Prediction of Support for the Preliminary Design of the Anilio Tunnel (Egnatia Motorway)

By Gunter Riedmüller, Wulf Schubert, Arnold Steidl and Wolfgang Holzleitner

The Egnatia Motorway is one of Europe's most spectacular traffic projects. The alignment follows the Ancient Roman Via Egnatia through the mountainous area of northern Greece. After completion of the Egnatia Motorway a high capacity road will exist between Igoumenitsa at the Adriatic Sea and Thessaloniki at the Aegean Sea. The successive natural and man-made environments along the alignment are exceptionally diverse, both through the Pindos mountains of Epiros and Western Macedonia, and the plains of Central Macedonia and Thrace.

One of the key sections of the motorway is the Anilio Tunnel which will bypass the picturesque small town Metsovo located in the Pindos mountains (Figure 1). Initially the bypass was planned as an open section downhill of the village Anilio situated at the north-westerly exposed left slope of the Metsovo River. Due to active deep seated

Ingenieurgeologische Untersuchungen und Prognose der Stützmittel für die Vorplanung des Anilio-Tunnels

Für den Anilio-Tunnel, einem Schlüsselprojekt der Egnatia-Autobahn in NW Griechenland wurden ergänzende Erkundungen und Analysen durchgeführt. Die Tunneltrasse befindet sich in dem komplex aufgebauten Falten- und Deckenbau der Pindosdecke. Die Erkundungen umfassten geologische Geländekartierungen mit strukturgeologischen Analysen als besonderen Schwerpunkt, die geotechnische Definition von Gebirgstypen und geophysikalische Explorationen. Die Ergebnisse der Geländearbeit, kombiniert mit den Ergebnissen von Laboranalysen an Gesteinsproben, ermöglichten die Berechnung von Radialverschiebungen und der Tiefe plastischer Zonen. Beide Parameter bilden einen wesentlichen Input für die Erfassung von Stützmittelklassen.

Supplementary investigations and analyses were performed for the preliminary design of the Anilio tunnel which is one of the key projects of the Egnatia Motorway in NW Greece. The tunnel alignment is located in the complex fold-and thrust belt of the Pindos nappe. The investigations included geological field mapping with special emphasis on structural geological analyses, the geotechnical definition of rock mass types and geophysical surveys. The results from these field studies combined with the results from laboratory analyses of rock samples were used to calculate radial displacements and the depths of broken zones, both parameters being an essential input for the assessment of support classes.

Fig. 1 Location map.
Bild 1 *Lage des Projektgebiets.*

Fig. 2 Project area showing the unstable slope at Anilio village.
Bild 2 *Projektgebiet mit dem instabilen Hang beim Ort Anilio.*

Fig. 3 East portal of the Anilio Tunnel.

Bild 3 *Ostportal des Anilio-Tunnels.*

slope creep and sliding (Figure 2) a tunnel alternative which underpasses the mass movements was designed. The west portal of this tunnel will be connected with a viaduct which will bridge the Metsovo River. The east portal is located in a gentle slope with local superficial creeping and sliding. After successfully coping with geotechnical difficulties during construction of the pre-cut the tunnel excavation has recently started at this portal (Figure 3). The twin tube tunnel is planned to have a total length of 2 135 m, with a maximum overburden in the range of 240 m.

For the preliminary design of this tunnel additional engineering geological site investigations, mechanical laboratory testing and geomechanical analyses were performed. The objective of these geotechnical studies was the assessment of the geological architecture, the determination of geotechnical relevant key parameters as basis for the rock mass characterisation and the prediction of displacement magnitude and support class distribution along the tunnel route.

