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Three case histories of different specific uncommon geogrid-reinforced slopes

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ABSTRACT: Geosynthetic-reinforced steep slopes and walls became very popular worldwide during the last 15 years because of their financial, technical, ecological and landscape-related advantages. Meantime, a wide range of solutions is possible based on the use of modern reinforcing geosynthetics. Although significant experience is already available, information on executed projects is believed to be always useful, especially while dealing with specific non-common solutions like landslide stabilisation, combined systems (e.g. on piles) or extreme heights. Therefore three specific cases across Europe are presented: first, a high geogrid-reinforced landslide stabilisation structure from local soils in the Austrian Alps in 1994, second: a geogrid-reinforced slope founded on piles in German Alps in 2002, third: a very high geogrid-reinforced steep embankment from blasted rock in Spain constructed in 2002 on the Highway Madrid-Irun-Paris, being one of the highest structures of this type on a European highway.

1 GEOSYNTHETIC-REINFORCED "WALLS" AND "SLOPES": INCLINATION AND COMPOUND STABILITY

Geosynthetic-reinforced steep slopes and walls ("GRS" = Geosynthetic-Reinforced Soil) became very popular because of their financial, technical, ecological and landscape-related advantages. They are very cost-efficient (GRI 1998) and become an increasingly adopted and well-established solution (Alexiew 2005).

Although definitions, design principles and failure modes to be checked are believed to be well known, sometimes there is some confusion and even heavy mistakes in the designs – which can result in failure. This is most likely while calculating (resp. *not* calculating) the so-called compound stability or the stability of internal interfaces etc. (Alexiew 2005, Berg & Meyers 1997). In this regard, it is believed to be helpful to present information of successfully designed and constructed projects.

2 LANDSLIDE STABILISATION NEAR LECH, AUSTRIA, 1994

The project dates back more than 10 years. The project is worthy of a short mention as it is a highly interesting application of a GRS-system with a chaning inclination and curvature and the use of local soil.

A landslide had taken place below the lift station of the Steinmähderwand in the high mountains above Lech, taking away the whole slope from the corner of the station down to the road (Figs 1 & 2).

Figure 1. The landslide endangering the lift station.

The approximate shape of the sliding surface can be seen in Figure 2. The width at the toe is over 50 m. The slope had to be stabilised in summer 1994, just before the approaching ski season. The following aspects were important for the choice of stabilisation concept: fitting the landscape (the greatest possible flexibility to shape the front face), "green facing" with vegetation, minimum transport cost of any construction materials, quick and easy to build,

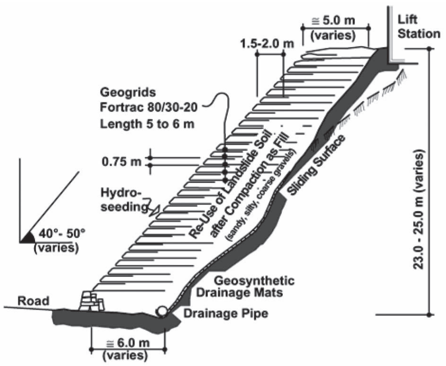

Figure 2. Typical cross-section of the geogrid-reinforced landslide reconstruction and stabilisation system.

permanent solution, spoil from the landslide should be reused as fill.

The latter was a gravel/sand/silt mixture. The requirements led to the choice of a GRS-system with geogrids as an optimal solution.

As shown in Figure 2, soil layers of 0.75 m thickness were involved, which, for that time, were unusually thick and were intended to speed up the building process. High tenacity flexible polyester geogrids with an ultimate tensile strength (UTS) of 80 kN/m in MD were chosen. The interaction coefficient of these geogrids with the fill is ≥ 1.0, thus there are no potential slip surfaces at the interfaces soil/reinforcement (Alexiew 2005), and their hydraulic flow resistance is practically zero. A reinforced package of soil and geogrids forms a *ductile* slope stabilisation with optimal behaviour. The slope water is conducted into drainage mats (Fig. 2). The fill was compacted to a density of ≥ 98% of Proctor.

