Design and construction of high bermless geogrid walls in a problematic mountainous seismic region in Bulgaria

Conception et construction de murs renforcés par des géogrilles de grande hauteur et sans risberme dans une région montagneuse sismique problématique en Bulgarie

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Geogrids made of geosynthetics can replace conventional building materials like concrete. In this article, goal and scope, basic data and the results of a comparative life cycle assessment of concrete reinforced retaining walls (CRRW) and geosynthetics reinforced retaining walls (GRRW) are described. One running meter of a three meters high retaining wall forms the basis for comparison. The two walls have the same technical performance and an equal life time of 100 years. The GRRW has a lower demand of steel and concrete compared to the CRRW. The product system includes the supply of the raw materials, the manufacture of the geotextiles and the concrete, the construction of the wall, its use and its end of life. The life cycle assessment reveals that the GRRW causes lower environmental impacts. The cumulative greenhouse gas emissions of 300 m CRRW are 400 t and 70 t in case of GRRW. The use of an environmentally friendlier lorry in a sensitivity analysis and monte carlo simulation confirm the lower environmental impacts caused by the construction of a GRRW compared to a CRRW. More than 70 % of the environmental impacts of the geogrids production are caused by the raw material provision (plastic granulate) and the electricity demand in manufacturing.

RÉSUMÉ : Les Géogrids peuvent remplacer les matériaux conventionnels comme le béton. Cet article contient une description de l'objectif et du champ d'étude, l'inventaire et les résultats d'une analyse comparative du cycle de vie d'un épaulement géotextile et d'un soutènement conventionnel. La comparaison est faite sur un mètre courant d'un épaulement de trois mètre de hauteur. Les deux alternatives ont les mêmes propriétés techniques et la même durée de vie de 100 ans. Les systèmes contiennent la provision des matériaux, la fabrication des géotextiles et du béton, la construction, l'utilisation et l'évacuation de l'épaulement. L'analyse de cycle de vie démontre qu'un mètre courant d'un épaulement géotextile cause moins d'impacts environnementaux qu'un mètre courant d'un épaulement de béton. 300 mètres d'un épaulement de béton entraînent 400 t CO2-eq, celui de géotextile 70 t CO2-eq des émissions des gaz à effet de serre. L'utilisation de camions aves des émissions réduites ne change pas les résultats. Une simulation « monte carlo » confirme la stabilité des résultats. La provision des matériaux et l'électricité utilisé dans la fabrication de la couche de filtre géotextile sont des facteurs primordiaux (plus de 70 %) en ce qui concerne les impacts environnementaux du géogrille utilisé dans l'épaulement géotextile.

KEYWORDS: geogrid-reinforced walls, facing, seismicity, slope instability, steep slopes
MOTS-CLÉS: épaulement, géotextile, géogrilled, béton, analyse de cycle de vie, ACV

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 along the river had to be moved from the river valley to the hills by up to some hundred meters. The new route 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. 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 has a significant seismic activity.

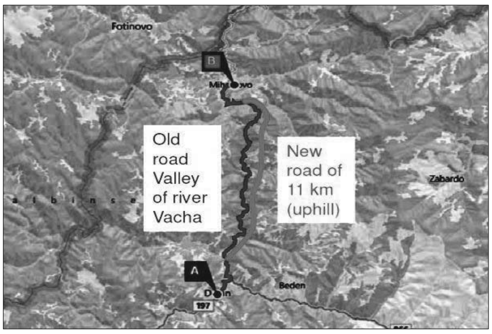

Figure 1. Old route of Road III-868 in the valley and new one uphill through the mountains.

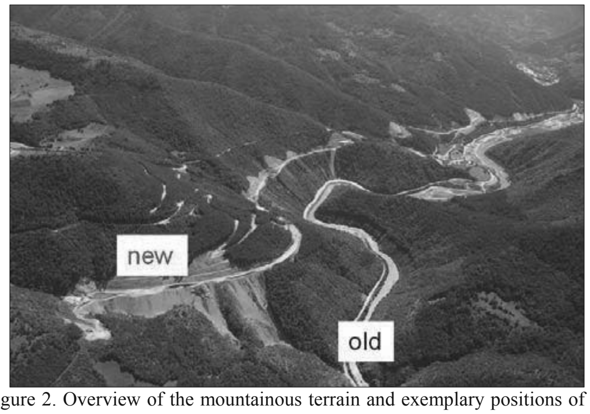

Figure 2. Overview of the mountainous terrain and exemplary positions of the old and new road.