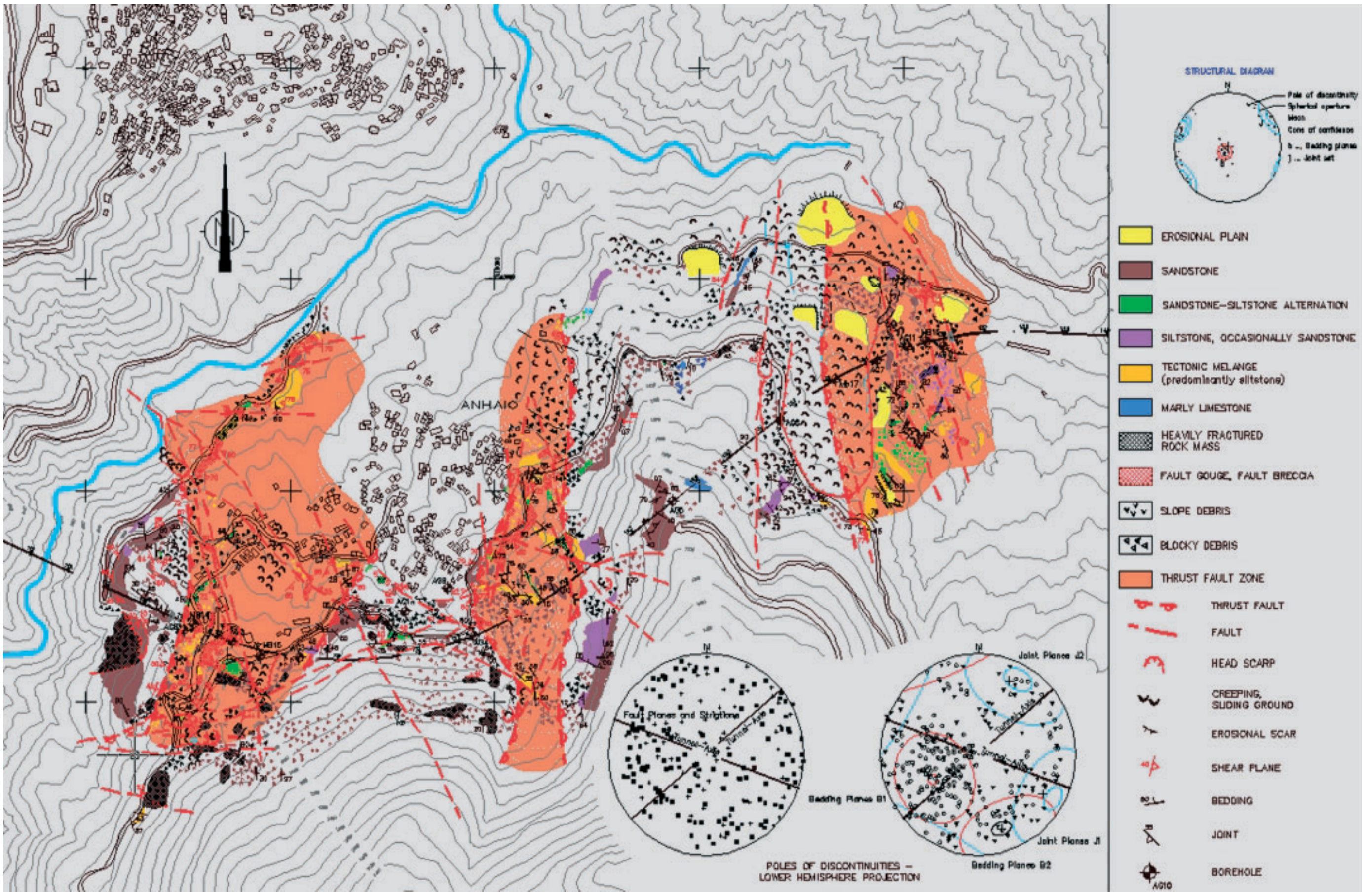
Regional geology

The tunnel alignment is located in the Pindos flysch nappe which consists of a flysch sequence of the early Tertiary period. The sediment series, reaching a thickness of several thousand meters, include an alternation of sandstone and siltstone with intercalations of claystone. The sequence is composed of three major sections: a wildflysch unit displaying large and irregularly sorted blocks resulting from subaquatic sliding forms the top, underlain by a thick sequence of greywacke intercalations in the central part. Grey to red marls, the so called "Red Flysch" form the base. (1).

