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High Geogrid Reinforced Walls in a Mountainous Seismic Region in Bulgaria

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ABSTRACT: In the Rhodope Mountains in the south of Bulgaria the trace of an important road being part of the National Road Network had to be completely changed due to the erection of a new dam. The trace had to be moved from the old river valley up to the hills by up to some hundred meters. The new stretch has a length of 11 km. The mountainous terrain is characterized by sophisticated topography (very steep irregular slopes), varying geological and hydrological conditions, instability tendencies in some places and non-availability of easy access for construction. Additionally, the region is an area of significant seismic activity. The optimization of the solution from the point of view of environment, costs, geology, seismic resistance, soil-mass balance, technology and time schedule was a challenge. After checking different options the final optimized solution included twenty geogrid-reinforced walls with a total length of 2 km, heights of up to 20 m and a face inclination of 10:1 (say nearly vertical) without any berms, what is quite unique. The geogrid-reinforced soil structures were chosen (besides other advantages) due to their excellent adaptation to the environment and their high ductility resulting in high robustness against seismic impact and slope movements. Flexible geogrids being wrapped-back at the front were implemented. A special type of thin stone-filled wall facing was adapted to fit the environment, to use local rocky material, to allow a flexible execution schedule and to provide a good seismic resistance. In the paper the project environment, the main problems and typical solutions will be shortly explained. Design and calculation philosophy and procedures incl. of the seismic design applying modified Bulgarian Codes, final schemes, typical cross-sections and materials will be treated focusing on the specific points. During construction some unexpected topographic and hydrologic problems were faced, but successfully solved in a quite quick and simple way, demonstrating additional advantages of geosynthetic solutions. The entire road was handed over for operation in time in summer 2010 and demonstrates a good performance. This transportation project is may be one of the most distinctive in the region during recent years.

1 INTRODUCTION

In the Rhodope Mountains in the south of Bulgaria the route of the important Road III-868 from Devin to Mihalkovo being part of the National Road Network had to be completely changed due to the erection of a new dam on the River Vacha. The old road built some decades ago in a “common way” along the river had to be moved from the river valley to the hills by up to some hundred meters. The new stretch has a length of 11 km (Figure 1). Figure 2 provides an overview of the mountainous terrain, of the position of the old road in the valley and of the new road uphill.

Unfortunately the mountainous terrain is characterized by sophisticated topography (very steep irregular slopes, Figure 2), varying geological and hydro logical conditions, instability tendencies in some places and non-availability of easy access for construction. Additionally, the region is an area of significant seismic activity. The optimization of the solution from the point of view of environment, costs, geology, seismic resistance, soil-mass balance, technology and time schedule was a challenge. After checking different options the final optimized solution included twenty walls from geogrid-reinforced soil (GRS) with a total length of 2 km, heights of up to 20 m and a face inclination of 10v:1h (say nearly vertical) without any berms, what is quite unique.

Figure 1. Old route of Road III-868 in the valley and uphill through the mountains.

Figure 2. Overview of the mountainous terrain new one and exemplary positions of the old and new road.

The GRS-structures were chosen (besides other advantages) due to their excellent adaptation to the environment and their high ductility resulting in high robustness against seismic impact and slope movements. Flexible geogrids were used as reinforcement. A special type of thin stone-filled wall facing was adapted to fit the landscape, to use local rocky material and to allow a flexible execution schedule. Beside this the facing is very flexible and thus of higher resistance against earthquakes.

During construction some unexpected topographic and hydrologic problems had to be solved in a quick and simple way, demonstrating additional advantages of geosynthetic solutions.

2 GENERAL CONCEPT AND PHILOSPHY

The project for the new road and the GRS-walls was developed by the General Consultant Energoproekt - Hydropower" (Sweco Group) Bulgaria and by the Road Designer "Burda Engineering" Bulgaria with some consultancy from the company of the authors. Some specific points have to be mentioned:

A. Because of the very steep natural slopes (sometimes steeper then 1v:1h) the optimal positioning and foundation of all walls asked for very steep, almost vertical front inclinations of 10v:1h to achieve a better adaptation to the slope geometry. The concept was to minimize the base width of the generally trapezoidal cross-sections thus minimizing excavation (Figure 3c) and expansion down the slope as well (Figure 3a).

