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# A road embankment with slopes reinforced with geosynthetics – A Portuguese case study

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ABSTRACT: In this paper the behaviour of a soil reinforced system with geogrids is analysed based on results of site monitoring. At first the reinforced system is presented, as well as its monitoring plan. The selected parameters to monitor are: face movements, horizontal internal movements, reinforcement strains and vertical soil pressure. Face movements were measured topographically from a fixed station, horizontal internal movements were registered in two inclinometers tubes, reinforcement strains were measured with linear extensometers, and earth pressures were registered in load pressure cells. The slope behaviour at the end of construction and after ten months of service is compared and discussed. The face movements at the end of the construction shows different configuration then after ten months of service, although its maximum values are quite small (in the order of 5 cm). Qualitatively similar configurations were observed at the end of construction and after ten months service, in what concerns horizontal internal movements and reinforcement strains. Maximum horizontal internal movements (of about 2.5 cm) and maximum strains in the reinforcements (in the order of 0.25%) are very small. Earth pressures measured are in accordance with that expected theoretically. Finally, the main conclusions of the study are presented, for example, that the behaviour of the road embankment with slopes reinforced with geogrids was very good, although its height and geometry and that the use of Equilibrium Limit principles in the design of soil reinforced systems with geogrids leads to a conservative behaviour of the structure and more expensive construction.

## 1 INTRODUCTION

The lack of experience and the different behaviour of geosynthetic reinforcements, when compared with metallic ones, lead to discouraging attitude when a geosynthetic soil reinforcement solution is put forward, despite its advantages.

Usually reinforced systems with geosynthetics were designed based on Limit Equilibrium principles according Jewell (Mendonça, 2004) which, due to intrinsic characteristics of the technology, were proved conservatives and uneconomical methods.

Monitoring reinforced systems is an important way for the evolution of the knowledge concerning these systems design methodologies and also for predicting its behaviour.

With this goal, a real embankment with lateral slopes reinforced with geogrids was monitorized in its highest section.

The main aim of this paper is to improve the confidence on the technology of soil reinforced systems with geosynthetics and also in its designing methods.

## 2 EMBANKMENT DESCRIPTION

The embankment with slopes reinforced with geogrids (Figure 1) was built between Régua and Reconcos in the main itinerary 3 (IP3) and is a part of the reestablishment 2. The reinforced slope has an extension of about 206 m, is in curve and the reinforced

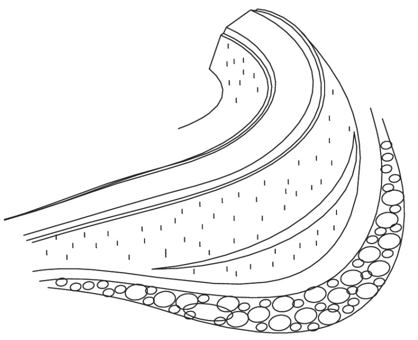

Figure 1. Geogrid reinforced slope: perspective.

area reaches a maximum height of about 20 m in the outside curve slope at 150,0 m of extension (km 0 + 150) (Mendonça, 2004).

The maximum inclination of the reinforced slope is about 60° (with horizontal). On the reinforced sections higher than 10 m a bench with variable width parallel to the road pavement was built. The maximum width of the bench was 3 m. The bench had the following objectives: to reduce the medium inclination of the slope in the zones of larger height, to facilitate the drainage and, consequently, to reduce the superficial erosion.

The reinforced system was designed based on Limit Equilibrium principles according Jewell (Mendonça, 2004).

The reinforcements, with 13 m length, placed horizontally and spaced 0.60 m vertically are high density polyethylene (HDPE) uniaxial geogrids with tensile strengths selected according the height of the embankment. The most resistant geogrids were placed near the slope base and the less resistant ones were placed near the crest.

The face elements are in a square metallic net with 0.15 m side. Behind the face elements a biodegradable mattress was placed in order to easier the vegetation growth and slope erosion control.

The foundation of embankment is dense granite. Also the backfill is a granite residual soil, which characteristics are presented in Table 1. The soil layers were placed with a height of 0.30 m after compaction.

Table 1. Fill material characteristics.

| | | |
|---|---|---|
| Grains size | (% < 0.074 mm) | 12.7 |
| | LL | NP |
| Limits | LP | NP |
| | IP | NP |
| $W_n$ | (%) | 10.9 |
| SE (sand equivalent) | (%) | 33.0 |
| Proctor | $\gamma_{dmáx}$(g/cm$^3$) | 1.95 |
| | $W_{opt}$(%) | 10.2 |
| CBR | 95% | 22.3 |
| | Exp. | 0.20 |
| Triaxial | c′(kPa) | 0.0 |
| (two tests) | φ′(°) | 36.0 |

## 3 OBSERVATION PLAN

The monitored slope cross section is at km 0 + 150. The slope cross-section, the monitoring devices used and their positions are schematically represented in Figure 2. The monitoring devices characteristics and their location in the slope were selected based on published case histories (Mendonça, 2004).

