PERMANENTLY STABILIZING A CREEPING SOIL SLOPE BY A FLEXIBLE SLOPE STABILIZATION SYSTEM

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ABSTRACT: The alignment of a new highway in the North of Greece required several massive cuts in soil slopes. Mainly due to creep movements within the superficial layer of a cut soil slope, the shotcrete facing reached its limitations and failed. The friction forces as a result of interaction between shotcrete facing and soil surface caused an overstressing of the stiff facing and finally its collapse. The shotcrete was removed and replaced by a flexible slope stabilization system consisting of a high-tensile steel wire mesh cover in combination with an adequate nailing. Flexible slope stabilization systems are widely used to stabilize soil and rock slopes. They are economical and a good alternative solution to stiff measures with shotcrete or massive structures with the possibility of revegetating stabilized slopes. Special concepts have been developed for the dimensioning of flexible slope stabilization systems considering superficial instabilities. Numerous implemented cases in soil as well as in rock with and without vegetated faces confirm that these measures are suitable for practical application.

Keywords: landslide, cut slope, flexible slope stabilization, highway

INTRODUCTION

A modern closed motorway 680 kilometres long over the greatest part of its length following a new alignment and running across Epirus and Northern Greece from Igoumenitsa to Evros, the Egnatia Motorway is one of the largest road construction projects in Europe. Nine major vertical axes connect the motorway with Albania, Macedonia, Bulgaria and Turkey. Furthermore, 5 ports and 6 airports service the road. The Egnatia Motorway as the modern reincarnation of the great Roman highway was designed to the specifications of the Trans-European road network.

In the area of Metsovo / Peristeri, a section of the Egnatia Motorway was constructed but not finished in 1992. Thereby, several natural slopes needed to be cut and were stabilized with soil nailing in combination with a shotcrete facing. This was a tremendous natural impact without considering natural aspects.

Figure 1. Egnatia Motorway illustrated by the red line, location of the project in the area of Metsovo, Peristeri (red dot).

Seven years after cutting numerous natural slopes and stabilizing with soil nailing in combination with a shotcrete facing, EGNATIA ODOS A.E. worked out a proposal to remove the partly failed and unnatural looking shotcrete coverage in regard to

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visual aspects and static requirements. The main goal was to renaturate and successfully stabilize slope cuttings in the area of Metsovo / Peristeri. A cost effective and reliable solution for greening and recultivation with local plants, to obtain a natural state and prevent the slopes from further erosion and any instabilities, was demanded. Finally, one specific section was replaced by a flexible slope stabilization system consisting of a high-tensile steel wire mesh in combination with a nailing to date.

PROJECT

The renaturated slope cutting is situated near Peristeri, Greece, above a tunnel open pit constructed on an altitude of about 720 m a.s.l. (location A) The inclination of the stabilized 420 m long slope with a height of 40 m in the entrance area as well as 18 m above the covered tunnel amounts to 40 – 60 degrees.

The climatical conditions are comparable with the inner-alpine dry zones of mountain and subalpine altitudes. The annual precipitation amounts to approximately 920 mm. The seasonal distribution of precipitation is not uniform, longer dry periods in summer and autumn are changing with rainfall-periods in winter. The project area is exposed to the north, the incidence of sun-rays is moderate.

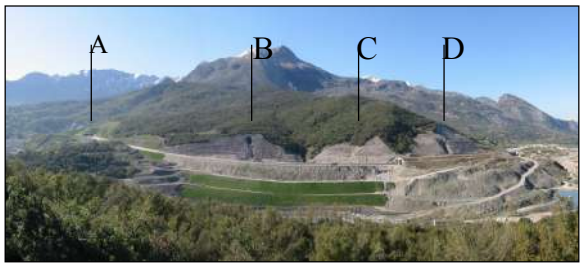

Figure 2. Overview looking south to Egnatia

The project area is surrounded by undisturbed slopes covered by a continuous vegetation layer established during along process over some centuries. This ecological system is in a labile balance and therefore reacts very sensitive to man made cuttings and impacts.

GEOLOGY

The area of interest is location A (ch. 4+511 – ch. 4+616) where sandstones are prevalent.

