Temperature monitoring of a geosynthetic-reinforced embankment in a seismic area

Mésures des temperatures dans un rémblai rénforcé en région séismique

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ABSTRACT

Field data on reinforced embankments are of upmost importance for improving knowledge on their long behaviour. In Valdina, Sicily, Italy, following a landslide that involved a slope in clay soils, a reinforced embankment has been constructed. Valdina is a small village in the Eastern Sicily that displays a high frequency of landslides since clay soils outcrop extensively. In 2006, the reinforced embankment constructed on a clay slope was instrumented and the results of the following 2 years of reinforced embankment monitoring are presented together with an analysis of the collected data of temperatures. The equipment installed allows the measurement of the weather parameters (rainfall, wind, air humidity and air temperature), of the loads and deformations of the reinforced embankment, and of the ground vibrations caused by earthquakes. To estimate the trend of deformations, temperature, humidity and loads along the geogrids used to reinforce the structure, measurement instruments were installed within the structure at different depths.

RÉSUMÉ

Les résultats des investigations en situ sont très important pour comprendre le comportement a long terme des rémblais rénforcés.En particulier on va présenter le rémblais rénforcé de Valdina, en Sicile, Italie, réalisé suite à un glissement de sol dans la pente de nature argileuse. En 2006, le rémblais rénforcé a été instrumenté soit pour les paramètres climatiques (la pluviosité,le vent, l' humidité de l' air et la temperature de l' air), soit pour les contraints et les déformations de la structure rénforcée, soit pour les vibrations dues à événements séismiques. Pour évaluer les contraints, les déformations, les témperatures et l' humidité dans la géogrille de rénforcement, les different instruments ont été installés dans la structure rénforcée à differents niveaux.

Keywords: prediction, instrumented reinforced embankment, temperature monitoring

1 INTRODUCTION

This paper focuses on an instrumented geosynthetic reinforced embankment constructed in Valdina (Sicily, Southern Italy). Following a landslide that involved a slope in clay soils, a reinforced embankment has been constructed.

Cazzuffi & Rimoldi (1994) investigated the earth-reinforced embankment behaviour in static conditions. Moreover, due to little data available about internal temperature in reinforced embankment and in seismic condition, their behaviour are still not clearly known (Bathurst, 1990).

The knowledge of average temperature in the reinforced embankments is a key factor for understanding the geosynthetic tensile creep behaviour and therefore for the overall design of earth reinforced structures.

To overcome these problems a reinforced embankment has been instrumented with strain gauges, vertical load cells, temperature and humidity sensors and accelerometer vibrations sensors.

The structure was monitoring since the initial phase of construction and during the service phase. During this period there wasn't relevant seismic phenomena, therefore the paper presents mainly the collected data of temperatures.

2 DESIGN AND CONSTRUCTION

The design was carried out in the town of Valdina, in the province of Messina in South Italy to following landslide that involved a slope in clay soils. There were two problems to solve: a slow slope movement due to a deep failure surface involved the city of Valdina and a shallow instability phenomenon involved the SP8 road connecting Valdina to the main road SS113. In order to stabilise the slope, it was decided to reconstruct the slope by means of a reinforced soil slope with a sheet pile wall at the top of the slope and a concrete wall based on piles at the toe of the slope (Figs.1-2).

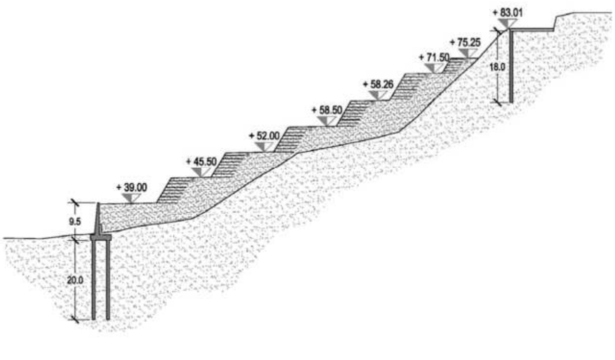

Figure 1. Scheme of the stabilization project.

