizontal deformations, which must be adequately supported by the soil. If the soil has not the appropriate resistance, then a local or global failure of the embankment can occur. The use of geotextiles can strongly reduce such an event.

Thus the geotextile used at the area of the extension works of the Port of Thessaloniki must fulfill the following functions:

- increase of the drainage conditions
- strengthening of the soil resistance
- increase of the embankment stability

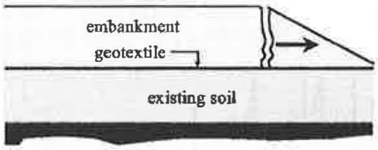
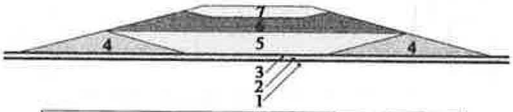


Figure 6. Lateral collapse of an embankment.



Legend:

1. Positioning of the first layer of geotextile
2. Layer of the embankment of 30cm
3. Positioning of the second layer of geotextile
4. Some quantities of the material of the embankment are laid at the edges of the geotextile, in order to secure correct anchoring
5. Succesive layers of the embankment of 40cm
6. Succesive layers of the embankment of 50cm
7. Construction of the remaining part of the embankment

Figure 7. Construction of the embankment.

Table 3. Geotextile requirements in order to avoid lateral collapse.

Sea depth	Embankment height	Embankment weight	Required resistance of geotextile	Resistance of geotextile used
(m)	(m)	kN/m^3	kN / m	kN / m
0,0	2,0	19,50	19,50	200
2,0	4,0	14,75	59,00	200
4,0	6,0	13,20	118,80	400
6,0	7,0	11,34	138,90	400
6,0	8,0	12,40	198,40	400

4 *Required resistance and appropriate design of the geotextile*

A failure of an embankment can occur in one of the following ways, (Tan Siew-Ann et al, 1994), (Espinoza, 1994):

- Inappropriate resistance of the foundation soil. The geotextile is not influencing significantly the improving of the soil strength. However, analyses show that this improvement is small (around 10%) and for safety reasons, it is usually neglected at the design of the embankments, (Profillidis, to be published).

- Sliding of the embankment. The use of geotextile can significantly contribute to avoid such a risk. The appropriate geotextile's resistance can be reduced from application of the Bishop's method. In our case, calculations deduced for depths from -2m to -6m a geotextile resistance during operation of T=300 kN/m. In order to fulfill this requirement, two layers of geotextile of a tensile strength of 200kN/m have been used. For depths from 0 to -2m, calculations gave that only a layer of geotextile is necessary.

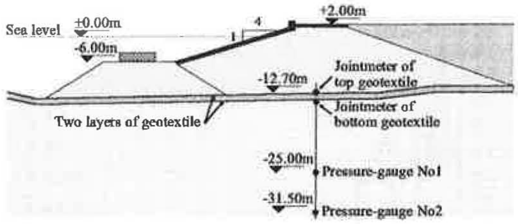


Figure 8. Typical profile of the embankment

- Lateral collapse, which takes place when lateral forces are greater then the soil resistance of the embankment (Fig. 6). In order to avoid this event the geotextile must have the appropriate elasticity modulus and assure a sufficient friction angle embankment-geotextile. Application of the classical lateral forces methods give in our case the results of Table 3.

However, for the soil-geotextile friction angle φ_{g-s} and for the elasticity modulus E_{geot}, the following required values have been deduced:

$$\varphi_{g-s}: 30°$$

$$E_{geot}: 2000\ kN/m^2$$

5 *Technical details during construction*

The construction of the project has been realized in the following procedure:

- excavation of a layer of a depth of 1m, in order to normalize the bottom and improve the foundation of the embankment
- positioning of devices for monitoring pressures exerted during construction
- positioning of the first layer of the geotextile
- positioning of devices for monitoring deformations of geotextile
- construction of the first layer of the embankment of a thickness of 30cm
- positioning of the second layer of the geotextile
- construction of the embankment by positioning successive layers of a thickness each time approximately of 50cm
- positioning of devices for the calculation of deformations and stresses of the embankment

Fig. 7 illustrates the successive stages of construction of the embankment. Special emphasis must be paid on the correct and permanent anchoring of the geotextile.