Geologically, the area is structured by flysch of Pindos zone. Tectonically, the flysch is intensely folded and sheared. On the surface, the flysch is weathered and shattered down to a 6 to 7 m depth. Seasonal perched water tables are developed in the surface loose and shattered flysch zone. The erosion caused by Metsovitiokos river at the base of the landslide plays an important role in the landslide of area A.

Failures were observed in embankment fill, the weathered part of the flysch and the deeper layers within the flysch.

The failures observed can be separated into creep and landslides. The biggest part of A area is an active deep landslide with local creep. Creep causes instability at shallow depth.

Figure 3. Shotcrete facing at location D

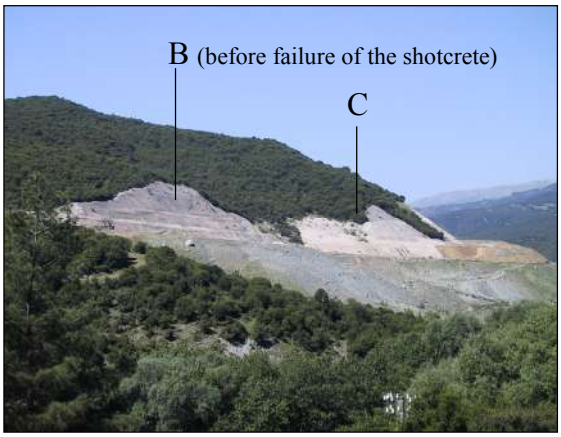

Figure 4. Neighbouring shotcrete slopes

SHOTCRETE FACING WITH NAILING

In the surveyed section, the slope surfaces were completely covered with a shotcrete layer of varying thickness (5 – 25 cm) and inhomogenous quality. The overall stability of the slope was guaranteed by steel bar anchors of type GEWI D = 28 mm with 12 m length, applied in a grid of approximately 3.0 x 3.0 m. In steeper slope sections, the shotcrete was generally reinforced by a steel mesh with an opening size of 100 mm and wire diameter of 3 – 4 mm, connected to the anchor heads with quadratic spherical steel plates.

In flater areas, the shotcrete was reinforced with steel fibres approx. 50 mm long.

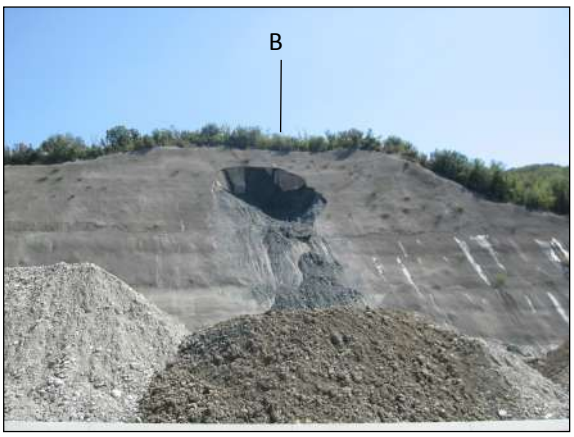

Figure 5. Failed shotcrete in the Flysch zone

Figure 6. Superficial cracked shotcrete

In the periode between 1992 and 1999, no major problems concerning the overall stability were observed, exluding two small and shallow landslide areas resulting in a complete destruction of the shotcrete coverage.

In general, the applied shotcrete is of poor quality. Evidently, the fraction of cement added was partially too low visible due to the darker colour of the shotcrete. In those areas, up to 20 – 25 mm of the top layer the shotcrete facing is strongly weathered and mellow with the result of cracks within the shotcrete facing. The areas lighter emerging are of better quality less weathered and in better condition. Next to the bad quality of the shotcrete facing, the main problem was the erosion of the subsoil just behind the shotcrete due to insufficient or not adaquate drainage measures, respectively. Locally, there was no contact anymore between the subsoil surface and the shotcrete facing.

