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Geosynthetic-reinforced earth walls and slopes in extremely challenging applications

Murs et talus renforcés par géosynthétiques dans des contextes extrêmement difficiles

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ABSTRACT: The application of geosynthetic-reinfoced steep slopes and walls in extremely challenging applications, respectively under extreme boundary conditions, has successfully been demonstrated in various projects. This paper presents a technically expedient and practically feasible solution for the use of geosynthetic-reinforced retaining structures on project subjects to extremely difficult geotechnical and topographical conditions. Within the paper different cases are reported on projects with special requirements. The last case study presents in a great extent a very complex situation in the alps, where an existing road had to be replaced within a creeping slope.

RÉSUMÉ: L'intérêt du recours à murs et talus renforcés par géosynthétiques pour des applications extrêmement difficiles ou dans des conditions limites extrêmes, a été démontré avec succès dans de nombreux projets. Cet article présente une solution, techniquement opportune et à la mise en oeuvre adaptée au contexte, de massifs de soutènement renforcés par géosynthétiques sur des projets soumis à des conditions géotechniques et topographiques extrêmement difficiles. Dans ce document, les différents cas décrits sont des projets aux exigences très spécifiques. Par exemple, la dernière étude de cas développe l'exemple d'une situation très complexe dans les Alpes, où une route existante a dû être déviée et remplacée sur un versant présentant une instabilité par glissement.

Keywords: Geotextile reinforced wall; landslide; stabilization; steep slope

1 *INTRODUCTION*

1.1 General

Geosynthetic-reinforced steep slopes and walls became very popular worldwide during the last decades 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 and tests is believed to be always useful.

The main focus of this paper is to demonstrate and report on the excellent behavior of geosynthetic-reinforced earth walls (GRS) under extremely challenging boundary conditions, such as large walls heights, high and concentrate loads close to the facing, overstep facing inclinations and/ or long-term deformations of the foundation soils. Also the behavior of GRS walls under earthquake action has proven an excellent and in regard to concrete walls outperforming behavior, but this will not been discussed in this paper.

Typically multiple horizontal layers of geosynthetics, mainly geogrids, are filled with compacted granular material and arranged on top of each other with a vertical spacing of 0.4 m to 0.6 m. In order to prevent slope failure and/ or excessive deformation the required design strength and length of the single geogrid layers has to be estimated in a geotechnical design.

2 SELECTED CASE STUDIES

The past experience with the GRS walls facilitated the use of such structures in ever more challenging projects, as it will be shown in the following section.

2.1 Large wall heights

A disused quarry in Tuttle Hill, Nuneaton, East Midlands, UK, has been regenerated in order to provide a new housing site for Redrow Homes. The former quartzite and diorite quarry, ceased operation in the late 1990's and covers an area of 40 acres. The quarry consists of a large 'main void' and smaller partially in-filled 'shallow void'.

In order to facilitate the regeneration of the site for housing the 'shallow void' was in-filled in order to provide a stable development platform, whilst the 'main void' is to be left as an open body of water. The reclamation works comprised the following main activities:

- Excavation of loose fill from the shallow void
- Selected removal of overhanging/excess rock contours by limited drilling and blasting or mechanical ripping
- Preparation and processing of materials on site for placement
- Construction of a 35m high Fortrac® geogrid reinforced soil slope between the 'shallow' and 'main' voids
- Placement of engineered fill behind the reinforced soil block to provide a stable development platform for housing

Figure 1. GRS wall after complition of construction

Figure 2. GRS wall after vegetation

The slope face is formed using a wraparound type structure (Figure 1). At Midland Quarry, due to the presence of the quarry lake, the risk of wave action on the slope face required the use of gabion stone, installed within the front section of the slope face for the lower two thirds of the slope height. The upper third of the slope comprises a topsoil face to aid vegetation above the water line (Figure 2). The wraparound face construction is formed using a temporary climbing shutter system.