As the geosynthetics are extensible materials, special care were put on the monitoring of the strains induced to the inclusions, the movements of the reinforced area and of the face were registered, in order to have an idea of the internal and external deformation of the structure. The vertical soil pressures at the levels of the instrumented reinforcements were also measured in order to analyse the possible relations between them and reinforcements deformations. As any problems related with groundwater levels and rainfall water were not expected pore pressures were not registered.

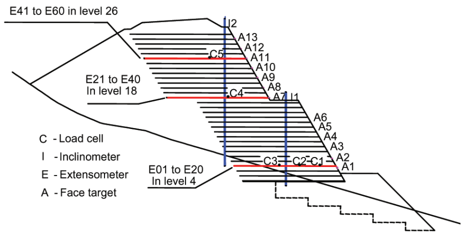


Figure 2. Instrumented profile.

The reinforcement strains were measured in three reinforcement levels, i.e. 4$^{th}$, 18$^{th}$ and 26$^{th}$ (see Figure 2) using extensometers with 0.50 m spacing (20 extensometers per monitoring reinforcement level). This way it would be possible to determine the strains distribution through the reinforcement length, as well as the zone of maximum force.

Using load cells, near the three reinforcement levels mentioned before, the soil vertical stresses were recorded (see Figure 2). At the reinforcement level where larger forces are expected (4$^{th}$ level), three load cells were placed (at about 2, 4 and 6 m of the face), while one cell was placed in the remaining two levels (18$^{th}$ and 26$^{th}$), at about 4.5 m behind the face.

The reinforcement strain values and earth stresses were recorded by an automatic data acquisition system, placed on the slope base.

The internal horizontal displacements in the slope were recorded using two inclinometer tubes, placed at about 6.5 m (inclinometer tube I1 – Figure 2) and 11.5 m (inclinometer tube I2 – Figure 2) from the slope base, with approximately 10 and 20 m height, respectively. This positioning of the inclinometer tubes was chosen to allow the evaluation of the internal horizontal displacements of the lower portion of the slope, i.e., from the base to the bench of the slope (inclinometer tube I1) and of the entire height of the slope, i.e., from the base to the crest of the slope (inclinometer tube I2).

Inclinometer tubes were placed before fill execution and were grouted into the drilling casings in the foundation for anchorage.

The reinforced slope behaviour was observed during a total period of about 13 months, which include three months of construction. This way it was possible to obtain information about the slope behaviour both during and after construction (the first 10 months of service).

## 4 OBSERVATION RESULTS

### 4.1 *Face displacements*

The horizontal and vertical face displacements at the face are presented in Figure 3 at the end of construction and two and ten months after its end.

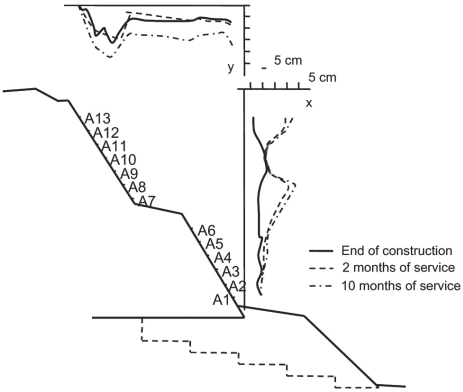


Figure 3. Horizontal and vertical displacements at the face.

The face movements control was done topographically, from a fixed station, to the nearest 0.1 mm. At first, the initial position of the face topographic targets was recorded, afterwards, the face movements were measured referred to that position. The targets initial position was recorded as each one was placed.

The horizontal displacements at the face during service are quite different from the one at the end of construction. In fact, at the end of construction the maximum horizontal displacement occurred at the lower area of the upper portion of the reinforced slope and the minimum value at the top. At the end of construction, the face horizontal displacements showed certain uniformity at the lower portion of the slope.

After two months of service, the horizontal displacements on the lower portion of the slope presented a very significant increase towards the bench. At this time on the upper portion of the slope the horizontal displacements increased significantly, however the magnitude of that increase diminished considerably at the level where, at the end of construction, the maximum face displacement occurred. On the top of the upper portion of the slope face horizontal displacements increase significantly during service.

Although with differences of configuration, the distinct face displacements behaviour observed after two months of service construction is maintained during the first ten months of service.

### 4.2 *Slope internal horizontal displacements*

Figure 4 shows the internal horizontal displacements of the slope recorded in inclinometer tubes I1 and I2 at the end of construction, two, six and ten months after construction.

