4thWLF2017
4th World Landslide Forum
LJUBLJANA SLOVENIA EU

# HIGH GEOGRID-REINFORCED SLOPES AS FLEXIBLE SOLUTION FOR PROBLEMATIC STEEP TERRAIN: TRIEBEN-SUNK PROJECT, AUSTRIA

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**Abstract**

A large-scale construction project was implemented between June 2006 and September 2008 to reroute the B114 mountainside link road between Trieben and Sunk in Austria. In addition to comprehensive drainage and anchorage measures, the works included the extensive use of extra-steep, geosynthetic-reinforced slope structures to build the route and stabilize critical slip-prone slopes. This paper presents a technically expedient and practically feasible solution for the use of geosynthetic-reinforced retaining structures on projects subject to extremely difficult geotechnical and topographical conditions. Following a description of the geotechnical situation and associated problems, the procedure for dimensioning the geogrid-reinforced structures and practical aspects of the site operations are outlined, explained and discussed.

**Keywords**

Geotextile reinforced wall, landslide, stabilization, steep slope

## 1 Introduction

### 1.1 General

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.

### 1.2 Geotechnical challenge

The steeply rising section of the road to Sunk immediately outside the town of Trieben crosses an extensive geological fault zone (see Fig. 1).

Until recently, the damage caused to retaining structures (see Fig. 2), 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 (see Figure 2). Apart from the risks posed by localized problem areas, even the possibility of large-scale landslips could not be completely ruled out.

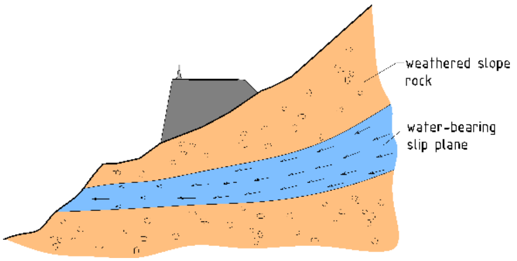


Fig. 1 Schematic diagram showing geological fault zone

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.

Fig. 2 Damage to retaining walls along "old" route

## 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 (see Fig. 3). 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 3). 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.

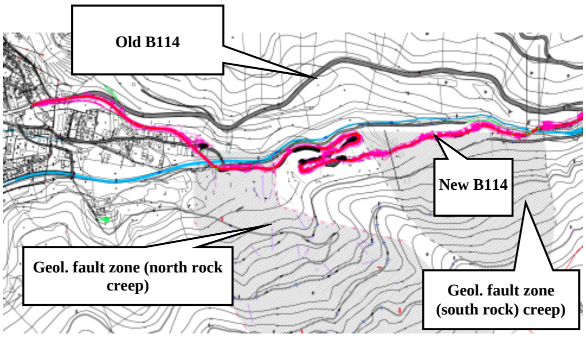


Fig. 3 B 114 route between Trieben and Sunk

## 3 Slope Stabilization and Retaining Structures

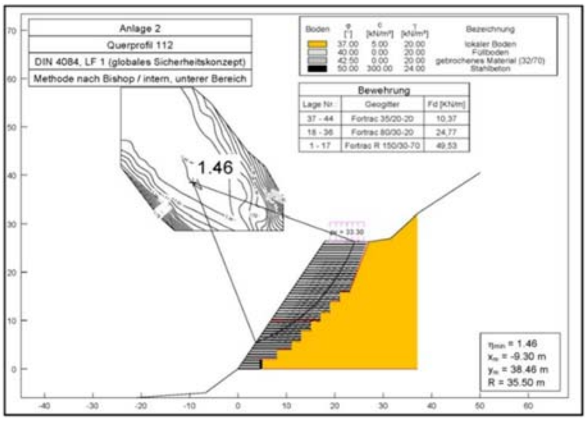
Given the virtually impassable terrain, dotted with steep slopes, and the fault zones on this side of the valley, the application of conventional stabilization methods using reinforced concrete, sheet piling or gravity constructions had to be rejected. After extensive analysis of the options, detailed 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.

## 4 Structural Stability Calculations

### 4.1 Dimensioning of reinforced earthworks using iterative analytical methods

The geosynthetic-reinforced retaining walls were dimensioned in a separate process – independently of a consideration of the overall structural stability of the surrounding terrain – on the basis of iterative analytical verifications. The analysis did, however, make allowance for the sometimes steeply inclined areas of fill necessitated by the topography behind the reinforced earthworks. The structural stability of the overall slope fill was thus shown to be regulations-compliant. In general, this also led to an improvement of the overall stability of the slope in the area around the structure (see Fig 4).