The main geotechnical properties of the soil used for the construction of the geosynthetic reinforced embankment and of the in situ soil, are showed in Table 1.

For the design of the geosynthetic-reinforced soil embankment an internal soil friction angle (Φ_{cv}) of 34° was used.

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To ensure the face stability and geometry, the structure was constructed using "left in place" welded wire formworks. They are composed of wire mesh precut to an height of about 6.50m and bent to the face at an angle of 60°. The fill soil was compacted in layers of 0.3m thick using a vibrating roller (80 kN).

Table 1. Main geotechnical properties of fill and foundation soils.

	In situ soil	Fill soil
γ [kN/m^3]	20	20
ϕ' [°]	26	45
ϕ_{cv}' [°]	-	34
c'[kN/m^2]	0.0	0.0
OCR	1.5-2.3	-
RR	0.02-0.03	-
CR	0.12-0.15	-

Figure 2. Phase of the stabilization project construction.

In the geosynthetic-reinforced embankment at toe of the slope several measurement instrumentations were installed. The scheme of the instrumentation is showed in Figure 3.

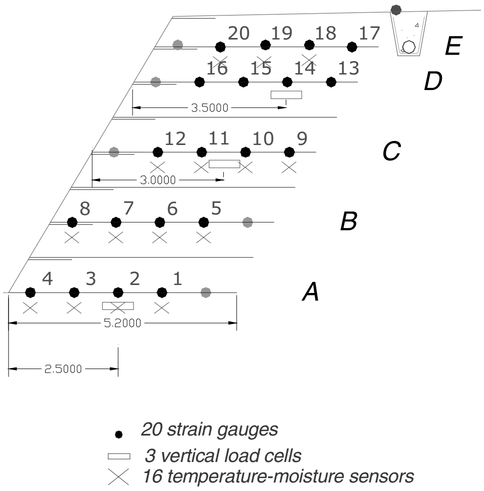

Figure 3. Scheme of the different installed instrumentation.

The geogrids were instrumented with self-temperature compensated strain gauges having a nominal gauge length of 5mm and a maximum strain of 10% with a measurement accuracy of 0.5%. The strain gauges were glued to the geogrid ribs with cyanoacrylate adhesive using a multi-step method. This procedure allows the measurement of the geogrid strains up to 10%, over a period in excess of two years and during freezing temperatures. Four strain gauges were installed on each reinforcement layer at a spacing of about 1.00m. The strain gauges were protected with silicon rubber and with a 0.10m-thick sand layer. The effectiveness of this procedure has been demonstrated by the low mortality rate of the sensors (only one out of 63 sensors malfunctioned) [Moraci et al. 1999; Carrubba et al. 2000]. The electrical connection was made using a three wires Whetstone quarter bridge. The strain gauges were connected to an automatic data acquisition unit which is capable of recording up to 100 sensors every 15 minutes. Additional specimens of geogrids, were instrumented with strain gauges, were prepared and tested in the laboratory to provide a basis for calibration and correlation between strain and tensile stress. The stress-strain curves and modulus for both geogrids were established with laboratory testing. These relationships are function of time, temperature, stress and strain. The following tests were performed to define the time dependent properties of the geogrids: in isolation index single rib tensile tests, low strain rate tensile tests, and different load tensile ratio creep tests.

Three vertical total stress cells, each having a diameter of 300mm, were installed at three different reinforcement layer to record the actual vertical total stress in soil. These cells were located at 2.5m, 3.0m and 3.5m inside the wall face (Fig.4).

A weather station was installed to monitor external meteorological parameters (Fig. 5). The station is composed by an anemometer, a rain collector, a barometric pressure and external temperature/humidity sensor.

The anemometer includes both wind speed and wind direction sensors. Rugged components stand up to hurricane-force winds, yet are sensitive to a light breeze.