Figure 7. Thin shotcrete cover of Flysch material

APPLICATION OF THE FLEXIBLE SLOPE STABILIZATION SYSTEM TECCO®

In a first step, the shotcrete facing was completely removed. Instead of a cover layer impermeable with a stiff behaviour, a flexible slope stabilization system was installed consisting of the high-tensile steel wire mesh TECCO® in combination with special system spike plates adapted to the high-performance steel wire mesh in its size and bending resistance based on numerous puncturing and bending tests. GEWI D = 28 mm with a length of 8 m and in a pattern of 3.0 m x 3.0 m are used for the nailing of the slope whereas the mesh is connected to each nail head by special spike plates. The forces are then transferred from the mesh over the plate into the anchors.

Rock and soil anchors offer the possibility to stabilize steep slopes comprising of soil or rock. When the slope inclination is restricted to 50 – 60 degrees for soil slopes and to 70 degrees for rock slopes, the anchoring can be combined with a complete slope protection system including a tensed

static system for surface stabilization and a vegetation layer to prevent the slope surface from erosion caused by heavy rainfalls, snow, water outflows or even wind.

Figure 8. After installation

Figure 9. After one year

The use of high-tensile steel wire meshes as a flexible surface stabilization measure has proved its suitability in numerous cases and is often an alternative to massive concrete constructions. This success of this technology is decisively influenced by numerous laboratory and field tests as well as long-term experiences and practical applications worldwide. The open structure of the meshes permits thereby to realize a full-surface vegetation face.

Furthermore, the open structure has the effect that no water pressure can be built up. Of course, to avoid any erosion problems, the surface needs to be revegetated and if there is noteworthy hillside water existing, corresponding drainage measures are required as well.

In standard layout, the high-tensile steel wire mesh TECCO® for surface stabilization is made from a high-tensile steel wire of a tensile strength of the individual wire of at least 1,770 N/mm2 of 3 mm diameter which has an aluminium-zinc coating (so-called GEOBRUGG SUPERCOATING®) for protection against corrosion. The diamond-shaped meshes measuring 83 mm · 143 mm are produced by single twisting. The TECCO® steel wire mesh provides a tensile strength of 150 kN/m. Thanks to its three-dimensional structure, the mesh clings to the soil in an ideal manner and, additionally, serves to optimally secure subsequent sprayed-on greening.

Special diamond-shaped system spike plates matching the TECCO® mesh serve to fix the mesh to soil or rock nails. By tightly pressing and if possible slightly impressing the spike plates in the ground to be stabilized, the mesh is tensioned in the best possible manner.