The solution had to meet a wide range of criteria and goals: low costs, quick and easy construction, soil-mass balance (say minimum export / import of soil, say maximum re-use of excavated local soils), minimal environmental impact, as light as possible additional construction materials to ensure easy transportation and low energy consumption ("carbon finger print"), minimum use of heavy equipment, narrow base for retaining walls for an easy into-slope-adaptation, seismic resistance, and last but not least a tight time schedule of less then three years for the 11 km of new road incl. of a tunnel.

The final optimized solution meeting the criteria mentioned above in a balanced way 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 (see below).

The GRS-walls were chosen (besides other advantages, e.g. more than 30% costs savings versus “common“ concrete solutions) 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 speed up construction. The facing is very flexible and thus of higher resistance against earthquakes and possible slope movements.

2. GENERAL CONCEPTS AND PHILOSOPHY

The project was developed by the General Consultant “Energoprojekt - Hydropower” (Sweco Group) Bulgaria and by the Road Designer “Burda Engineering” Bulgaria with 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 almost vertical front inclinations of 10v:1h to achieve a better adaptation to the slope geometry. The base width of the cross-sections had to be minimized thus minimizing excavation (Figure 3c) and expansion down the slope as well (Figure 3a).

B. To optimize the soil mass balance but also based on common practice and conservatism three types of cross-sections were foreseen: without berms (typically up to 6-8 m), with one berm (typically up to 14 m) and with two berms (up to 22 m) (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 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 specifications put to tender were founded on the basic concept and on the typical cross-sections in Figure 3 a, b, c (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 topographical conditions along the 11 km of road, because due to the extremely difficult access the survey and site investigation had been relatively modest.

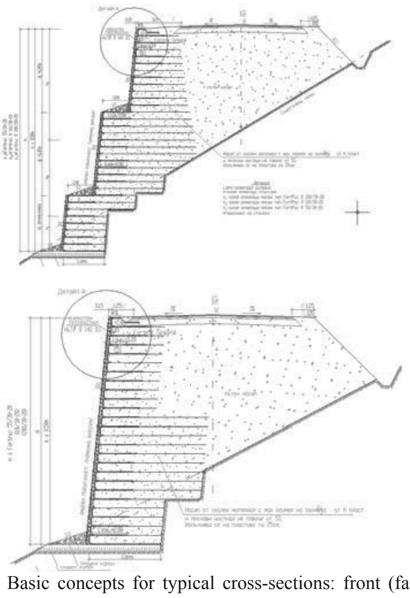

Figure 3. Basic concepts for typical cross-sections: front (facing) inclination always 10v:1h, but different number of berms; from top to bottom: a, b, c.

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 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.

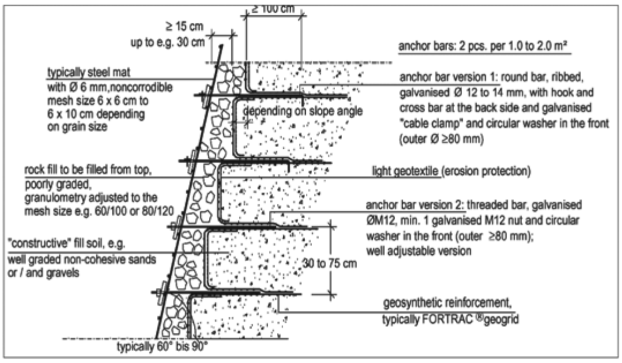

Figure 4. A typical version of the facing system Muralex®.

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. This enormous inhomogeneity resulted in a low level of predictability not only regarding the local slope soils, but also regarding the parameters of the fill soil; 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. 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 local soils and fill parameters. Many of the walls cross small valleys; in such cases standard culverts were planned being integrated into the GRS-walls. No water veins were known before beginning of execution. Nevertheless for all walls drainage blankets were implemented at the wall base.