The whole project was completed in less than two months in late summer 1994 (Fig. 3). Placing could take place independently of the weather because of the temperature insensitive properties of the geogrids (flexible even at low temperatures). Regionally sustainable hydro seeding ensured successful integration into the surrounding landscape. The final structure no longer looks like an artificial slope. Over the intervening more than 10 years and many changes of seasons (extreme climates) the system has proved itself not only as slope stabilisation but also as part of the landscape. For more information see Alexiew (2005).

3 RETAINING STRUCTURE NEAR OBERSTDORF, GERMANY, 2002

A new retaining structure had to be built in high mountains across a slope near Oberstdorf. A GRS structure turned out to be the optimum solution from the points of view of value for money and natural appearance as well as economical and ecological reasons. Furthermore, the project had to be completed within a construction period of two months: Therefore import of good fill material was excluded and local cohesive soils (clayey silts and silty clays) had to be reused.

To ensure the external stability of the structure the consultants decided for a GRS system founded on concrete piles with beams on top, at distance of 3 m c/c. The gap between the beams was covered with extremely high strength geosynthetic reinforcement span perpendicular to the axis of the beams (Fig. 4). The design – based on existing methods of analysis and experience (Alexiew 2004) – resulted in three geogrid-layers with a required short-term tensile strength of 1200 kN/m at a strain of only 5% laid parallel to the facing of the slope. Figure 5 shows the layer deflection between the beams after installation and compaction of the first fill layer. This deflection

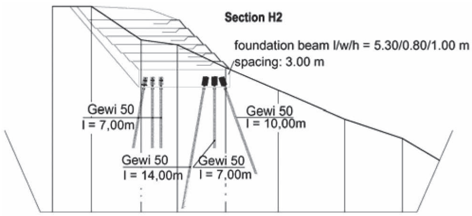

Figure 4. Typical cross section of the retaining structure.

Figure 3. Slope stabilisation shortly before completion.

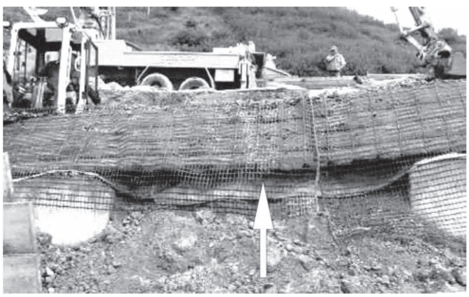

Figure 5. Front view: deflection of the bottom geogrid layer between the beams (span 3 m c/c).

is typical for pile bridging systems and is evened out as more of the system is constructed. As long as high strength but low-creep reinforcement is used there is also no danger of secondary deformation during the period of service (Alexiew 2004). The remaining geogrid layers were then placed perpendicular to the slope and had a significantly lower tensile strength.

Similar systems have also been used earlier (Jossifowa & Alexiew 2002).

The use of the cohesive local soils as fill material could only be considered after lime-stabilisation, as the shear parameters had been very low and the water content very high. Use of lime-cement stabilisation leads to strongly elevated pH-values (pH > 11) therefore excluding the use of geosynthetic reinforcement from raw material Polyester (FGSV 1994). Consequently, Polyvinylalcohol (PVA) as raw material is highly recommended. PVA is durable in high pH environments, combines high tensile strength at low strains with very low creep (Alexiew et al 2000) and has therefore been used on many projects over recent years.

4 GRS STRUCTURE ON THE MADRID-PARIS MOTORWAY AT ETXEGARATE, GIPUZKOA, SPAIN 2002

The new Madrid – Irun – Paris motorway passes through mountainous countryside in northeast of Spain. A separate carriageway was designed to take traffic in the direction from Madrid to Paris. This involved the construction of very high and steep embankments. In a particularly challenging area in Etxegarate, a steep embankment, 300 m long and up to 22 m in height had to be constructed.