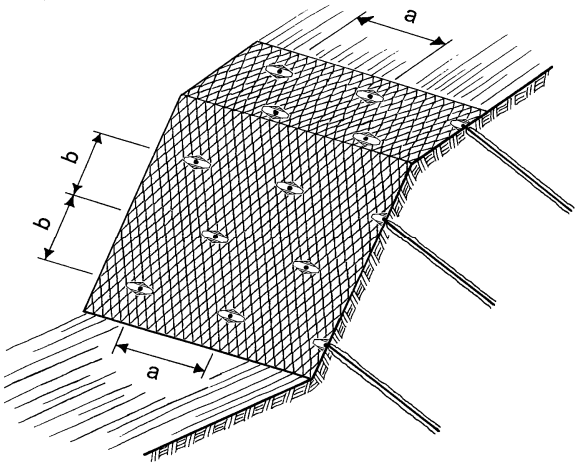

Figure 10. general nail arrangement

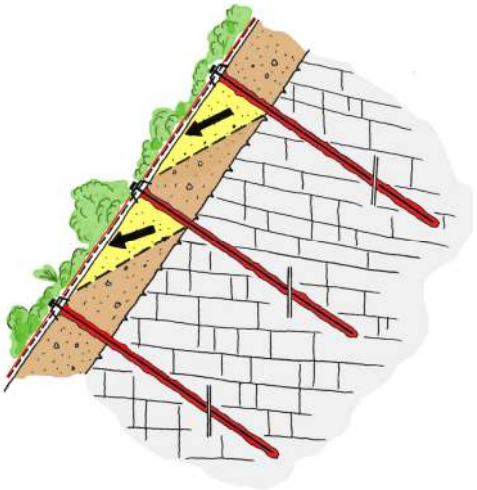

Figure 11. Local instabilities between single nails

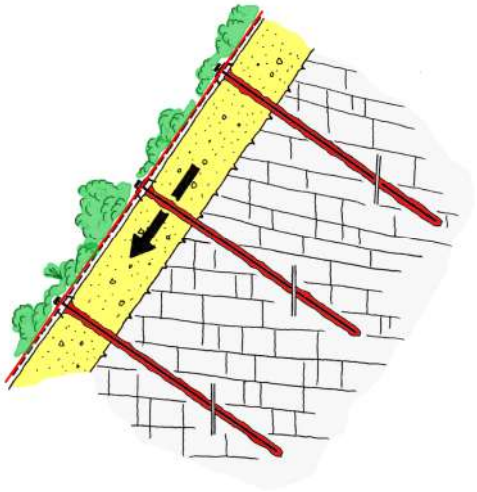

Figure 12. Slope-parallel instabilities

The nailing was adapted to the static requirements based on the investigation of the overall stability considering sliding mechanisms with deeper-seated sliding surfaces. In addition to this, one needed to check if the flexible slope stabilization system consisting of the mesh cover and corresponding system spike plates in combination with the existing nailing can withstand all stresses as a result of superficial instabilities. Based on the RUVOLUM® dimensioning concept world-wide published and accepted, local instabilies between the single nails as well as superficial slope-parallel instabilities as shown in figure 11 and 12 had to be investigated. Thereby, all proofs of bearing safety could be fulfilled.

REVEGETATION

The application of a vegetation layer is limited by the soil or rock properties and is also dependent on a certain amount of water supplied from rainfalls and groundwater following the slope layers. Furthermore the consideration of the regional micro climate is a very important factor for the selection of the seed to be applied.

The steeper the slope cuttings are the harder it is to raise up a durable vegetation. The system has to be flexible to be able to slightly move under frost effects. This is not possible with a shotcrete cover. Additionally water exist at the surface of the slope should be taken spreaded over the full surface and be guided back to the natural circular cause.

Based on the underground characteristic and the climate conditions, the organic mass has to be applied with high water restoring capacity. Because of the slope steepness, the erosion stability during strong rainfalls and frost is one of the most important points.

The seed mixture has to be specially adapted to the local conditions for getting a succesful regreening. Aim of the first step is a fast surface covering greening, which is so planned that the used species can develop, during different steps of evolution, to a locally adapted dry biosphere.

Since this solution is based on the complete removal of the shotcrete coverage, a proper connection of the vegetation layer to the natural slope surface is guaranteed. This fact is very important for a continuous and sufficient water supply of the vegetation and also for the most reliable long term solution.

Figure 13. High-tensile steel wire mesh TECCO®

Figure 14. High-tensile steel wire mesh TECCO®

In steep slopes featuring fine-grained, non-cohesive loose rock or severely weathered rock there is a danger of erosion. Such fine material can be washed through the TECCO® mesh and flushed away underneath it. Hereby channels and hollows may be formed under the mesh.

The cause is emerging hillside, layer or fissure water, or in otherwise dry slopes also drain water from heavy rainfalls. Emerging hillside, layer or fissure water must generally be captured and drained. Permanent water outflows will always lead to problems and must be coped with before the slope stabilization measure is started, since corrective action is hardly possible afterwards. Particular care must also be taken that no larger quantities of surface water from above flow over the slopes. If appropriate, drain channels must be provided above the edge of the slope so that the water is drained to the side in a controlled manner.

CONCLUSION

Two years from installation with dry and hot summers and cold, wet winter weather the slope is establishing a continuous vegetation cover itself, even so it is built into flysch mainly consisting of sand and siltstones. After an initial grass greening the local vegetation is slowly creeping back onto the stabilised cut slope with bushes and shrubs. No additional irrigation or revegetation has been carried out during this period. The visual impact of the slope as described is much more appealing compared to the big grey patches formed by the older shotcrete slopes.

Designed to be maintenance free, the slope will further grow into the surrounding landscape and contribute to a safe and economical operation of Egnatia Highway. Numerous applications have proven that the fully designable TECCO® system can ideally combine slope stabilization with revegetation measures tailored to the actual climatic and environmental conditions.

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