The rain collector is designed to meet the guidelines of the World Meteorological Organization. Rain enters the collector cone, passes through a debris-filtering screen, and collects in one chamber of the tipping bucket. The bucket tips when it has collected an amount of water equal to the increment in which the collector measures (0.01" or 0.2 mm). As the bucket tips, it causes a switch closure and brings the second tipping bucket chamber into position. The rain water drains out through the screened drains in the base of the collector.

The external temperature/humidity sensor measures relative humidity and air temperature.

The geosynthetic-reinforced soil embankment was instrumented with soil moisture and temperature sensors on each reinforcement layer (Fig.6). The soil moisture sensor is an indirect, calibrated method of measuring soil water content. It is an electrical resistance type sensor. The soil moisture/temperature station converts the electrical resistance reading from the sensor into a calibrated reading of centibar of soil water suction with a range from 0 to 200 centibar.

The geosynthetic-reinforced soil embankment was instrumented with an 1D seismic vibration sensor and a 3D surface vibration sensor. These sensors can measure the vibration of the soil during an earthquake in a range +/- 3g pK, sensibility equal to 1000mV/g and resolution of 30micro-g. (Fig.7).

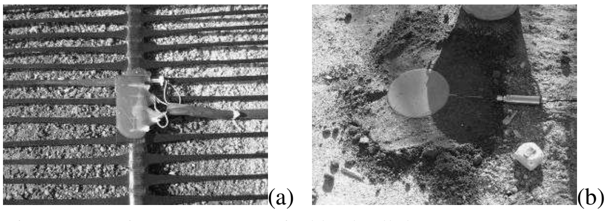
(a)
(b)

Figure 4. Strain gauge (a); Vertical load cell (b).

Figure 5. External Weather Station.

Figure 6. Soil moisture sensor.

Figure 7. Seismic vibrations sensors.

3 ANALYSIS OF RECORDED TEMPERATURE DATA

The change of internal temperatures over time (November 2006– March 2008) at the different reinforcing layers related to outside air temperature (continuous line) is shown in Figures 8-10 for different points of the reinforced embankment referred to a potential failure surface.

The figures show that the temperature inside the reinforced embankment is always greater than the outside temperature except in the period of the summer (July 2007 - August 2007). Such circumstance shows a thermal inertia inside the reinforced soil embankment. Only in these cases the outside temperatures overcome the internal temperatures. Moreover they seem to not depend on the distance from the face.

A different trend can be noticed in the shallower zone (placed on the top of the embankment). In fact, in this case thus trend is not well defined and the internal temperatures follow those external (Fig. 9). This behaviour may be due to the proximity of the thermocouples to the top of the embankment.

Anyway, the extreme values of outside temperature (6° and 35°) never were reached inside the embankment. The maximum internal temperature reached is equal to 31° in B8 sensor while the minimum internal temperature is equal to 11° in E20 sensor.

The average value of internal and outside temperature, in the observed period, are also showed in figures 8-10.

Referring to the internal average temperatures it can be noticed that in the upper layer (line E) the value is equal to 20° while the outside average temperature is equal to 16°.

In the middle layer (line C) the internal average temperature value is equal to 22° while the outside average temperature is equal to 16°.

In the lower layer (line B) the values are respectively equal to 22° for the internal average temperature while the outside average temperature is equal to 16°.

The first analysis of monitoring temperatures data seems to show a thermal inertia inside the reinforced soil embankment. However a longer period of monitoring is necessary to define with more detail the correlations existing. Therefore, the data will be collected in the next years.

