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Prediction and performance of reinforced soil structures

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ABSTRACT: Design of geosynthetics reinforced soil structures is based on creep behavior determined by tests that do not consider interaction between soil and reinforcement. However, the strength mobilization in geosynthetics reinforcement within real reinforced fill structure is usually much lower than calculated. This results in over design of the reinforced soil structures. SG GEOTECHNIKA has monitored many reinforced soil structures for several years and compared their behavior with predictions. For this contribution three high structures built in Czech Republic were selected to demonstrate this discrepancy. They were:

– 9 m high retaining wall reinforced with polyester strips with concrete partial height panels facing
– 17 m high road embankment with 50 degree slope (no facing) reinforced with polyester geogrids
– 14 m high reinforced fill structure with polyester geogrids. Segmental facing (lower part) combined with steel wire mesh facing (upper part)

Strength mobilization within the geogrid was measured by means of extensometers fixed at various distances from the facing. The measured extension was later converted into strength mobilization using the stress-strain diagram from the laboratory tests. The mobilization of the strength never exceeded one half of the design value.

1 INTRODUCTION

Design of reinforced soil structures is based on local practice in each country as no universally accepted approach or European standard exist so far. Due to creep behavior of the geosynthetics reinforcement the design tensile stress in reinforcement is usually a fraction of the tensile strength and depends more on serviceability criteria of the designed structure. For steep slopes the extension of geosynthetics reinforcement in the range between 2 to 3% is usually considered acceptable. This means that for typical polyester geogrid the corresponding tensile stress is at about 20% of the tensile strength (TP 97). For polypropylene and polyethylene geosynthetics the tensile stress will even be less; in case of polyvinylalcohol this value may reach 50%.

Acceptable deformation of the hard facing of near vertical retaining structures should normally be kept within the range of 0.2 to 0.5% of the height (prEN 14475). The resulting reinforcement extension is below 1% and corresponding tensile stress for polyester does not exceed 10% strength.

However, most of the design approaches apply a system of partial coefficients for creep, installation damage, environmental effects and other factors that reduce the tensile strength to the design value. The resulting design stress is generally at 40 to 50% of the tensile strength, which is substantially higher than 10 to 20% strength that would correspond to maximum acceptable extension from the serviceability point of view.

In order to clarify this discrepancy SG Geotechnika has monitored various reinforced fill structures for several years and compared the measured extension of the geosynthetics with predicted values in the design. The construction monitoring still goes on and results are presented for three structures: one reinforced soil retaining structure with hard vertical facing, second is a combined vertical wall with superceded steep embankment slope, third monitored structure is a high mountain road embankment with steep slope. Polyester strips were used as reinforcement in the first case and polyester geogrids were used in the two latter cases.

2 MLCECHVOSTY - RETAINING WALL

The reinforced soil structure that was built as part of the retaining structure protecting the newly reconstructed railway line reached maximum 9 m height. However a non-reinforced fill continued from the edge of the vertical wall in 1H: 2V slope up to max. 22 m height. The wall was designed as VSoL system with polyester strip reinforcement covered by polyethylene coating and vertical wall facing made of concrete panels. The strips had vertical spacing of 0.75 m and length maximum 11 m. The strength of reinforcing strips varied from 30 to 70 kN. The strips were laid in a web-like pattern on the compacted soil layer turning the strip around face panel rod mounted on its back face and the steel rod laid on the compacted layer at 11 m distance from the panel. Sandy gravel was used as backfill soil. Unreinforced fill above the wall was made of compacted silty soil. The site during construction is on Figure 1.

Figure 1. Mlcechvosty, spreading fill on strip reinforcement.

The reinforcing strips were tensioned at approx. one third of their capacity. This tensile stress should generate approx. 2% of extension. The extension of geosynthetics strips has been monitored at three different locations for over 4 years, now. There was 3 m, 4 m and 4.5 m of the fill above the monitored elevations. The geostrip extension varied between 0.22 and 0.36%, i.e. approx 5 to 10 times less than estimated in the design for given tensile stress. When the wall was completed (November 2001) the extension of the strips was between 0.11 and 0.26%, which should have been sufficient to generate the active earth pressure conditions. Nevertheless the measured earth pressure was 25% higher than at rest condition. This situation was due to compaction of the fill behind the concrete slab facing. However this pressure decreased within 4 months to active value and after one year the earth pressure is much below the active pressure value, almost negligible. This means the stress relaxation in the reinforcement and friction of the soil on reinforcement has reduced the earth pressure below active earth pressure value. The typical results of strain of the geosynthetics strips are at Figure 2.

