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Two geogrid-reinforced steep slopes as combined structures on columns and piles: Case histories

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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. It is possible to combine them with other elements or systems e.g. piles or columns especially to ensuring external stability. Two specific geogrid-reinforced steep slopes set on columns or piles are described: The first one in Bulgaria on a steep slope in a seismic region, the second one in Germany on an instable slope of softer soils.

1 INTRODUCTION

Steep slopes and walls from geosynthetic-reinforced soil (GRS) became very popular because of their cost-effectiveness, blending in well with the landscape, fine-tuning for optimum functionality, ductile behaviour etc. (GRI 1998, Alexiew 2005). They become an increasingly adopted and well-established solution. The broad range of available geosynthetic reinforcement allows optimisation and eliminates any limits to height and load capacity.

Nevertheless, problems may arise like compound stability (Berg & Meyers 1997) as well as (quite often) external stability when the GRS-slope is positioned on steep or unstable natural slopes, sometimes in combination with seismic impact. In the latter cases "dowelling" columns or piles below the GRS-wall or slope can be used to increase the external stability to the level required.

Two typical projects of this type are shortly described.

2 PROJECT YUGOVSKO HANCHE, BULGARIA

A short stretch of a road in the Rhodopa Mountains in Bulgaria had to be stabilized and widened due to increasing traffic and indications of slope instability. During construction the traffic had to be kept running at least on the right lane of the road (Fig. 1), thus the existing old stone masonry retaining wall had to remain in place during widening and stabilization works.

Note, that both the terrain and the rock bed become even steeper to the right in Figure 1, which is not shown in the figure itself due to the lack of place. Additionally to the requirement of keeping the right half (on Fig. 1) of the existing road under traffic, the Road Authority asked for a solution which should be safe, easy to built, cost efficient and landscape friendly.

Critical sliding surfaces were identified below the road and the old wall through the local slope soil. It consists of silts and gravels (with some infiltrating water from the right on Figure 1) on a weathered rock substratum (Fig. 1).

Generally, the road and the masonry wall were built in the early 30ies. The stability analyses performed now were based on actual geotechnical data and resulted – especially with the planned widening to the left (Fig. 1) – in global factors of safety of 1.0 to 1.1 and even <1.0 under seismic conditions, which was alarming.

The stability analyses included both circular (Bishop) and polygonal (Janbu) failure surfaces according to DIN 4084.

A combined solution was found to be the optimal one (Fig. 1): a new GRS-wall was added in front of the

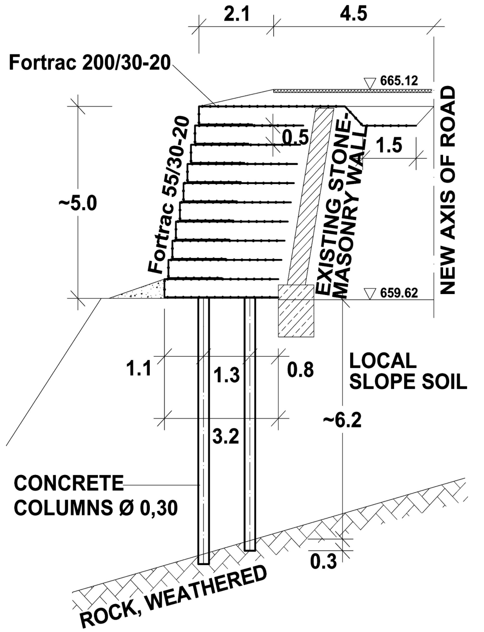

Figure 1. Yugovsko Hanche: typical geotechnical situation and solution with a combined system.

Figure 2. Yugovsko Hanche: 2/3 of the GRS-wall ready; old masonry wall to the left; geogrids not connected to it.

old stone masonry using crushed well-graded gravel and geogrids Fortrac®55/30-20; the GRS-package was founded on dowelling concrete columns. To make construction easier and to save time due to the critical situation (see above) the geogrids were not connected to the old retaining wall (Fig. 2). The high coefficients of interaction in both shear and pullout modi of the flexible geogrids used and the fill, evaluated in corresponding tests, made this efficient solution possible: no inner interface sliding could occur, and the design resulted in short anchorage lengths as well. Note: a

Figure 3. Yugovsko Hanche: anchoring of the upper final geogrid behind the old masonry wall (see Figure 1).

single stronger Fortrac®200/30-20 was applied on top and anchored behind the old wall and below the outer lane of the road to ensure integrity of new and old structure in both horizontal and vertical direction even in the case of an earthquake (Figs. 1 and 3).

Small diameter (0.3 m) concrete columns in two rows were installed below the GRS-wall to allow the use of light drilling equipment in the narrow space in front of the old wall; their position and spacing were optimised during design.

The combined system presented was cheaper and easier to build than e.g. a second new concrete or RC-wall. A new type of protective "green" facing was finally added to the wraparound geogrid wall (the so called "Muralex®") to meet the environmental (landscape) requirements. The entire system was successfully built up in less than two months by a local contractor without any problems despite its lack of experience with geogrid reinforcement, confirming the easiness of construction. An "inner formwork" of well sand-filled bags was applied during compaction in the front area. The technique is very easy and efficient in combination with the flexible geogrids used (Figs. 2 and 4).

The new widening and retaining system is since some years under traffic without any indications of movement, differential settlements etc. The solution seems to be successful.

3 RETAINING STRUCTURE NEAR OBERSTDORF, GERMANY

A new road had to be built in the 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. Above all, the project had to be completed inside two months: As the project was in a scenic mountainous area, ecology and economy made it necessary to use local cohesive soils

Figure 4. Yugovsko Hanche: completing GRS-wall and road widening (before installation of the final Muralex® facing).

