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GEO12-FW-013 - High Geogrid-reinforced Walls with a Flexible Stone-filled Facing in a Mountainous Seismic Region

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ABSTRACT
In the Rhodope Mountain in the south of Bulgaria the route of a national road had to be completely changed due to the construction of a new dam. The new stretch of 11 km crosses mountainous terrain characterized by very steep irregular slopes, varying geological conditions and seismic activity: a challenge from the point of view of environment, geology, seismic resistance, costs, technology and time schedule.
The final optimized solution includes twenty walls from geogrid-reinforced soil (GRS) with a face inclination of 10v:1h and heights of up to 20 m without any berms. These were chosen - among other reasons - due to their high robustness against seismic impact. A special type of thin stone-filled wall facing provided a range of advantages.
The project environment, construction problems and typical solutions are explained, as well as design and calculation philosophy and methods, with typical cross-sections and materials illustrating the specific points. Some important construction related issues and experiences are also reported.

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 construction of a new dam on the River Vacha (Tzankov Kamak Hydropower System). The old road built some decades ago in a "usual way" along the river, had to be moved from the river valley to the hills by up to some hundred meters. The new stretch of Road III-868 has a length of 11 km (Figure 1). Figure 2 gives an overview of the mountainous terrain, the position of the old road in the valley and of the new road uphill.

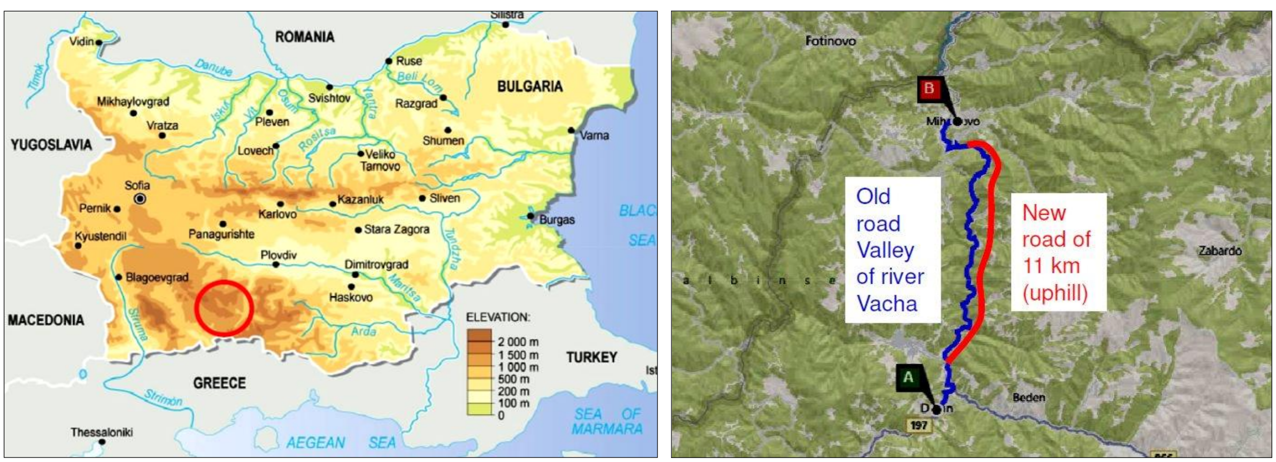


Figure 1. General project location (left); old route of Road III-868 in the valley of River Vacha and new uphill route through the mountains (right).

The mountainous terrain is characterized by complex topography (very steep irregular slopes, Figure 2), varying geological and hydrological conditions, instability tendencies in some places and limited 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 (nearly vertical) without any berms, which is quite unique. The GRS-structures were chosen (besides other known advantages) due to their excellent adaptation to the environment and their high ductility resulting in excellent 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 rock material and to allow a flexible construction schedule. 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 the additional advantages of geosynthetic solutions.

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

2. GENERAL CONCEPTS AND PHILOSOPHY: MAIN POINTS

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 author. 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 required 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 (to the right in Figure 3) and expansion down the slope as well (to the left in Figure 3).

