



REPLACEMENT OF A FAILED SHOTCRETE FACING BY A FLEXIBLE SLOPE STABILISATION SYSTEM

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Abstract. The alignment of a new highway from Igoumenitsa to Evros in the north of Greece required several massive cuts in soil slopes. Mainly due to erosion and creep movements within the superficial layer of a cut soil slope, the shotcrete facing failed. The friction forces as a result of interaction between shotcrete facing and soil surface caused an overstraining of the stiff facing, and finally its collapse. The shotcrete was removed and replaced by a flexible slope stabilisation system consisting of a high-tensile steel wire mesh cover in combination with an adequate nailing. Flexible slope stabilisation 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 reintroducing vegetation. Special concepts have been developed for the dimensioning of flexible slope stabilisation systems considering superficial instabilities. Numerous implemented cases in soil as well as in rock with and without vegetated faces confirmed that these measures were suitable for practical application.

Key words: landslides, facing, flexible slope stabilisation system, TECCO, slope failure, reintroducing vegetation.

Abstrakt. Przeprowadzenie nowej autostrady z Igoumenitsa do Evros w północnej Grecji wymagało szeregu poważnych wcięć w stoki chronione powierzchniowym zacementowaniem. Niestety, zacementowanie to nie wytrzymało wkopów w powierzchniowe warstwy gleby, osłabione już uprzednio erozją i zsuwami. Spotęgowane siły tarcia między strefą cementową i powierzchnią gleby doprowadziły do nadmiernych naprężeń w usztywnionej strefie, która w rezultacie rozpadła się. W związku z tym usunięto pokrywę cementową i zastąpiono ją elastycznym systemem stabilizacyjnym, składającym się z bardzo wytrzymałej siatki stalowej, odpowiednio przyszpilonej do zboczy. Elastyczny system stabilizacyjny jest powszechnie stosowany do wzmacniania zboczy zbudowanych zarówno z gleby, jak i ze skał. Umocnienia te są bardzo ekonomiczne i stanowią alternatywę dla umocnień cementowych, a także dla masywnych struktur. Jednocześnie umożliwiają ponowne wprowadzanie roślinności. Wypracowano również nowe rozwiązania, pozwalające dopasowywać rozmiary siatki do zagrożeń powierzchniowych.

Słowa kluczowe: osuwiska, ogrodzenie zabezpieczające, elastyczny system stabilizacji zboczy, TECCO, uszkodzenie zbocza, rekultywacja poprzez zasiew.

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, five ports and six airports service the road.

The Egnatia Motorway as a modern reincarnation of the great Roman highway was designed to the specifications of the Trans-European road network.

In the Metsovo/Peristeri area, a section of the Egnatia Motorway was constructed but not finished by 1992. Thereby, several natural slopes needed to be cut and were stabilised with soil nailing in combination with a shotcrete facing. This was

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a tremendous natural impact without considering specific aspects of the nature.

The company EGNATIA ODOS A.E. was established in September 1995 as a product of discussions between the European Community and the Greek Government to advance the implementation of the 2nd Community Support.

Programme and management of the project put a special emphasis on the minimisation of the project's impact on the natural and man-made environment. The Egnatia Motorway is one of the first large-scale public works to apply a system of environmental management, that is, a method of organising and implementing environmental protection measures during the design, construction and operation stages of the project.

Seven years after cutting numerous natural slopes and stabilising them 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 because of visual aspects and static requirements. The main goal was to return to nature and successfully stabilises slope cuttings in the Metsovo/Peristeri area. A cost effective and reliable solution was demanded for greening and recultivation with local plants, to obtain a natural status and prevent the slopes from further erosion and other instability. Finally, only one specific section was replaced to-date by a flexible slope stabilisation system consisting of a high-tensile steel wire mesh in combination with nailing.

THE PROJECT

The recultivated slope cutting is situated near Peristeri, Greece, above a tunnel open pit constructed at an altitude of about 720 m a.s.l. (location A, Fig. 1). The inclination of the stabilised 420 m long slope, 40 m high at the entrance area as well as 18 m above the covered tunnel, amounts to 40–60°.