Figure 5. Oberstdorf: failure due to insufficient external stability on the soft slope.

from the natural slope (clayey silts and silty clays) to be used as fill in the GRS.

The possible problem of external stability had not been really identified because of some lack of detailed geotechnical investigation and soil testing and overestimation of the shear strength of the soft natural slope especially when wet. Thus, the first GRS-structure failed quite quickly at beginning of construction because of insufficient external stability (Fig. 5). The part of the GRS-wall moved and rotated downslopes. It is a situation like in a learning book for soil mechanics.

Consequently, the consultants decided to put the GRS-wall on slim RC-piles with beams on top, bridging the 3 m distance between the beams also with geosynthetic reinforcement (Figs. 6 and 7). The idea was to use the typically ductile behaviour of GRS-systems being able to adapt some small slope movements (despite the dowelling piles) without problems. Thus, the system was different from the solution for

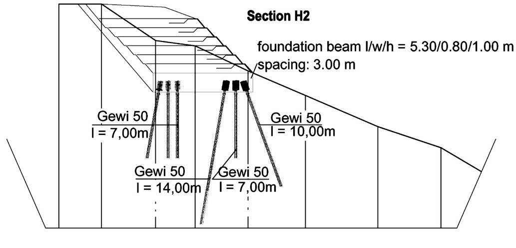

Figure 6. Oberstdorf: typical cross section of the retaining structure set on piles.

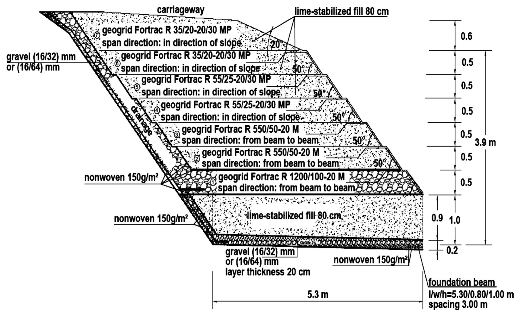

Figure 7. Oberstdorf: geogrid reinforcement (the bottom geogrids spanning over the beams are installed with their strong MD parallel to the road axis).

Yugovsko Hanche, but the same principle of external stabilisation with piles was applied. The design was based on existing methods of analysis and on experience dealing with pile-supported fill bodies (Alexiew & Vogel 2001, Alexiew 2006), applying uniaxially spanning design procedures in this case. The use of the cohesive local soils as fill could only be considered after lime-stabilisation, after which it would be strongly alkaline (pH > 12). Under such conditions, the use of Polyester is forbidden (FGSV 1994).

Polyvinylalcohol (PVA) as raw material is very appropriate in such cases. The geogrid family. Fortrac® M & Fortrac® MP from PVA Kuralon® was chosen. The reinforcement is durable in high pH environments and combines high tensile strength at low strains, very low creep (Alexiew et al 2000) and high coefficients of interaction to stabilised cohesive soils (Aydogmus et al 2006). Positive experience with many projects over recent years was already available. A special feature of this project is the twin load-carrying action of the lower geogrid layers, Fortrac®1200/100-20 M and Fortrac®550/50-20 M, which are installed with their strong unrolling machine direction (MD) of 1200 and 550 kN/m respectively parallel to the road axis and span over and between the beams. At the same time they act as "conventional" slope reinforcement transversely to the longitudinal axis of the road with their

Figure 8. Oberstdorf: installation of the first (bottom) geogrid layer parallel to the road axis.

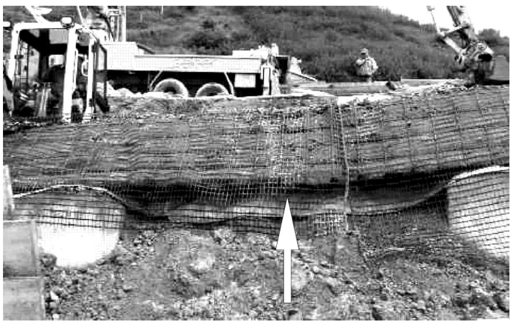

Figure 9. Oberstdorf: front view of the GRS-body on the piled beams, deflection of the bottom geogrid layer between the beams (span 3 m).

weaker cross-machine directions (100 and 50 kN/m respectively), see Figure 7.

Figure 8 shows the installation of the first geogrid layer, and Figure 9 the deflection between the beams (at 3 m distance) after installation and compaction of the first fill layer. This deflection is typical for pile bridging systems and is evened out as more of the system is constructed. High strength low-creep reinforcement gives rise to no significant deformation in service (Alexiew 2006).

At Oberstdorf this was confirmed once more.

The GRS-structure is since some years in operation without any problems. Both the very specifically reinforced GRS-body and the piling system seem to be designed and constructed appropriately.

4 CONCLUDING REMARKS

Retaining walls and slopes from geosynthetic-reinforced soil (GRS) are very flexible and adaptive in shape and geometry and demonstrate an advantageous ductile behaviour in the sense of soil mechanics. The wide range of modern geosynthetic reinforcements (especially geogrids) eliminates practically any limitation to heights and loads in terms of internal and compound stability. Today it is possible to find an optimal (from the point of view of geometry, loads, ultimate and serviceability limit states and specific environment) appropriate reinforcement for any GRS-wall or slope. Possible problems with the external stability can be solved successfully by combining GRS-walls with other techniques like columns and piles. The two projects presented shortly herein from two European countries – designed and constructed for different purposes and subject to different restraints and requirements – are believed to demonstrate the above mentioned.

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