B. To optimize 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).

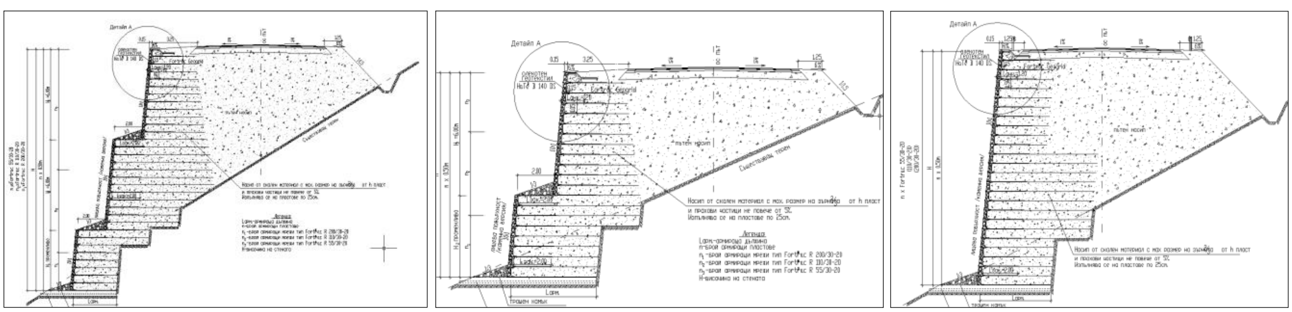


Figure 3. Concepts for typical cross-sections: front (facing) inclination always 10v:1h, but different number of berms.

C. The final stability analyses and design of the GRS-walls were to be completed after the commencement of the construction of the twenty walls along the new route; (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 therefore founded on the basic concepts and on the typical cross-sections in Figure 3 (these were indicative only, being based on preliminary stability analyses); it was assumed that these would not be the final solutions. The reason for this philosophy was the uncertainty in the actual site specific geology and topography along the 11 km of road; this was due to the extremely difficult access causing the preliminary surveys and site investigation to be relatively modest.

D. The facing was an important issue. After checking different options the “Muralex® Stone” facing system was chosen. The concept of this system is based on the principle of a “hanging facade” added and connected at a later construction stage to the “real” bearing geogrid structure (Figure 4).

The system leads to important advantages:
- the geogrid elements are hidden and therefore protected against UV, impact, fire and vandalism;
- possible wall deformations during construction occur <u>before</u> the facing installation – so the facing starts its design life deformation-free;
- <u>ductile behavior of the facing under seismic impact</u> and generally under wall deformations of any type in the post-construction stage, because it is quite “independent” and flexible; there is no rigid connection to the “real” GRS (Figure 4);
- no special facing foundation is needed;
- a wide range of rock fill material could be used and it was known that appropriate crushed rock material (see “rock fill” in Figure 4) would be available on site due to cuts in rock slopes and tunnel excavation spoil.