B. To optimizing the soil mass balance (cuts vs. walls along the new road) but also to some extent based on common practice and conservatism three typical cross-sections were foreseen: lowest cross-sections without berms, higher cross- sections with one berm and the highest sections with two berms (Figure 3).

C. The final stability analyses and design of the GRS-walls were to be completed after beginning of construction (due to site logistics and access reasons few of the structures could be started at the same time, in reality a progressive construction was carried out along sections of the route). The project and specifications put to tender were founded on the basic concept and on the typical cross-sections in Figure 3 (these were indicative only, being based on preliminary stability analyses); it was assumed that these will be not the final solutions. The reason for this philosophy was the uncertainty in the real geotechnical and to some extent topographical conditions along the 11 km of road, because due to the extremely difficult access the survey and site investigation had been relatively modest.

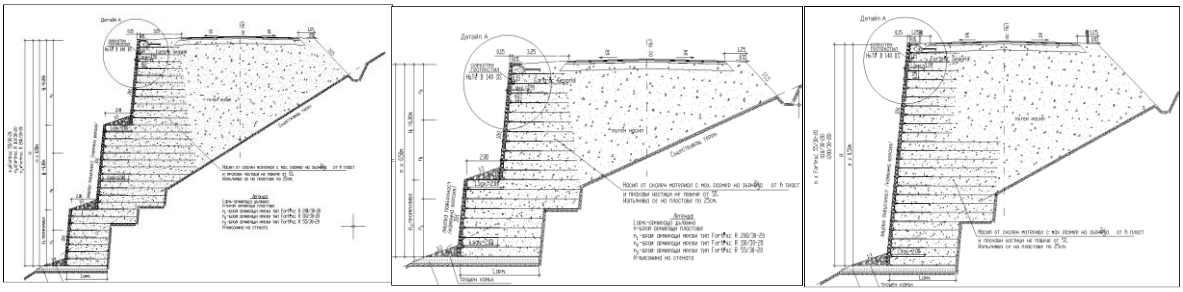

Figure 3. Basic concepts for typical cross-sections: front (facing) inclination always 10v:1h, but different number of berms.

D. The facing was an important issue. After checking different options the so called "Muralex® Stone" facing system was chosen. Its concept is based on the idea of a "hanging facade" added and connected in a later construction stage to the "real" bearing geogrid structure (Figure 4).
The system leads to important advantages:
- the geogrids are hidden and protected against UV, impact, fire and vandalism;
- possible wall deformations during construction occur before facing installation - the facing starts its design life deformation-free;
- ductile behavior of the facing under seismic impact and generally under wall deformations of any type in the post-construction stage, because it is quite "independent" and flexible, say there is no rigid connection to the "real" GRS (Figure 4);
- no special facing foundation is needed;
- a wide range of rocky material available from the excavations on site can be used etc.