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 rain-fall-periods in winter. The project area is exposed to the north; the incidence of sunrays is moderate.

Undisturbed slopes covered by a continuous vegetation layer, established during long process of over several centuries, surround the project area. This ecological system is in a labile balance and, therefore, reacts very sensitively to man made cuttings and impacts.

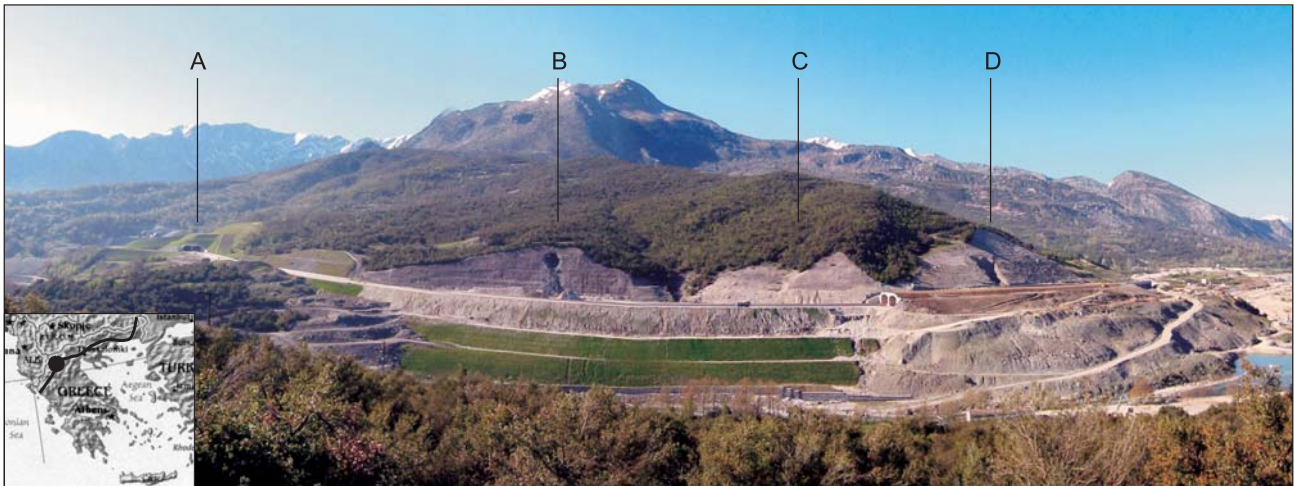


Fig. 1. Project overview looking south of Egnatia

GEOLOGY

The area of interest is the location A (Fig. 1) (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 of the loose and shattered flysch zone. The erosion caused by Metso-

vitiokos River at the base of the landslide plays an important role in the landslides of area A.

Failures were observed in the embankment fill, the weathered part of the flysch, and the deeper layers of the flysch. The failures can be separated into creeps and landslides. The largest part of the A area is an active deep landslide with a local creep. Creep causes instability at shallow depth (Figs. 2–4).