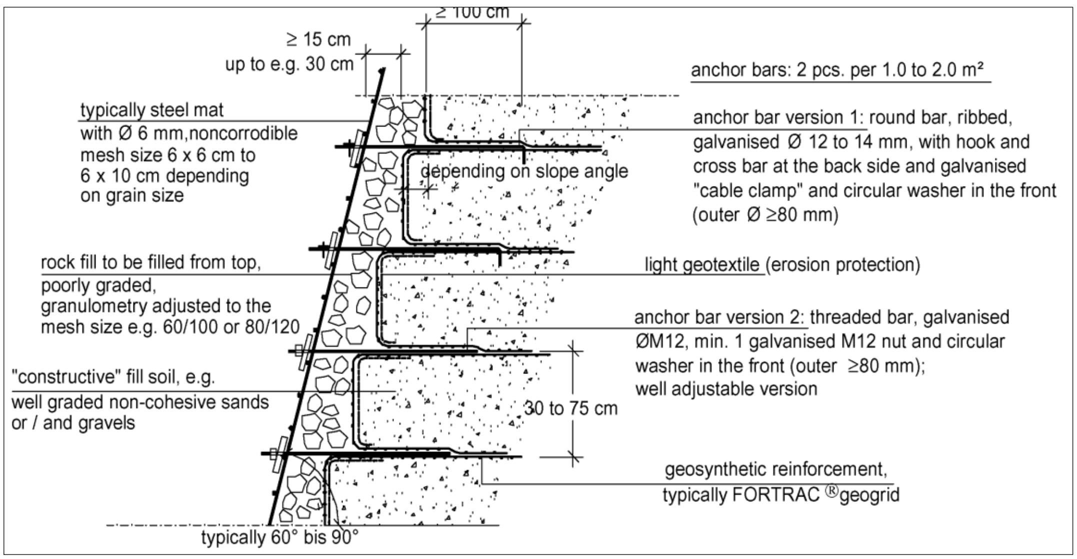


Figure 4. An example version of the facing system Muralex®.

3. GEOLOGICAL AND HYDROLOGICAL CONDITIONS

The geology along the new route varies significantly (Figure 5). The GRS-walls and their foundations can be founded on and embedded in (Figure 3) any local soil from silty or sandy clays with stone inclusions (slope talus) to a more or less monolithic rock. Due to brevity no details of these variations are explained herein. This inhomogeneity resulted in a low degree 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) of excavated local material from different cuts along the new route.

The geotechnical survey before beginning 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 stability analyses to be performed for the final solutions relatively conservative average fill parameters. Although it was possible to identify the local slope soils for every particular wall in a much more precise way, a similar conservative philosophy was adopted 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-bearing veins or strata were known before the beginning of construction. Nevertheless for all walls water drainage blankets were implemented at the wall base (but not in the contact zone to the in-situ material).

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 Sliding Blocks Method (similar to the method of Janbu, but considering the

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

shear resistance between the blocks). All analyses were performed in the Engineering Department of the company of the author.

The concept of global factor of safety (FOS) was applied throughout the project from the beginning (preliminary designs in 2004, see Chapter 2) until the last adaptations and changes under construction in 2009, although in the meantime the German design concepts had changed to partial factors of safety. All analyses considered the “internal” (failure planes crossing only the geogrid-reinforced zone), “external” (failure planes not crossing any reinforcement) and “compound” stability (failure planes crossing 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 a failure plane of whatever type and shape it is. For more details see Alexiew (2004 & 2005).

It can be noted that in the meantime in the new issue of the German recommendations, EBGEO (2010), the distinction between internal-external-compound was eliminated, as well as 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 their inherent flexibility to assist ease of 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 (by comparison German ones asked for a FOS > 1.4). In Figure 6 typical Bishop analyses are displayed.