2.2 High concentrated loads close to the facing

GRS walls are also more commonly applied as bridge abutments (Figure 3). By the use of GRS walls, the construction of a bridge abutment can be done much faster by the use of light construction vehicles and in many cases with local fill material. Due to the high sensitivity of bridges regarding deformation, such as settlements of the abutment or tilting of the sill beam, real scale tests had been performed, to analyze and check the load bearing behavior. The load from the bridge is transferred to the bridge abutment via the sill beam, which has a limited width of 2 to 3 m located very close to the facing of the GRS wall.

Figure 3. GRS wall as highly loaded temporary bridge abutment

At the LGA Nuremberg, Germany, a 4.5 m high vertical geogrid-reinforced soil wall was constructed and tested in the function as bridge abutment (Figure 4). A heavily reinforced 1.0 m wide concrete block was used as a sill beam, transferring the load from the hydraulic jacks onto the reinforced soil wall.

This concrete block was placed only 1.0 m away from the edge of the vertical wall. The wall was reinforced by 9 layers of geogrids (Fortrac 80/30-35M) from PVA with an ultimate tensile strength of 80 kN/m. The layers were 5.0 m long and the spacing between the layers was 0.5 m. In the front of the wall the layers were ‘wrapped-around’, creating a so called “soft facing”.

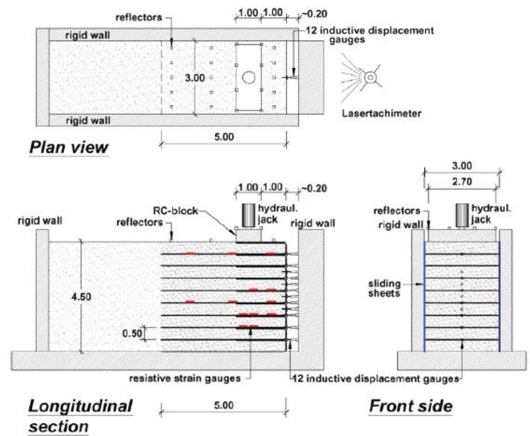

Figure 4. Test set-up and instrumentation of a full scale geogrid reinforced bridge abutment loading test (Alexiew 2007)

The fill was a well graded crushed sandy gravel with an internal friction angle of between 40° and 45°, depending on the compaction grade. Various measurement devices were installed on top and in front of the wall to measure vertical deformations of the wall surface, and horizontal deformations of the wall facing, during the test. For further details of the test set-up and instrumentation (Alexiew 2007).

The main focus of this test was to obtain the magnitude of horizontal and vertical deformation in the usual contact pressure range of 150 to 250 kPa and the ultimate contact pressure, which would drive the GRS to failure. Two separate tests were carried out. In test 1 the maximum load was 400 kPa, i.e., twice the contact pressure normally experienced under a sill beam. After each load increment a pause took place until the requirements of the plate bearing tests, in accordance with DIN 18134, were reached regarding the change of settlement. The aim of test 2 was to take the GRS block to failure using the full capacity of the hydraulic jacks of 650 kPa.

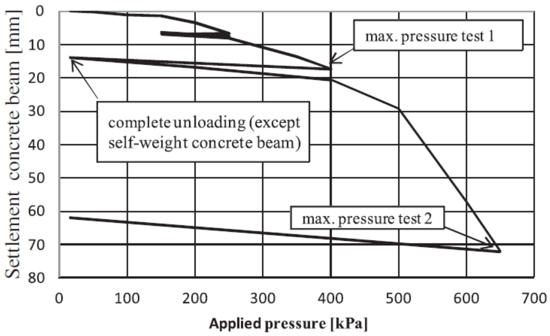

Figure 5. Settlement of the concrete block during the load test 1 and 2

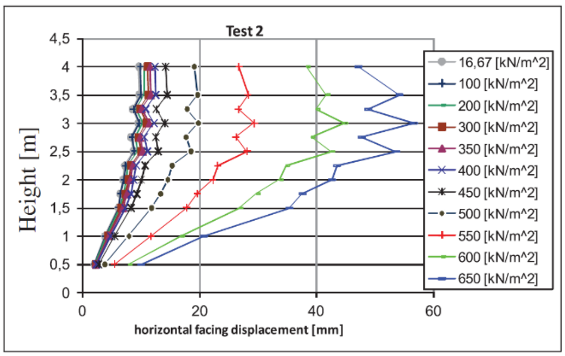

Figure 6. Horizontal facing displacement for the load test 2

The following remarks can be made (Figure 5 and figure 6):