Anlage 2
Querprofil 112
DIN 4084, LF 1 (globales Sicherheitskonzept)
Methode nach Bishop / intern, unterer Bereich

| Boden | φ [°] | c [kN/m²] | γ [kN/m³] | Bezeichnung |
|---|---|---|---|---|
| 🟨 | 37.00 | 5.00 | 20.00 | lokaler Boden |
| ▭ | 40.00 | 0.00 | 20.00 | Füllboden |
| ▨ | 42.50 | 0.00 | 20.00 | gebrochenes Material (32/70) |
| ■ | 50.00 | 300.00 | 24.00 | Stahlbeton |

| Bewehrung | | |
|---|---|---|
| Lage Nr. | Geogitter | Fd [kN/m] |
| 37 - 44 | Fortrac 35/20-20 | 10.37 |
| 18 - 36 | Fortrac 80/30-20 | 24,77 |
| 1 - 17 | Fortrac R 150/30-70 | 49.53 |

$\eta_{min}$ = 1.46
$x_m$ = -9.30 m
$y_m$ = 38.46 m
R = 35.50 m

Fig. 4 Screenshot internal stability check

Where necessary, low-level drainage or additional works to stabilize the foundation level or support deeper-seated slip surfaces were separately designed as an adjunct to the main structure. This dimensioning and verification approach had been tried out several times previously for the rehabilitation of landslip areas in unpredictable Alpine terrain using geosynthetic-reinforced soil (GRS) structures. The external geometry of the earthworks, as applied in the calculations, was selected with due regard for the planned route and the requirement for a body of soil of maximum homogeneity at the foundation level of the road structure.

Once the external geometry of the slope had been established, it was then possible to specify the required geometry of the cuttings. Here, the first step was to perform structural checks on external stability. As with slope/embankment verifications for standard retaining walls, only slip surfaces running outside the reinforced earthworks were considered. These verifications were performed in accordance with DIN 4084 (1981) using Bishop's method for circular slip surfaces and the vertical slice method for diverse polygonal slip surfaces. This allowed determination and verification of the cutting geometry needed or predetermined by fixed geometric points. In this particular case, the calculations had to allow for the fact that any changes arising from the iterative determination of the required reinforced earthwork dimensions automatically entailed an adaptation of the cutting geometry – thereby significantly increasing the computational effort. The definitive arrangement of the reinforcement layers was then specified and the requirements for the incorporated geosynthetic reinforcement products established. This involved further iterative analysis, likewise based on circular (i.e. "mixed") and polygonal slip surfaces, either running only inside or running inside and outside the reinforced earthworks. The length and spacing of the reinforcement layers along with the design strength of the incorporated geosynthetic products were repeatedly varied until the optimum solution was found (see Fig. 5).

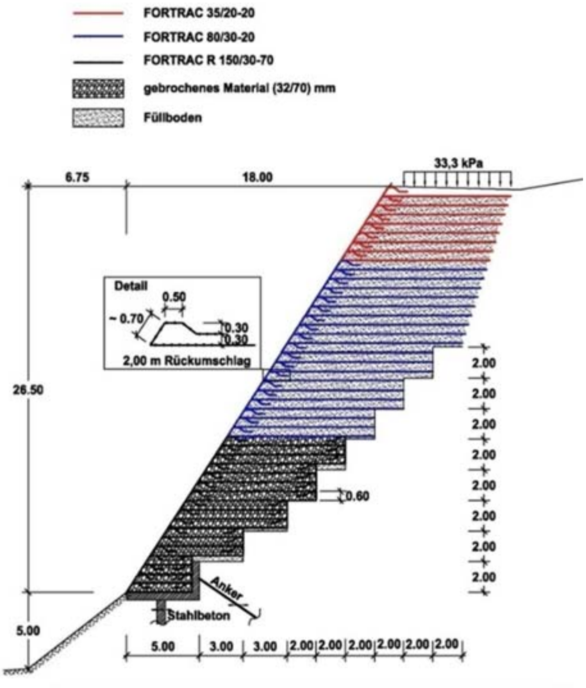


Fig. 5 Layout geogrid reinforced slope

Important background information on the iterative analytical design of GRS structures is set out, for example, in EBGEO 1997 ("Recommendations on soil reinforcement with geosynthetics"). Further details and recommendations, specifically regarding the impact of the terrain gradient in the backfill zone – which was particularly relevant to this project – and the allowance for slip surfaces running through the backfill zone and reinforced earthworks, are also presented in Alexiew 2005.

### 4.2 Numerical analysis of structural stability improvement due to retaining wall

The analytical procedure described in Section 4.1 for specification and dimensioning of the reinforced earthworks was complemented by a detailed finite element method (FEM) analysis carried out for a diploma thesis at Graz University of Technology using the commercially available Plaxis 2D V8 and Plaxis 3D Tunnel computational software. The focus here was on investigating the impact of spatial failure mechanisms and different construction stages. The numerical simulations provided confirmation of the analytical calculation results and showed how the completed works served to stabilize the slopes. Parametric studies additionally allowed estimation of the maximum projected geogrid and anchor forces together with overall settlement. The applied background conditions, material laws and computational parameters for the numerical simulations are described in Lackner 2008 (see Fig. 6).