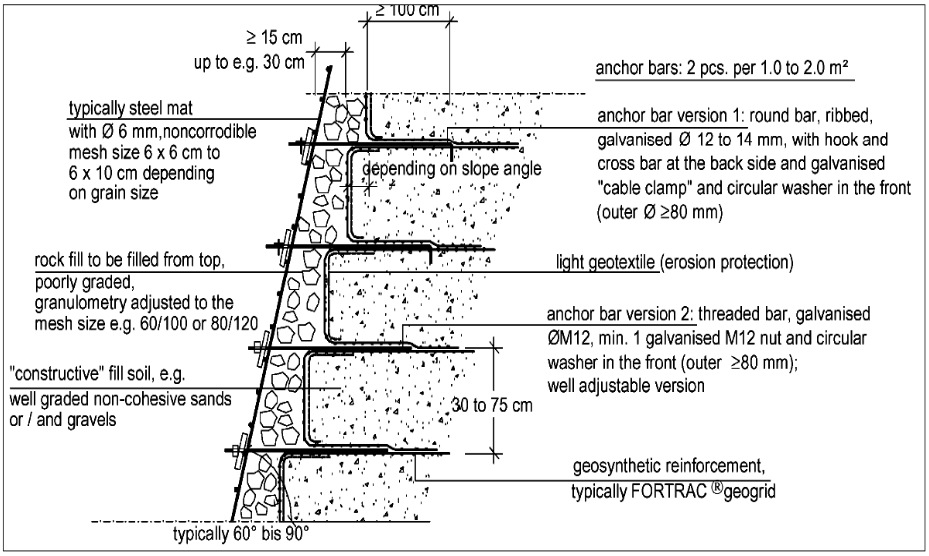

Figure 4. A typical version of the facing system Muralex®.

3 GEOLOGICAL AND HYDROLOGICAL CONDITIONS

The geology along the new route varies significantly (Figure 5). The GRS-walls and their foundations can contact at the back resp. be embedded in (Figure 3) any local soil from silty or sandy clays with stone inclusions (slope talus) to more or less monolithic rock. Due to brevity no details can be explained herein. This enormous inhomogeneity resulted also in a low level of predictability not only regarding the local slope soils for every wall, but also regarding the parameters of the fill soil for the walls; the latter consists (although after pre-selection) from excavated local materials from different cuts along the new route.

The geotechnical survey before beginning of construction was not very detailed along the entire 11 kilometers of the planned road (see Chapter 2). It was decided together with the General Investor "National Electricity Company", Bulgaria, the General Contractor "Alpine Bau", Austria, the Consultants (see above) and the Bulgarian Subcontractors for the road construction to assume in all final stability analyses relatively conservative average fill parameters. Although it was possible to identify the local slope soils resp. rocks for every particular wall in a much more precise way, a similar conservative philosophy was adapted for the local slope soils.

Many of the walls cross small valleys; in such cases standard culverts were planned being integrated into the GRS-walls. No water veins or water-bearing strata were known before beginning of execution. Nevertheless for all walls water drainage blankets were implemented at the wall base (but not in the contact back-zone to the local terrain).

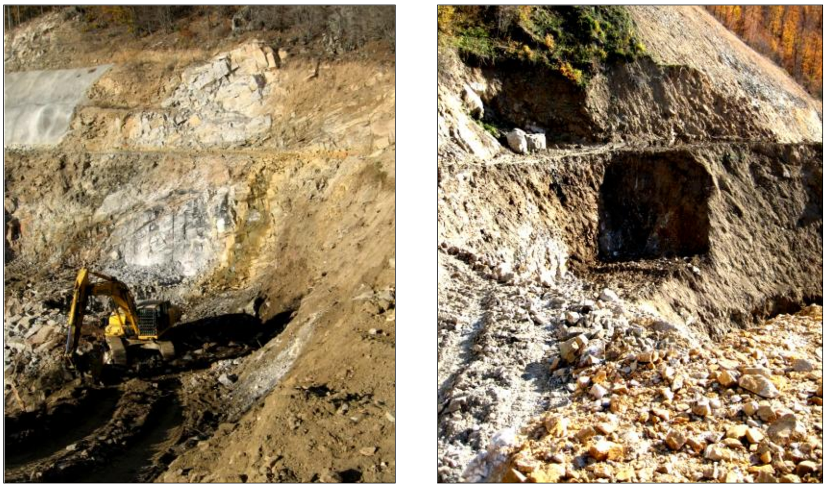

Figure 5. Examples of the enormous inhomogeneity of the local soils and rocks.

4 SOME STABILITY ANALYSIS ISSUES

For all stability analyses the well known method of circles according to Bishop was used together with additional analyses of polygonal failure planes using the so called Sliding Blocks Method (similar to the method of Janbu, but considering the shear resistance between the blocks). All analyses were performed in the Engineering Department of the company of the authors.