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 All analyses were performed in the Engineering Department of the company of the authors. The concept of global factor of safety (FOS) acc. to the German Codes (e.g. DIN 4084) was applied throughout the project from the same beginning (preliminary designs in 2004) until the last adaptations and changes under running execution in 2009, although in the meantime the Codes had changed to partial factors of safety.

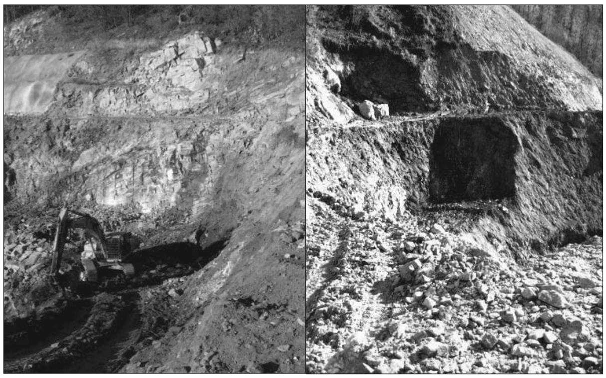

Figure 5. Examples of the enormous inhomogeneity of the local soils and rocks.

"Internal", "external" and "compound" stability modes were separately checked to keep conformity with the preliminary designs in 2004, although this differentiation is questionable; 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 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 factors of safety (FOS) were chosen according to the Bulgarian Standards with FOS > 1.3 for normal (static) conditions. In Figure 6 a typical Bishop circle analysis is shown (for the internal stability only, say the failure surface crosses exclusively the reinforced zone).

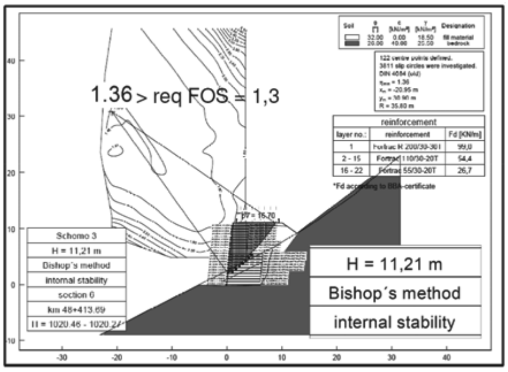

Figure 6. Typical example of stability analysis according to Bishop (only "internal" shown).

A specific issue was the seismic analysis; the region is 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.

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

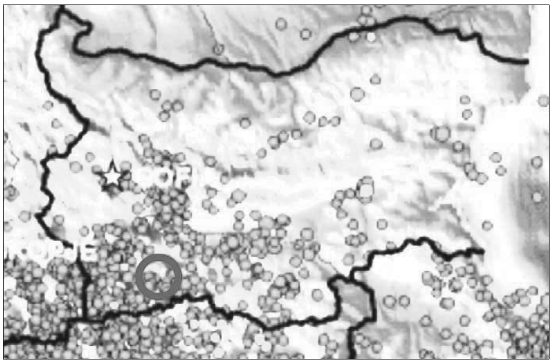

Figure 7. Seismic activities in Bulgaria, the project position is marked.

$$F_{seismic} = 1.30 \,.\, R_{response} \,.\, k_h \,.\, (\text{permanent loads} + 0.50 \,.\, \text{traffic loads}) \qquad (1)$$

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 GRS-walls under seismic impact.

Note that for seismic analyses the Bulgarian codes (CDBSSR 1987, CDRW 1986, SGDSR 1987) ask for a FOS > 1.1, for more details and previous "seismic" projects see e.g. Jossifowa & Alexiew (2002).

One specific issue more in the Bulgarian codes 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, 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 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 optimal 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 (among others; see the description of criteria, goals and optimized solution in Chapter 1). The success is based on the one hand on the advantages and flexibility of geosynthetic solutions in geotechnical engineering in terms of easy and quick construction process and adaptation and on the other hand on the excellent co-operation of all participants: Investor, Owner, 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 Balkan region during the last years.

7. ACKNOWLEDGEMENTS

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