- A contact pressure under the sill beam of up to 650 kPa (approx. 3 times that normally experienced) led to no obvious component or system failure. However, the increasing deformation rate starting at about 400 to 450 kPa can be seen as starting failure mechanism
- A contact pressure of up to 400 kPa (approximately twice the usual value) resulted only in completely acceptable deformations
- The tested system exhibited technically advantageous, ductile behavior with no discontinuities and seems to have a substantial reserve capacity
- The overall performance can be considered to be very good

2.3 *Overstep construction*

In the Netherlands, many roads are overbridged by so called ecoducts to allow animals a safe crossing of the motorways. In the case reported here, the ecoduct was constructed by a reinforced concrete frame with inclined side walls. The whole concrete structure was planned and executed in a very slender way. The strength of the side walls was not sufficient to take the earth pressure from the earth embankment on either side, which should allow the animals to access the bridge and to overpass the road.

Instead of strengthening the inclined side walls of the reinforced concrete frame, which would have been quite complex, an overstep geogrid reinforced soil wall was planned and constructed on either side of the concrete frame (Figure 7). The intention of the construction of the overstep geogrid reinforced soil structures was to eliminate the earth pressure from the inclined side walls by leaving a gap of about 20 cm between the facing of the reinforced soil structure and the inclined side walls. The reinforced soil structure acts as a “total earth pressure relief structure”.

Figure 7. Executed overstep GRS Wall in the function as bridge approach and earth pressure relief to protect slender concrete wing walls of an ecoduct

3 ROUTE CONSTRUCTION IN CHALLENGING TERRAIN

The approx. 48 km long B114 link road in the Austrian Province of Styria runs from the town of Trieben in the Paltental valley via the municipality of Hohentauern (Triebener Tauern pass) to Judenburg in the Murtal valley. With an estimated traffic volume of around 2,000 vehicles/24 h, including 9% heavy-goods vehicles (Lackner 2008), it constitutes an important north-south axis. Most of the southern part of the B114, which mainly runs along the Pölsbachtal valley, has a gentle gradient. The northern road section in the Tauernbachtal valley, on the other hand, covers a difference in altitude of some 570 m over a distance of 8 km. Until the 1970s, gradients of up to 21% were encountered in some places. During a first improvement project implemented at that time, the gradients were largely reduced to a maximum of 13%.

September 2008 then saw completion of a second improvement scheme on this road section, with its severe geotechnical and topographical challenges. This second scheme is described in greater detail in the following, with a particular focus on the steep geosynthetic-reinforced slopes constructed as part of the works.

3.1 Geotechnical challenge

The steeply rising section of the road to Sunk immediately outside the town of Trieben crosses an extensive geological fault zone (Figure 8).

Until recently, the damage caused to retaining structures, slope bridges and the pavement construction by creep movements in the slope necessitated major rehabilitation at regular intervals. Despite this, the condition of the road section continued to worsen noticeably: the pavement surfacing and lateral retaining walls exhibited substantial cracking. In places, this even led to the detachment of retaining wall facings or the destruction of rock bolts/anchor heads (Figure 9). Apart from the risks posed by localized problem areas, even the possibility of large-scale landslips could not be completely ruled out.

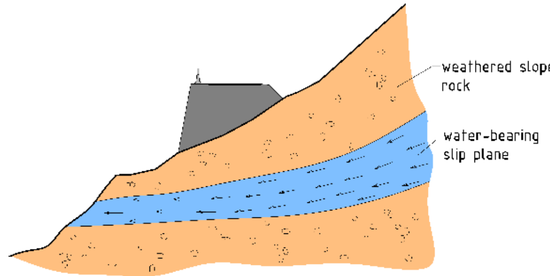

Figure 8. Schematic diagram showing geological fault zone

Given the extent of the existing damage and, above all, the anticipated scope of future damage to the road, the option of rehabilitating the existing route was rejected for both technical and financial reasons. The decision was thus taken to rebuild the affected road section.