The concept of global factor of safety (FOS) was applied throughout the project from the same beginning (preliminary designs in 2004, see Chapter 2) until the last adaptations and changes under running execution in 2009, although in the meantime the German concepts had changed to partial factors of safety. All analyses considered the so called "internal" (failure planes cross only the geogrid-reinforced zone), "external" (failure planes do not cross any reinforcement) and "compound" stability (failure planes cross both reinforced and unreinforced soil mass).

Strictly speaking this differentiation does not make any sense, because the soil mass in the state of failure simply follows the critical mechanism, say failure plane of whatever type and shape it is. For more details see Alexiew (2004 & 2005).

Note that in the meantime in the new issue of the German recommendations EBGEO (2010) the distinction internal-external-compound was eliminated, as well as e.g. the formal distinction between “slopes” and “walls”.

Geogrids from the “FORTRAC® T”-family were chosen as reinforcement due to their high specific short- and long-term strength, low short- and long-term strain, low creep, high coefficient of bond to a a wide range of soils and flexibility resulting into an easy installation. The range of geogrids for this project was from FORTRAC® T 55 to FORTRAC® T 200.

The required FOS were chosen according to the Bulgarian Standards with FOS > 1.3 for normal (static) conditions (in the same time the German ones asked for a FOS > 1.4). In Figure 6 typical Bishop analyses are shown. A specific issue was the seismic analysis, because the GRS-walls under discussion are situated in a region of significant seismic activity with a magnitude of VII acc. to Richter.

The Bulgarian concepts for seismic design from 1980 being still valid with small modifications during the period of analysis were adopted throughout the project (CDBSSR 1987, CDRW 1986, SGDSR 1987).

Figure 7 shows an overview of the seismic activity in Bulgaria together with the position of the Devin-Mihalkovo project and the zone with VII acc. to Richter with a coefficient of horizontal acceleration $k_h = 0.15$. A vertical acceleration is not being taken into account.

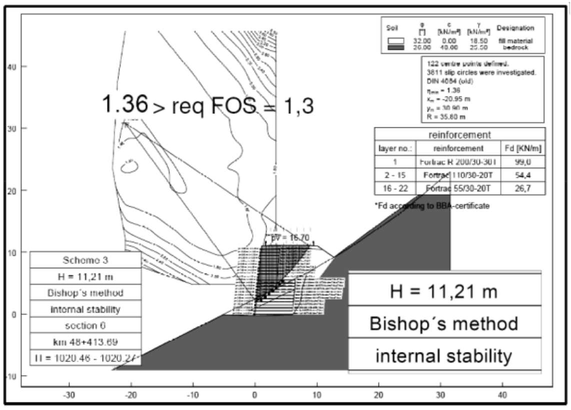

Figure 6. Typical example of stability analyses according to Bishop (only “internal” shown).

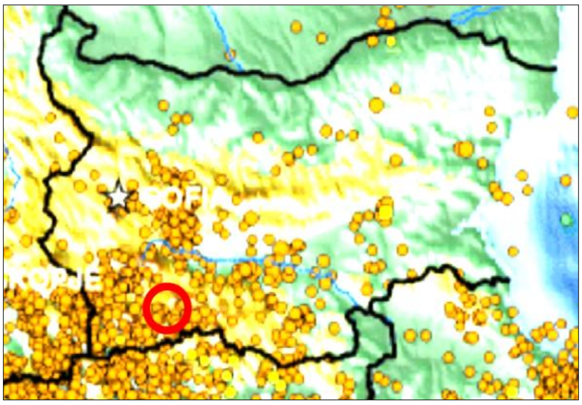

Figure 7. Seismic activities in Bulgaria, the project position is marked.

For the acting seismic forces $F_{seismic}$ the Equation 1 can be used (CDBSSR 1987, CDRW 1986, SGDSR 1987):

$$F_{seismic} = 1.30 \cdot R_{response} \cdot k_h \cdot \text{„dead loads“} + 0.50 \cdot \text{„moving loads“} \quad (1)$$

where $R_{response}$ = coefficient of response of the structure to seismic impact; k_h = coefficient of horizontal acceleration; 1.30 and 0.50 = partial safety factors on the side of action for seismic design cases.