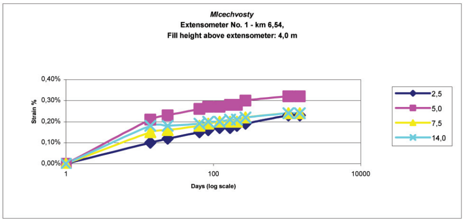

Figure 2. Mlcechvosty, creep strain of polyester strips.

Since complete loading of the reinforcement by the fill the creep extension was 0.1% in 4 years in average. In the first year the extension was double. i.e. 0.05%. Later the yearly creep extension has dropped to approx. 0.025% in average. When considering 100-year life for reinforced fill retaining wall and continuous reduction of the creep strain of the reinforcement the total extension should be in the range of 0.3 to 0.5%, which is the design value of the geostrip strength.

3 VRANCA ROAD - STEEP HIGH FILL

The mountainous road near the border between Czech republic and Slovakia overcomes 300 m vertical elevation in 3 km. In order to cope with the highly accidental terrain all embankments were designed as reinforced fill, and soil nailing supported most cuts. The highest embankment reached 17 m with 45 to 50° slopes as can be seen at Figure 3.

Figure 3. Vranca, 17 m high reinforced fill.

The soil used in the fill was mostly silty clay with variable amount of rock fragments. The unsorted material came from the cut sections and went directly into the fill. To reduce high moisture content the excavated soil was treated with lime. The polyester geogrids used as reinforcement were coated with PVC paste in order to cope with possible temporary high pH values from the lime soil improvement. The tensile strength varied from 110/30 kN/m at the base of the

17 m high fill to 35/35 kN/m at the upper part of the fill. The design tensile stress was 15 to 20 kN/m at 3 m above the embankment base. Corresponding extension was 2%.

Two horizontal extensometers were installed in the reinforced layer at 3 m above the fill base (14 m high fill above the measured level) and at 11 m above the base (6 m high fill above the measured level). The measured points were fixed at 2 m, 4 m, 7 m, and 10 m from the slope surface. The geogrid extension measured after completion of the fill 2 years ago has shown that only one fifth of the predicted geogrid extension really occurred (0.33 to 0.44% depending on the measured distance from the slope face). This extension corresponds to 5% of the tensile strength or one third of the predicted tensile stress. The measured extension at the upper extensometer was in the range of 0.17 to 0.30%.

The creep behavior of the geogrid reinforcement in the embankment is showing gradually decreasing trend as can be clearly seen from the Figure 4.

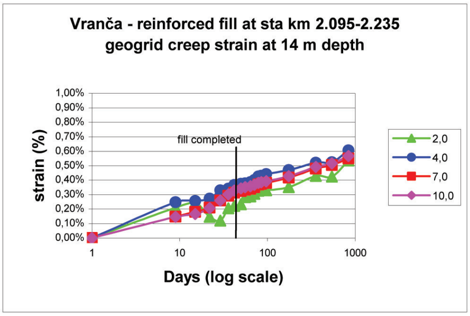

Figure 4. Vranca, geogrid creep strain vs. time.

If we extrapolate the straight line of the geogrid creep behavior to 100 years we receive the average extension approx. 0.8%, i.e. less than one half of the initial predicted value at the time of completion of the embankment.

The extensometer at the upper part of the embankment has demonstrated a significant slow-down of creep after completion of the embankment, but later, when the road was put into operation the slow creep was recorded. However, it is approx. in the range of 0.1% for one time section of the logarithmic scale. This gives predicted total extension between 0.5 and 0.6%.