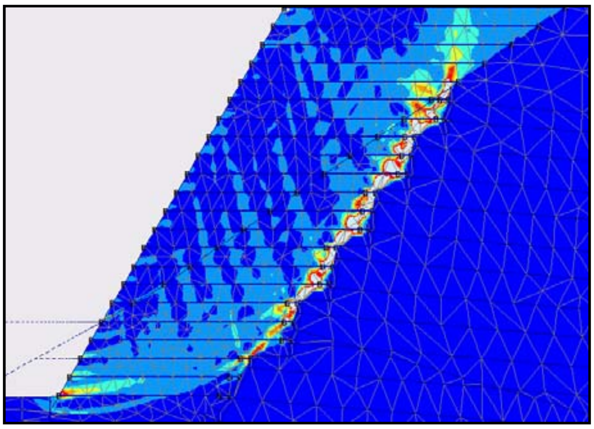


Fig. 6 Numerical simulation of the reinforced slope (Lackner, 2008)

Figure 7 shows the final schematic layout of the slope including the temporary slope securement by shotcrete and the permanent anchoring of the concrete base of the reinforced earth walls.

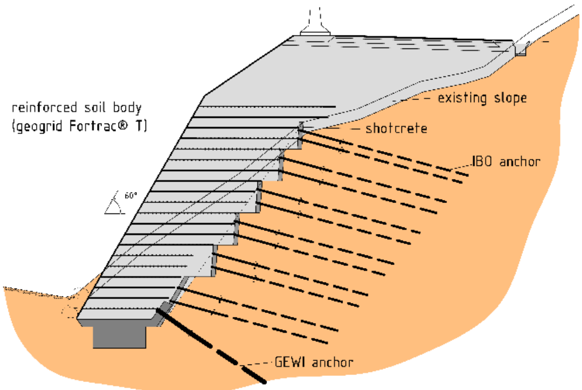


Fig. 7 Schematic of standard cross-section

## 5 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 (see Fig. 8).

Fig. 8 Haul roads

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 (see Fig. 9)

Fig. 9 folded and palletized geogrids

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 in Section 4.1, 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. 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 (see Fig. 10).

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.

Fig. 10 Measures to stabilize and drain slope cuttings at foundation level

## 6 Slope Face Design

Preformed steel mesh angles were incorporated in the wall face as lost formwork and vegetation support layer. 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.

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

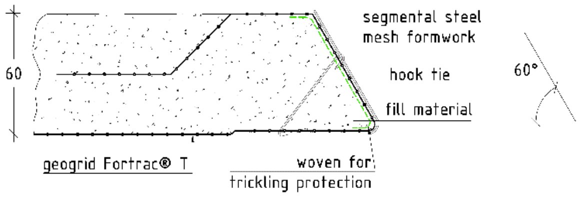


Fig. 11 Schematic showing front slope design with wrap-back and vegetation

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.

## 7 Measurement and Monitoring

To monitor the deformation behaviour of individual structures and, in particular, of the overall slope, and to verify the effectiveness of the various stabilization measures, numerous geotechnical measurement devices were installed in the course of the works. In addition to a tightly-knit arrangement of geodetic measurement points, these specifically included inclinometers and sensors to monitor anchor forces. Analysis of the initial measurement data shows that, while the expected slope deformation continues, its magnitude has been significantly reduced. All results confirm the fitness for purpose of the described system solution comprising ductile retaining and slope systems built with geosynthetic-reinforced soil, including anchorages, in conjunction with optimized geometry and layout for slope stabilization.

## 8 Summary

The featured project testifies to the high technical, economic and ecological efficiency of geosynthetic-reinforced constructions.

The ductile material behaviour of the geosynthetic reinforcement, which is tailored to local conditions, combined with a flexible outer skin makes this type of construction the ideal solution, even on creep-prone slopes. Not only does GRS offer favourable mechanical properties, the resulting structures can also be designed to blend harmoniously with the landscape setting. The high flexibility of the specified geogrids allows efficient and practical transportation to the work location – a major advantage, particularly on constricted sites.

The featured project is a prime illustration of the effective combination of different stabilization methods, such as GRS, anchorages, soil nailing and drainage, in difficult terrain.

The successful implementation of construction projects of this technical complexity requires in-depth experience and the commitment of all project team members to the pursuit of innovative solutions.

Fig. 8 View of some of the described GRS slopes

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