$R_{response}$ has higher values e.g. up to 0.40 for rigid (brittle, e.g. masonry, concrete) structures and lower values e.g. 0.25 for ductile structures like earth dams and embankments. It seems logic and conclusive that earth systems reinforced by flexible geogrids should be at least so ductile and able to dissipate seismic energy remaining intact as non-reinforced earth dams.

This concept and the corresponding calculation results seem to be coherent with the experience, conclusions and recommendations in e.g. Tatsuoka et al (1998) and other publications confirming the very advantageous behavior of geosynthetic reinforced soil (GRS) under seismic impact.

Note that for seismic analyses the Bulgarian codes (CDBSSR 1987, CDRW 1986, SGDSR 1987) ask for a FOS > 1.1 instead of e.g. 1.2 in Germany (DIN 4084 resp. DIN 1054), for more details and previous "seismic" projects see e.g. Jossifowa & Alexiew (2002).

One specific issue more in the Bulgarian codes used herein for design is the reduction of the angle of internal friction acc. to Equations 2 & 3 depending on the intensity of earthquake:

$$\varphi_{\text{characteristic, seismic}} = \varphi_{\text{characteristic, static}} - \Delta\varphi \qquad (2)$$

where

$$\Delta\varphi = \Delta\varphi \text{ (magnitude acc. to Richter)} \qquad (3)$$

For the project under discussion with a magnitude of VII acc. to Richter $\Delta\varphi = 3.5°$.

Because the software used (GGU Stability by Civil Serve) does not include a calculation conform to Equation 1 and considers only directly k_h, thus the latter had to be modified "by hand" before the input.

5 EXECUTION, PROBLEMS, SOLUTIONS, EXPERIENCE

Execution started in summer 2007. First problems arose soon: the topography deviated sometimes significantly from the expected one, the real terrain was sometimes higher or lower than it should be, the real slope inclination often steeper. Step by step many of the cross-sections had to be re-designed. At the end of the day all GRS-walls, even the highest with over 20 m height, became "bermless", what is quite unique.

The "bermless" solution offers significant advantages: the base width of the generally trapezoidal cross-sections becomes minimal (Figure 3). This helped to avoid deep cuts into the hillside and/or an expansion of the trapezoid beyond the steep slope line (to the left in Figure 3). Additionally, in some cases the geology deviated significantly from the assumptions; this resulted in re-design as well.

Often surprising water veins in the natural slopes had to be drained promptly. For this purpose thick wicks from rolled non-woven geotextiles were installed ending on the front side of wall as a quick ad hoc solution. In Figure 8 typical construction stages and details are depicted. Figure 9 shows one of the completed walls just before handing the route over for operation.

Figure 8. Left: construction stages (formwork, geogrids, anchor bars, facing), right: top view of the stone-filled facing used

Figure 9. Top view of a completed GRS-wall

6 FINAL REMARKS

The new Road III-868 from Devin to Mihalkovo in the Rhodope Mountains in southern Bulgaria was a challenge in terms of concept, design, execution, re-design during execution, time schedule and costs. It crosses a terrain with sophisticated topography and geology in a seismic region. Its length amounts to 11 km comprising one tunnel and twenty geogrid-reinforced almost vertical soil walls of totally 2 km length and up to 20+ m height.

A specific type of facing was adopted to fulfil a wide range of requirements.

Almost all GRS-walls had to be re-designed and adopted under running route execution, resulting throughout in non-common high bermless solutions.

Nevertheless, it was possible to meet all project goals regarding time schedule and costs. The success is based on the one hand on the advantages and flexibility of geosynthetic solutions in geotechnical engineering and on the other hand on the excellent cooperation of all participants: Investor, Consultants, Contractors and Geosynthetic Company.

The road is since summer 2010 under traffic, the GRS-walls demonstrate until now an excellent behavior both in terms of stability and low deformability. This transportation project is may be the most distinctive in the region during the last years.

7 ACKNOWLEDGMENTS

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