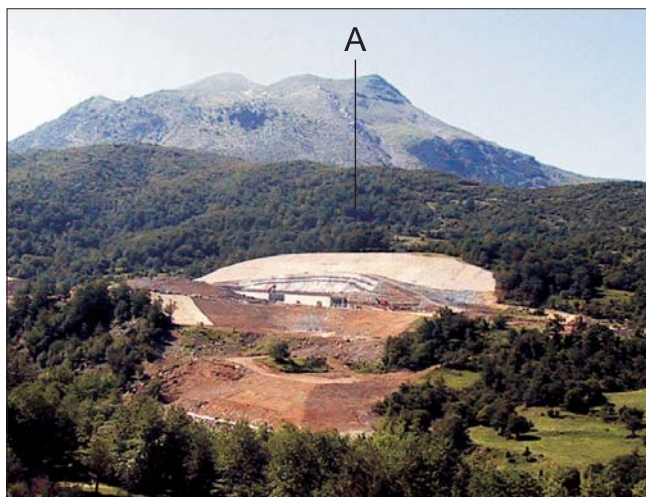


Fig. 2. Slope after TECCO installation

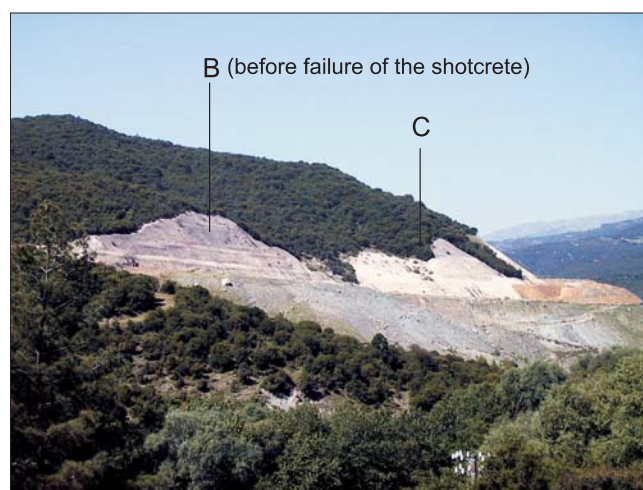


Fig. 3. Neighbouring shotcrete slopes

SHOTCRETE FACES WITH NAILING

In the surveyed section, the slope surfaces were completely covered with a shotcrete layer of varying thickness (5–25 cm) and of inhomogeneous quality. The overall stability of the slope was guaranteed by steel bar anchors of GEWI D = 28 mm type with 12 m length, applied in a grid of approximately 3.0×3.0 m. In the steeper slope sections, the shotcrete was generally reinforced by a steel mesh with 100 mm size of the openings, and wire diameter of 3–4 mm, connected to the anchor heads with quadratic spherical steel plates. In flatter areas, the shotcrete was reinforced with steel fibres, approx. 50 mm long.

Overlaying the anchor grid, a grid of 5" drainage plastic tubes was installed. Since there was no top drainage existing and most of the drainage tubes did obviously not work, the shotcrete was considered to be partly undermined by regular and extensive slope water outflows.

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

In general, the applied shotcrete was of poor quality. Evidently, the added fraction of cement was partially too poorly visible because of the darker shotcrete colour. In those areas, up to 20–25 mm of the top layer of the shotcrete facing is strongly weathered and mellowed with the resulted cracks. The appearing lighter areas were 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 beneath the shotcrete, due to insufficient or not adequate drainage measures. Locally, there were no more contacts between the subsoil surface and the shotcrete facing.

APPLICATION OF THE FLEXIBLE SLOPE STABILISATION SYSTEM TECCO

As the first step, the shotcrete facing was completely removed. Instead of a stiff impermeable cover layer, a flexible slope stabilisation system was installed consisting of the high-tensile steel wire mesh TECCO in combination with special system spike plates (Fig. 5) adapted to the high-performance steel wire mesh (Fig. 6). Its size and bending resistance have been based on numerous puncturing and bending tests. The GEWI D = 28 mm, with a length of 8 m and in a 3.0×3.0 m pattern, were used for the slope nailing, whereas the mesh was connected to each nail head by special spike plates (Fig. 7). The forces were then transferred from the mesh, over the plates into the anchors (Rorem, Flum, 2003; Rügger, Flum, 2001).

Rock and soil anchors offer the possibility to stabilise steep slopes comprising of soil or rock. When the slope inclination is restricted to 50–60° for soil slopes, and to 70° for rock slopes, the anchoring can be combined with a complete slope protection system, including a tensed static system for surface stabilisation and a vegetation layer to prevent the slope surface from



Fig. 4. Shotcrete facing at location D



Fig. 5. TECCO system spike plate



Fig. 8. After the mesh installation



Fig. 6. High-tensile steel wire mesh TECCO



Fig. 9. After the mesh installation (one year later)