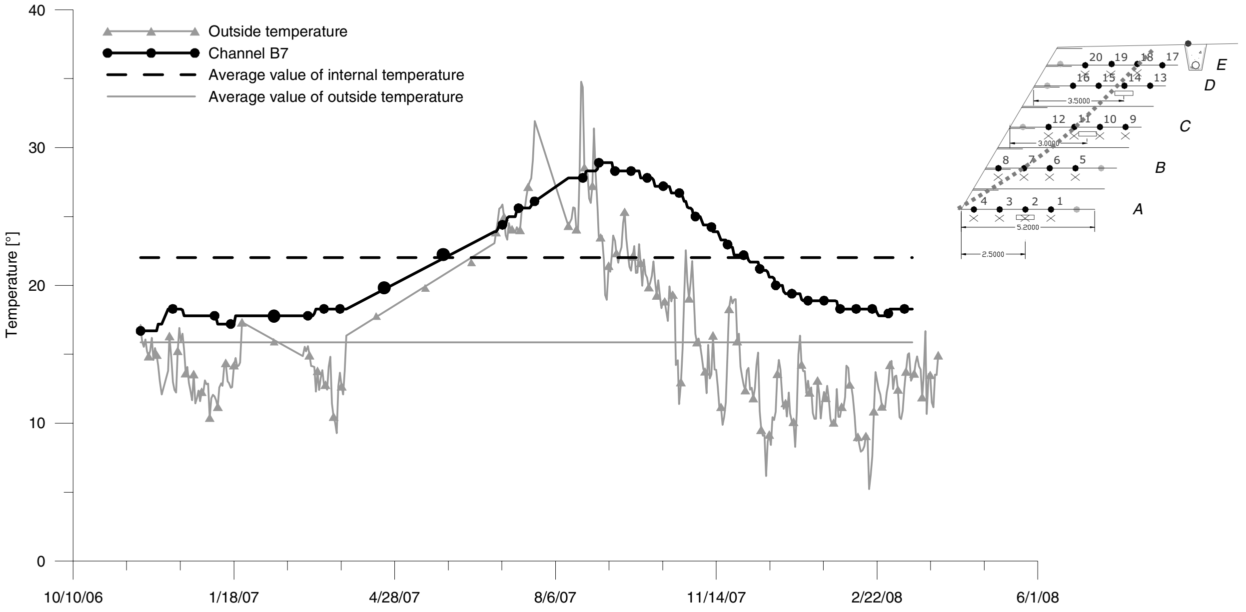

Figure 8. Trend of internal and outside temperatures over time in the lower layer of the reinforced embankment.