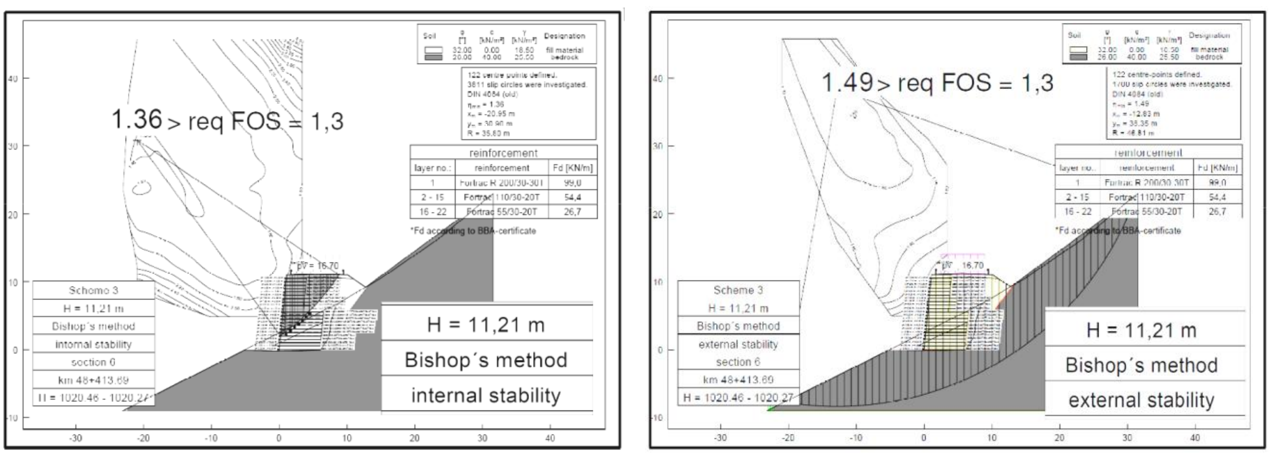


Figure 6. Typical examples of stability analyses according to Bishop (“internal” to the left, “external” to the right).

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 according to Richter. In agreement with the Investor and the Consultants the Bulgarian concepts for seismic design from 1980 were adopted with small modifications during the period of analysis (CDBSSR 1987, CDRW 1986, SGDSR 1987).

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

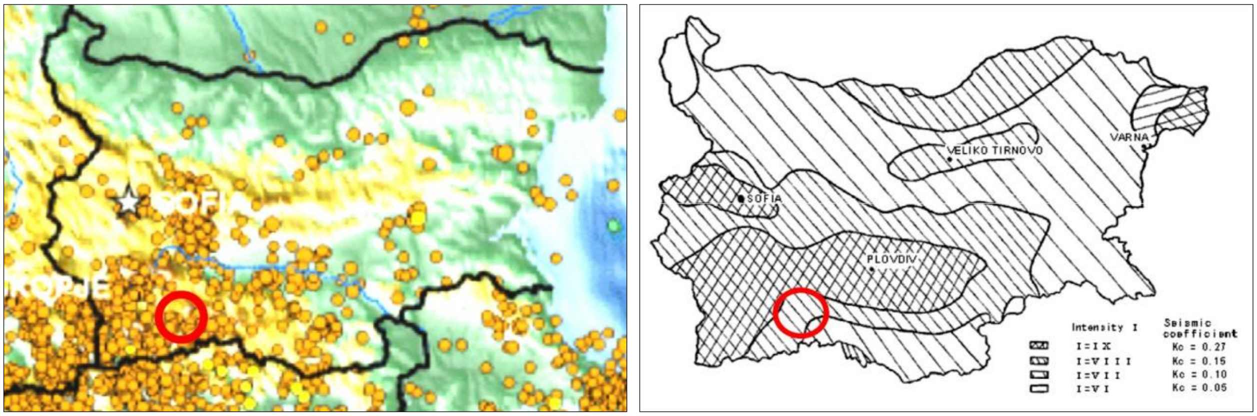


Figure 7. Seismic activities in Bulgaria (left) and zones with the intensities (magnitudes) according to Richter (right); the project position is marked.

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

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

Herein:

$R_{response}$, - : 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 case

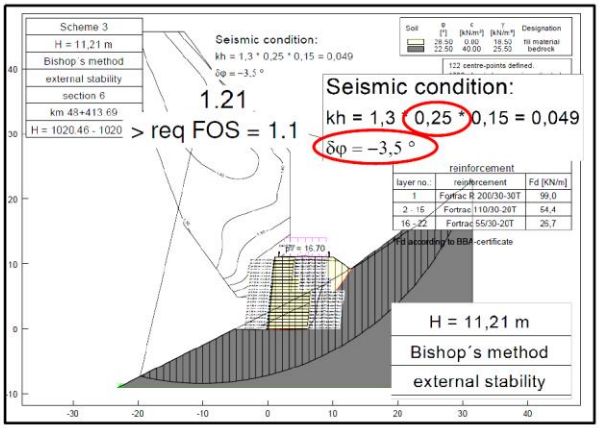
$R_{response}$ has higher values e.g. up to 0.40 for rigid (brittle, e.g. masonry, concrete) structures and lower values e.g. 0.25 for ductile structures like earth dams and embankments. It therefore seems logical and conclusive that earth systems reinforced by flexible geogrids should be at least as ductile and able to dissipate seismic energy and 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 Jossifowa and Alexiew (2002).
One additional specific issue in the Bulgarian codes used for the design is the reduction of the angle of internal friction acc. to Eq.2 depending on the intensity of earthquake:

$$\varphi_{characteristic,\ seism} = \varphi_{characteristic,\ static} - \Delta\varphi \quad [2]$$

Herein:

$$\Delta\varphi = \Delta\varphi\ (\text{magnitude according to Richter}) \quad [3]$$

For the project herein with VII according to Richter $\Delta\varphi$ = 3.5°
In Figure 8 a typical seismic Bishop analysis is shown. The reduction $\Delta\varphi$ mentioned above is marked.
Because the software used (GGU Stability by Civil Serve) does not include a calculation conform to Equation 1 but considers only directly k_h , the latter had to be modified "by hand" before the input as can be seen in Figure 8, upper part. The coefficient of response $R_{response}$ = 0.25 is marked as well. Also shown are the "static" and "seismic" soil parameters; note the different "seismic" φ already reduced by 3.5°.



„static“ soil parameters

Soil	φ [°]	c [kN/m²]	γ [kN/m³]	Designation
	32.00	0.00	18.50	fill material
	26.00	40.00	25.50	bedrock

„seismic“ soil parameters

Soil	φ [°]	c [kN/m²]	γ [kN/m³]	Designation
	28.50	0.00	18.50	fill material
	22.50	40.00	25.50	bedrock

Figure 8. Seismic external stability analysis for the cross-section in Figure 6 (left); and assumed soil parameters right.

5. CONSTRUCTION, PROBLEMS, SOLUTIONS, EXPERIENCE

Construction started in summer 2007, the new Road III-868 from Devin to Mihalkovo was handed over for traffic in time in summer 2010. Bearing in mind the 11 km length, one tunnel, twenty GRS-walls with a total length of 2 km and the very difficult terrain and access for any activity three years is a relatively short period.

The first problems arose soon after commencement: the topography deviated sometimes significantly from the “official” one assumed during planning. The real terrain was sometimes up to one meter higher or lower than it should have been, and the actual slope inclination often steeper. Step by step many of the cross-sections with walls had to be re-designed in terms of geometry and consequently in terms of reinforcement. At the end of the day all GRS-walls, even the highest with 20 m height became “bermless” like the last scheme to the right in Figure 3, which is quite unique.

The “bermless” solution offers a significant advantage: the base width of the generally trapezoidal cross-sections becomes minimal for a given constant position and width of the road on top. On the one hand this helped to avoid deep cuts into the hillside, on the other hand it avoids an expansion of the trapezoid beyond the steep slope line (to the left in Figure 3).

In some cases the geology deviated significantly from the assumptions; this again resulted in re-design. 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 face of the wall.

In Figures 9 and 10 typical construction stages and details are depicted. Figure 11 shows two high walls: the first one still under construction but with completed culvert, the second one completed just before handing over for operation.

Figure 9. From left to right: wall base with drainage blankets, top view of stone-filled facing used, construction stages (formwork, geogrids, facing).

Figure 10. Pre-cut folded flexible geogrids waiting for installation, geotextile wick drain from rolled non-woven at the back of wall, culvert on geogrid-soil cushion.

Figure 11. Front view of a GRS-wall before reaching the final height but with partially installed Muralex^{R} facing and completed culvert (left), top view of a completed wall (right).

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, construction, re-design during the construction, time schedule and costs. It crosses a terrain with complex 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.

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 (i.e. almost two years) under traffic, the GRS-walls continue to demonstrate an excellent behavior both in terms of stability and low deformability.

This transportation project is may be one of the most distinctive in the region during recent years.

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