6 *Evolution of stress and strain after construction*

Fig. 8 illustrates the position, where are placed the appropriate devices for the monitoring of evolution of strain of the geotextile and of pore pressure of the soil under the geotextile.

Fig. 9 illustrates the strain at the upper layer of geotextile. We see that the curve is normalized after 50

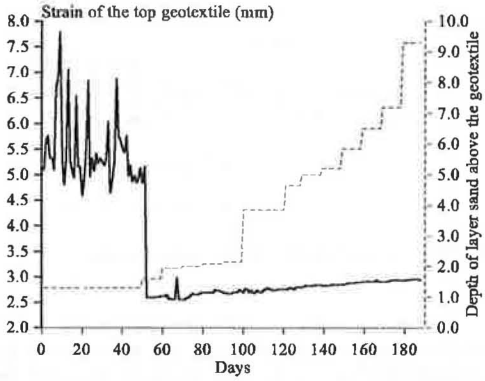


Figure 9. Indications of the jointmeter fastened to the top layer of geotextile.

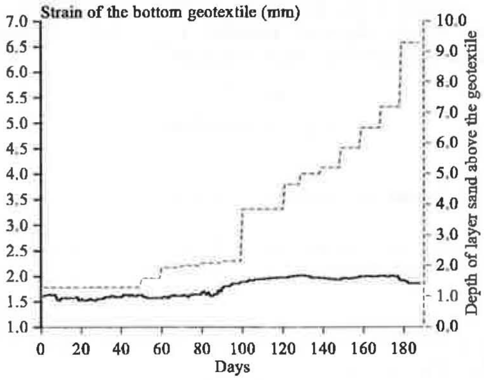


Figure 10. Indications of the jointmeter fastened to the bottom layer of geotextile.

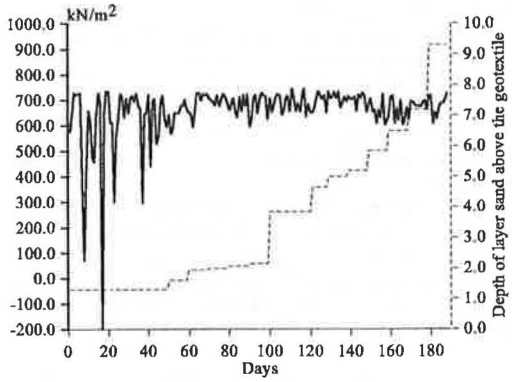


Figure 11. Indications of the pressure-gauge No 1.

days, when a second layer of 60cm of sand is laid on the first layer of 130cm. Concerning strain at the bottom layer of geotextile (Fig. 10), we see that it is more homogeneous and does not depend upon the layer of sand laid on the upper geotextile.

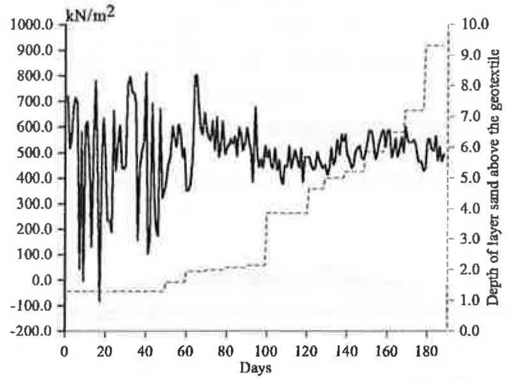


Figure 12. Indications of the pressure-gauge No 2.

Fig. 11 and 12 illustrate the evolution of pore pressure at the depth -25,0m and -31,5m from the sea level. Again the phenomenon is normalizing when the layer of 60cm is placed on the first layer of 130cm of the embankment.

7 *Concluding remarks*

An application of geotextiles combining all classical functions but also the emerging importance of preservation of the environment has been presented in this paper. The project consists of an extension of the Port of Thessaloniki in an area of polluted and low resistance materials. The appropriate design of the geotextile in relation to soil mechanics characteristics has been discussed. Details of construction techniques have been presented. The evolution of stress and strain after construction of the project has been also analyzed.

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