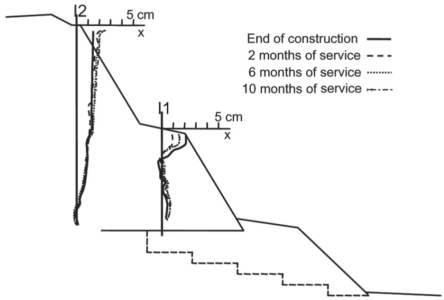


Figure 4. Internal horizontal displacements of the slope.

The internal horizontal movements of the slope were recorded during construction, in both inclinometers, until the bench level of the slope was reached. Configurations of the internal displacements recorded in both inclinometer tubes are quite different. On the contrary to what happen in inclinometer I2, where only the influence of the construction until the bench level is considered on the internal horizontal displacements of the slope, these displacements recorded in inclinometer I1 at the end of construction express, not only the influence, but also that of the construction of the upper portion of the slope on the deformation of the lower ones.

In both inclinometers the maximum internal horizontal displacements of the slope recorded through time of service occur on the upper part of the case (in tube I1 at about 1 m and in tube I2 at about 0.5 m deep). During six months after construction the maximum horizontal displacements increase, remaining practically constant until the end of the observation period. The configuration of the displacements, in each inclinometer, remains identical during service.

### 4.3 *Reinforcement strains*

Near the face, and in reduce length, were recorded important strains in the reinforcements. This configuration is different from the theoretically foreseen and is due to the high deformability of the face. It is important to note that those deformations don't influence the structure's behaviour reason for consider only the values inside the reinforced zone.

Figure 5 represents the strains at the 4th, 18th and 26th reinforcement levels recorded at the end of construction and of observation, as well as the position of a line passing through the points of the

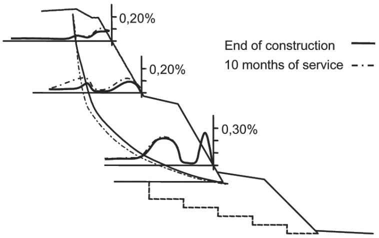


Figure 5. Strains on the 4th, 18th and 26th reinforcement levels and position of the line passing through the points of the reinforcements of maximum strains.

reinforcements where maximum strain were recorded. Figure 6 shows the strains on the 4th, 18th and 26th reinforcement levels recorded at the end of construction and two, six and ten months of service.

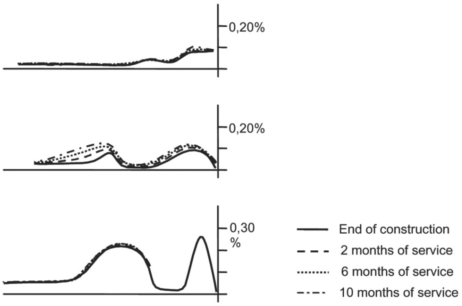


Figure 6. Strains on the 4th, 18th and 26th reinforcement levels.

Through the service time the maximum strains are practically constant, as, at this level major movement of the slope occur during construction. On the 18th and 26th reinforcement levels strains maintain values practically constant in the first 6 months of service and increases 10 months after construction. The line passing through the points of the reinforcements were maximum strains were recorded change its position during service (Figure 5), due to the larger strains observed on the upper reinforcements during that period.

### 4.4 *Earth vertical stresses*

Table 2 presents the earth vertical pressures recorded near the 4th, 18th and 26th reinforcement levels at the end of construction and two, six and ten months of service.

During the first six months of service, there are no variations on the earth vertical stresses. After ten

Table 2. Earth vertical stresses.

| | Earth vertical stresses (kPa) | | | | |
|---|---|---|---|---|---|
| Cells | Predicted | 0 months service | 2 months service | 6 months service | 10 months service |
| C1 | 70 | 140 | 140 | 140 | 133 |
| C2 | 180 | 144 | 144 | 144 | 143 |
| C3 | 230 | 165 | 165 | 165 | 165 |
| C4 | 150 | 123 | 123 | 123 | 127 |
| C5 | 70 | 67 | 67 | 67 | 81 |

months of service there is an increase on the earth stresses on the upper portion of the slope, larger as the road is near, probably due to higher service actions than on the previous period, which can be in some way related to a traffic increase. At the same time, the earth stresses on the reinforcement level closest to the foundation recorded on the cell C1 slightly decrease maintaining, however, larger magnitudes than the theoretical values which can be justified, partially, by its proximity to the face.

## 5 CONCLUSIONS

After presenting the results of the observation of the geogrid reinforced steep slope during the first ten months of service, it is important to emphasize the safety behaviour of the soil reinforced system, in terms of face displacements and slope horizontal displacements, and in terms of reinforcement strains and earth vertical stresses.

From the results the behaviour of the geogrid reinforced slope of IP3 can be considered very good. However, it enhances the Equilibrium Limit methods conservative design of this type of geosynthetic soil reinforced systems and encourages the research on design methods were particular characteristics of those systems are considered.

## ACKNOWLEDGEMENTS

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## REFERENCE

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