4 JABLONEC ATHLETIC STADIUM

Widening of the athletic stadium in Jablonec (North Bohemia) had to be realized in a very limited space. That's why the reinforced soil structure was chosen as the most suitable. The structure is combination of a vertical segmental wall 4 m high in the lower part of the structure and 700 steep slope with steel mesh facing. The upper part, which is 10 m high, was divided in two sections interrupted in the middle by a 1 m wide bench. Total height of the structure is 14 to 15 m. Due to complicated design conditions a numerical analysis was performed using the Geoslope software. Max. total horizontal deformations were calculated at 35 mm, creep deformations at 12 mm. Presentation of calculated horizontal deformations are at the Figure 5.

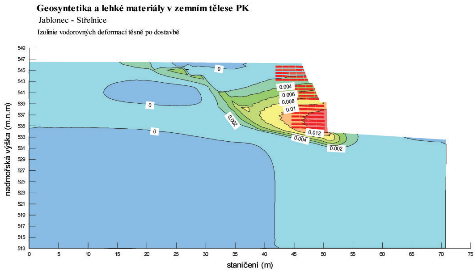

Figure 5. Jablonec, calculated horizontal deformations of the reinforced fill structure.

One unfavorable factor was that the construction was built about 1 m from an old apartment house that was inhabited during the works. Picture at Figure 6 shows the situation of the reinforced fill construction and the house.

Figure 6. Jablonec, building reinforced soil structure near the house.

The soil used in the structure was mostly the decomposed granitic rock the character of a silty-sandy gravel with a significant quantity of mica. The variable quantity of fines was the main problem during the construction. Reinforcement was polyester geogrid coated with PVC paste. Strength of the geogrids varied in relation to its position in the structure. The base layers were reinforced with geogrids having strength 110/30 kN/m, middle part had geogrids with 80/30 kN/m and the superior part was reinforced with 35/35 kN/m geogrids.

Due to high and complicated structure, vicinity of the existing residential buildings and heavy traffic at the toe of the fill the client agreed with continuous monitoring of the structure. Extension of geogrids was measured at two lowest reinforced layers at 2 m, 4 m, 7 m and 10 m distance from the facing. Measured data are in the graph on Figure 7. It is very clear that the creep is gradually slowing down and the measured values are lower than predicted.

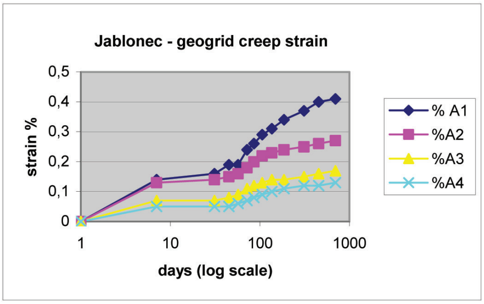

Figure 7. Jablonec, creep of geogrid.

If the existing tendency continues the total extension of the reinforcement at 100 years will be in the range of 0.2% (for 10 m reinforcement length) and 0.6% (at 2 m distance from the facing). When converted to horizontal movement it will be 12 mm at the base of the segmental wall with negligible values at the top of the structure. This data is three times lower than the predicted value by numerical model (35 mm). The measured strain is at the lower range of generation of the active earth pressure. It means that at the beginning of the loading of the reinforcement the stresses are much higher and are between at rest and active conditions. The extension of the geogrid when correlated to tensile stress will give about 6 kN/m tensile stress in 110 kN/m geogrid, i.e. 5% of the tensile strength or one third of the predicted stress.

Vertical deformations of the reinforced soil structure reached maximum 8 mm and also remained at about one third of the prediction (26 mm). The completed reinforced soil structure is behaving very well with no sign of distress at any part of the structure.

When the green surface will be completely established it will fit very well into the city environment. Figure 8 is showing the completed structure.

Figure 8. Jablonec, general view of the reinforced soil structure

5 CONCLUSION

Reinforced soil structures have become extremely popular due to their easy construction, low cost and positive impact on environment. However, most of the reinforced soil structures are over designed. As shown in the above shown examples only a very little fraction of the tensile strength of geosynthetics reinforcement is utilized. This means that correctly constructed structures undergo much less creep than predicted (minimum one half but sometimes 10 times less). Long term monitoring of the reinforced soil structures will sooner or later bring changes in the design specification and will bring substantial savings quantity of reinforcements.

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