To ensure safe operation of the road until completion of the new section, the first step entailed setting up a satellite-based system to monitor slope movement. The continuous measurement of absolute slope movement and deformation speed allowed landslip risks to be assessed and appropriate action to be taken, if necessary through complete closure of the "old" road section.

Figure 9. Damage to retaining walls along "old" route

3.2 Route mapping

The analysis of options for rehabilitation of the affected road section started as early as 1990. The decision-making process was, however, complicated by the extremely tough geological and topographical conditions. Ultimately, the client – the local public works office of the Austrian Province of Styria – in collaboration with the appointed engineering practices Birner and Dr. Lackner from Graz – opted to reroute the road on the opposite side of the valley, more or less parallel to the existing route. This allowed continued, unobstructed use by traffic of the old B114 road between Trieben and Sunk during the construction period. In all, the new road section is approx. 2.9 km long and covers a difference in altitude of 221 m. From Trieben, the route runs along the right-hand side of the Wolfsgraben valley when viewed in the downstream direction (see Figure 10). A 70 m long bridge carries it over to the left-hand side of the Triebenbach stream after approx. 1 km. To limit the gradient to 10%, two hairpin bends are integrated further along the route. Roughly 3 km out of the town of Trieben, the road crosses back to the other side of the valley over a 40 m long bridge. After a further 500 m, it then joins the existing road near the village of Sunk.

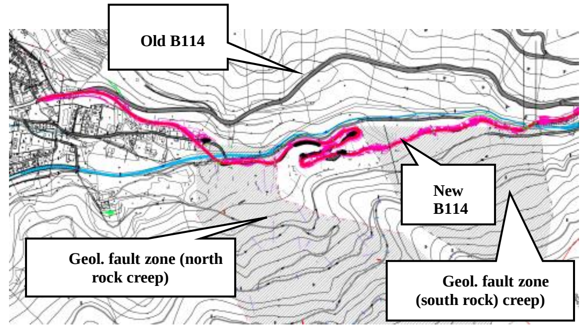

Figure 10. B 114 route between Trieben and Sunk

3.3 Slope stabilization and retaining structures

Given the virtually impassable terrain, dotted with steep slopes, and the fault zones on this side of the valley, the application of conventional stabilization methods using reinforced concrete, sheet piling or gravity constructions had to be rejected. After extensive analysis of the options, detailed parametric studies and careful assessment of the residual risks, a combined solution featuring geogrid-reinforced earthworks and rock bolts was adopted. The key advantage of this concept, developed by engineering practice Dr. Lackner, is the high ductility and geometrical flexibility of the resulting system. Absolute and differential displacement can be largely accommodated without damage and while maintaining structural stability and serviceability.

The geosynthetic-reinforced retaining walls, generally with a batter of 70°, reach heights of up to 28 m.

3.4 Construction works

The local geological and topographical conditions posed a major challenge for the Salzburg-based contractor, Alpine Bau GmbH.

Most of the works were performed in extremely difficult, steep terrain. The haul roads had to be built with very tight widths, steep gradients and small curve radii (Figure 11). Every effort was therefore made to maximize efficiency in the complex process of transporting soil and materials. The flexibility of the specified geogrid product (Fortrac®) played a key role in simplifying transportation. The geogrids were cut to size, folded and palletized at a central location on the basis of detailed placement plans. This allowed problem-free movement of the geogrids along the narrow haul roads to the work location.

Figure 11. Haul roads

In some places, slope debris had to be removed prior to construction of the GRS retaining walls. These excavations were performed in 2.0 m steps and stabilized by a reinforced, 15 cm thick shotcrete layer and IBO self-drilling hollow anchors.