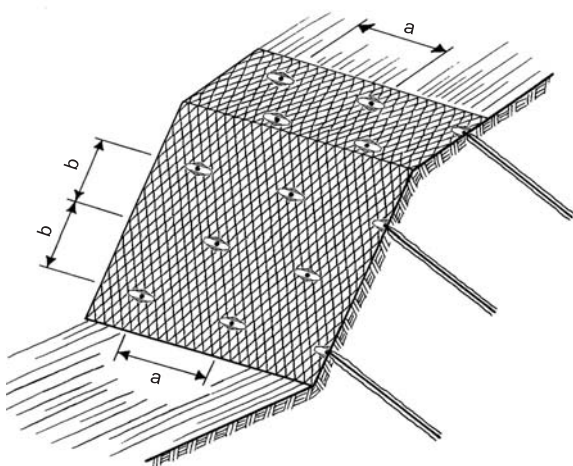


Fig. 7. General nail arrangement



Fig. 10. A detail view of the mesh installation

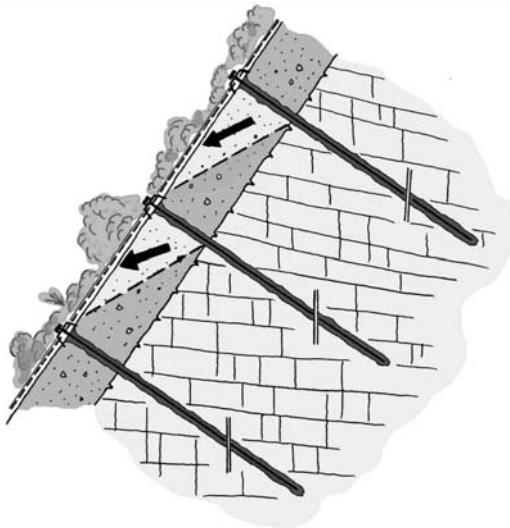


Fig. 11. Local instabilities between nails

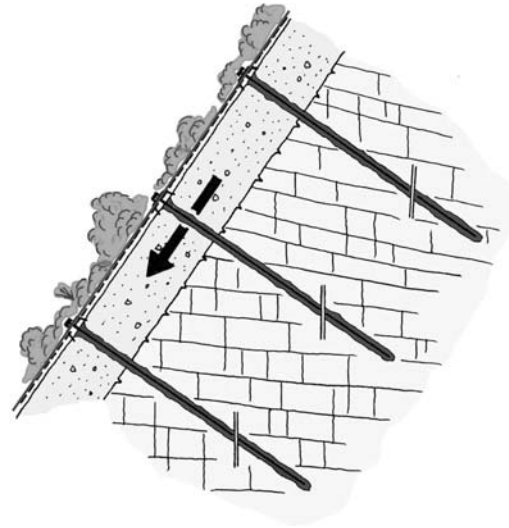


Fig. 12. Slope-parallel instabilities

erosion caused by heavy rainfalls, snow, water outflows or even wind (Figs. 8–10).

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

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

In a standard layout, the high-tensile steel wire mesh TECCO for surface stabilisation is made of a high-tensile steel wire, with the individual wire tensile strength of at least $1,770 \text{ N/mm}^2$. The wire is of 3 mm diameter, and has an aluminium-zinc coating (so-called GEOBRUGG SUPERCOATING) for protection against corrosion. The diamond-shaped meshes measuring $83 \times 143 \text{ mm}$ 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 stabilised ground, the mesh is tensioned in the best possible manner.

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

REINTRODUCING VEGETATION

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 microclimate 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 rise up 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 spread over the whole surface and be returned back in the natural circular way.

Based on the ground characteristic and the climate conditions, the organic mass has to be applied with a high water restoring capacity. Because of the slope steepness, the erosion stability during strong rainfalls and frost is one of the most important factors (Landslides..., 1996).

The seed mixture has to be specially adapted to the local conditions for getting a successful re-greening. The aim of the first step is a fast surface cover greening, planned that the used species can adopt, 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 with the natural slope surface is guaranteed. This fact is very important for a continuous and sufficient water supply for the vegetation and also for the most reliable long-term solution.

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

The causes could be the layer or fissure water emerging on hillside or heavy rainfalls water flowing on the otherwise dry slopes. The water emerging on hillside, must be generally captured and drained. Permanent water outflows will always lead to problems and must be coped with before the slope stabilisation measure started, since corrective action is hardly possible afterwards. Particular care must also be taken to ensure that no larger quantities of surface water from the 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 AND OUTLOOK

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

pared to the large 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 stabilisation with reintroducing vegetation measures tailored to the actual climatic and environmental conditions.

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