For economic and aesthetic reasons a solution with geogrid reinforced soil structure and planted external face was found to be optimal (Fig. 6) among other solutions as it was necessary to use as fill extremely

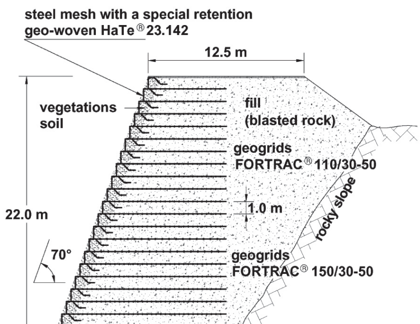

Figure 6. Typical cross section of the geogrid-reinforced motorway embankment at Etxegarate.

coarse soil (blasted unsorted rock) available from the excavations for an adjoining section of road (building a viaduct had therefore not been an alternative). Grain sizes of up to 250 mm were not unusual. For this reason, it was decided to place the fill in layers of 1.0 m thickness and to use heavy compaction techniques, usually filling should be limited to about 300 mm maximum per lift (Fig. 6).

Regardless to the grain size the fill was well graded, thus well compactable, was adequately draining and in spite of variations an angle of internal friction ≥ 45° could be assumed for design. As often happens (see Section 1), the analysis and stability calculations showed that the critical mode of failure for this project was the "compound mode" (Fig. 7). The extremely coarse blasted rock fill imposed two new special requirements for the geogrid. The interaction coefficient had to be ≥ 1.0 with this fill to avoid internal critical interfaces (see Section 1) and the placement of the blasted rock and its compaction should result in a minimum loss of tensile strength. These objectives were fulfilled with robust and flexible geogrids specially manufactured for this project with a mesh size of 50 × 50 mm – and an ultimate tensile strength varying between 110 kN/m up to 150 kN/m.

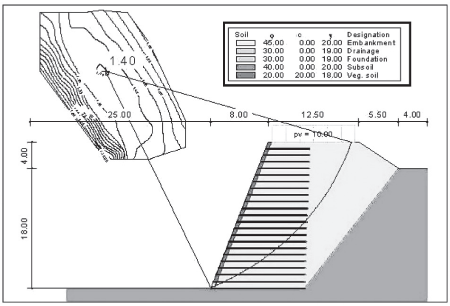

Figure 7. Critical "compound" mode of failure at the Etxegarate project.

Construction took place without problems under heavy lorries and compaction rollers. Figure 8 shows a detail of one construction phase on which the original soil, the fill and the formation of the external face (before planting) can be clearly seen. Figure 9 shows an aerial photograph, which gives an impression of the scale of the project. The finished structure was put into operation before the planting had time to develop and is shown in Figure 10. After almost 3 years of operation, this geogrid-reinforced embankment displays no deformation or signs of instability and the vegetation has established itself.

To the best of our knowledge, the 22 m high embankment at Etxegarate is the highest GRS structure without berms or intermediate steps on the European motorway system.

Figure 8. One of the construction phases: the person shows the scale.

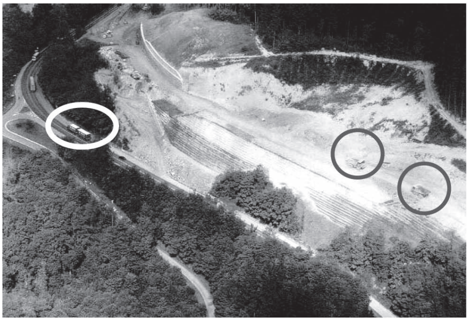

Figure 9. Aerial photograph during construction: the lorries and dump trucks show the scale.

Figure 10. Overall view of the geogrid-reinforced motorway embankment at Etxegarate shortly after entering service.

5 CONCLUDING REMARKS

GRS-systems are very flexible and adaptive in shape and geometry. Their behaviour is typically ductile in the sense of soil mechanics. Compared to conventional design of retaining structures GRS-systems can therefore compensate for higher differential settlements than e.g. RCC can do. To that reason, their use is not necessarily limited to locations of excellent ground conditions or expensive foundations can be avoided.

In analysis and design there are often two potentially critical modes of failure to investigate that are frequently forgotten or unknown. It is apparent from three GRS-structures in Europe constructed at different times, for different purposes and subject to different restraints and requirements that the system offers solutions to a wide range of problems. It can be combined with other techniques (e.g. piles). Today it finds use even on extremely high motorway embankments, an application what would have been viewed as too risky just a few years ago.

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