As mentioned before, the extremely steep terrain and sometimes very low stability of the slope necessitated the minimization of excavations for the base footprint of the geosynthetic-reinforced retaining walls.

In critical sections, the only means of providing a sufficiently strong, non-displaceable foundation level for the reinforced retaining walls was by constructing 1.0 m deep, 2.50 m wide vertical concrete ribs at 4.0 m intervals. Reinforced-concrete head slabs were additionally fastened to the concrete ribs and permanently tied back with GEWI anchors (Figure 12). To achieve a slip-free bond between the tied-back concrete base and the footprint of the geosynthetic-reinforced retaining wall, the concrete surface was textured with a special ribbed finish and covered by a course of crushed stone prior to placement of the first geogrid layer. Given the short geogrid lengths at the base of the structure, particular attention was also given to optimizing the bond between geosynthetic product and fill material. Specification of the geogrid mesh size (70 mm x 70 mm) was thus dictated by the nature of the coarse fill material used on the project.

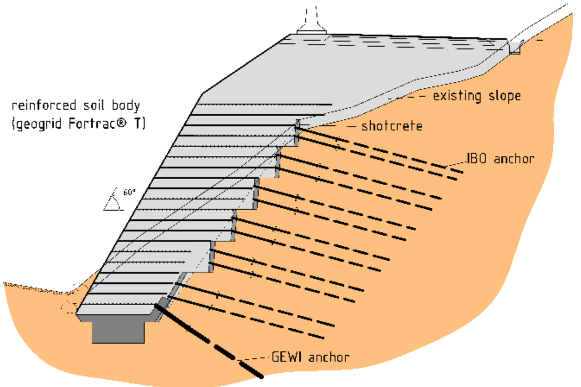

Figure 12. Schematic of standard cross-section

3.5 SLOPE FACE DESIGN

Preformed steel mesh angles were incorporated in the wall face as lost formwork and vegetation support layer (Figure 13). As these are not provided with any special corrosion-resistant coating, they cannot be viewed as being relevant to long-term structural performance. Hence, to ensure the permanent accommodation of earth pressure at the outer skin of the slope, the geogrids were wrapped back into the structure. A special fabric was also inserted inside the geogrid to protect against erosion and the washing-out of fine particles, and to provide a base for hydroseeding. Immediately upon completion, the slopes were vegetated using the hydroseeding method.

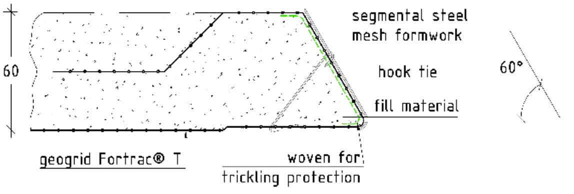

Figure 13. Schematic showing front slope design with wrap-back and vegetation

Years of experience have shown this design concept to offer a practical, reliable, durable and cost-effective solution.

A greater bar diameter was specified for the steel mesh on this project than for normal applications. This permitted the use of relatively heavy compaction plant also at the front of the retaining structure – thus enabling the works to proceed at an adequate rate to meet the tight construction window. At the start of the works, a continuous wall inclination was achieved by preforming the steel mesh with an opening angle precisely matching the slope batter. As the works proceeded, there was a switch to steel mesh with a 90° angle, the required batter then being achieved by means of horizontal set-backs between successive layers. This further simplified the process of soil placement and compaction. Moreover, the resulting berms in the structure facilitated the infiltration of rainwater into the wall, thereby promoting the growth of vegetation on the slope. Once the steel mesh was in place, the cut-to-size geogrids were installed with the extra length allowed for the wrap-back left temporarily hanging over the mesh units.

Figure 14. Constructed GRS walls

4 CONLCUSION

The paper summarizes different case studies, which demonstrate the wide application range of GRS walls under extrem condition. Walls can be constructed with great heights and overstep facing, widthstand huge concentrated loads and can be used in very difficult terrain, subjected to longterm deformation without significant damage.

GRS walls allow to fulfill stringent requirements under very complex boundary conditions.

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