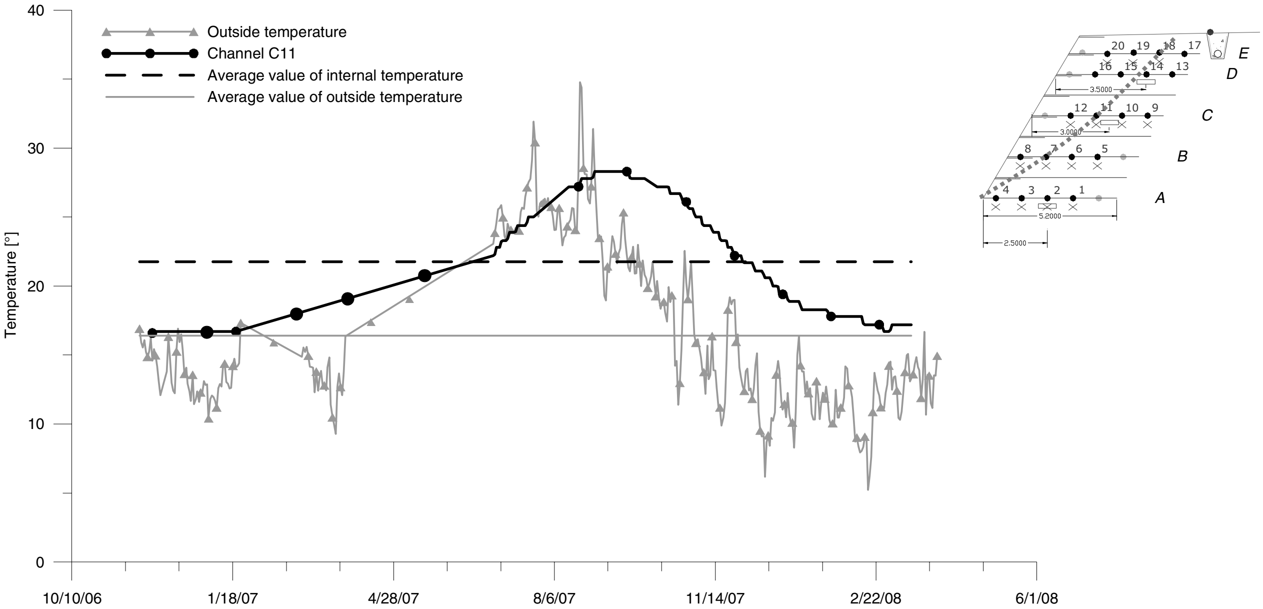

Figure 9. Trend of internal and outside temperatures over time in the middle layer of the reinforced embankment.

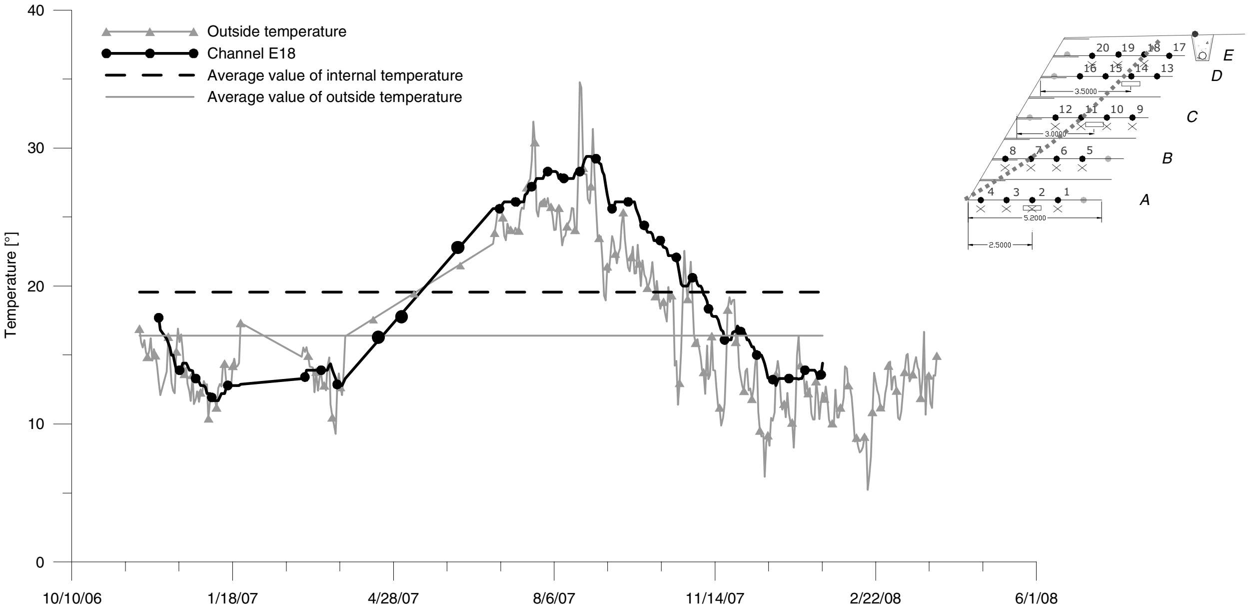

Figure 10. Trend of internal and outside temperatures over time in the upper layer of the reinforced embankment.

4 CONCLUSIONS

The collected data of temperatures demonstrate a good response of the internal instrumentation to the outside temperature changes, even if some discrepancies may be noticed. Generally, during the hot season, the outside temperatures are not reached inside the embankment. This effect is more pronounced when the external temperature is greater than 30 °C.

The first analysis of temperature monitoring seems to show a thermal inertia inside the reinforced soil embankment.

The study provides valuable insight in the reinforced embankment behaviour, especially on the factors that can affect short and long term behaviour of geosynthetics related to the tensile creep and aging affecting by temperature effects.

A longer period of monitoring must be performed to evaluate with more detail the correlations existing between outside and internal temperatures and to define a realistic long term tensile creep security factor to obtain the long term design tensile strength.

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