The Pindos flysch nappe is part of a fold-and-thrust belt which thrusted over the miogeoclinal sediments of the West Hellenic nappe in the west and was in turn overthrusted by melange terranes associated with ophiolithe and olistostrome complexes in the east. The N-S trending west vergent fold-and-thrust belt system displays a rough symmetry of typical external thin-skinned fold and thrust nappes. The age of overthrust is early to middle Miocene. Younger high-angle faults are present throughout the belt.

Fig. 4 Geological map of the tunnel alignment.

Bild 4 *Geologische Karte der Tunneltrasse.*



Alignment geology

The complex geological environment of the tunnel alignment required a structural geological analysis by means of outcrop studies and mapping in scale 1 : 5 000 (Figure 4). The results revealed extreme heterogeneous rock mass conditions. Thick competent layers of sandstone with siltstone interlayers alternate with the "Red Flysch" sequence. This thinly to medium bedded sequence with interlayers of sandstone and siltstone is intensely folded and sheared. Disharmonic kink and chevron folds developed which die out at faults (Figures 5 and 6). Of great geotechnical importance is the development of block-in-matrix-rock (2, 3). The bimrock units are limited to the "Red Flysch" sequence. This heterogeneous mixture of competent sandstone blocks embedded in a weak matrix of fine-grained, mainly clayey gouge, was found with considerable thickness along thrust faults (Figure 7).

The thrust faults, which intersect the tunnel axis with obtuse angles, form a number of individual listric sheets, all dipping moderately towards east. It is assumed that, at depth, the thrust faults terminate at branch lines along a basal floor thrust (Figure 8).

The thrust sheets are segmented by generally NW- to WNW-trending tear faults. The lateral termination of fold hings against these high angle strike-slip faults was observed in the vicinity of the west portal. It becomes obvious by this field observation that the tear faults accommodate differential displacements along the thrusts (4).

The geological model as revealed by detailed geological field studies was confirmed by exploratory drilling and geophysical surveys at depth. The authors strongly emphasise that in particular complex geological environments, such as Alpine fold-and-thrust belts, require careful geological field mapping prior to any subsurface investigations (5).

Fig. 5 Typical disharmonic chevron folds developed in the "Red Flysch" sequence.
Bild 5 *Typische disharmonische Chevron Falten in der „Red Flysch"-Folge.*

Fig. 6 Disharmonic chevron folds in sandstone of the "Red Flysch" sequence. The folds die out at a thrust fault.
Bild 6 *Disharmonische Faltung im Sandstein der„Red Flysch"-Folge. Die Falten enden an einer Aufschiebung.*

Definition of rock mass types

Based on the results of site investigations 6 rock mass types and 1 soil type were defined. The definition of rock mass types (RMT) takes into account the physical condition of the rock mass following the soil and rock description suggested by ISRM (6).

- RMT 1: Medium to fine-grained, brownish-grey, mainly thickly to medium bedded sandstone, occasionally with interlayers of siltstone (mudstone). Strength of intact rock ranges from medium to very strong (UCS 37 to 116 MPa). Discontinuities are very widely to moderately spaced (200 to 6 000 mm). The persistence of joints range from very low to medium (< 1 to 10 m). Joint surfaces are mainly rough and plain (JRC 8 to 14). Bedding planes are rather smooth to rough and planar (JRC 4 to 8). Discontinuity surfaces are partly stained. Thin infillings and coatings of residual soil, silt and clay may occasionally occur. The rock mass is generally fresh to slightly weathered.
- RMT 2: The same as RMT 1 but heavily fractured and locally strongly weathered. The strength of intact rock is decreased.
- RMT 3: Sequence of grey to brownish-grey or red siltstone (mudstone) with occasional intercalations of sandstone. Bedding plane spacing ranges from thinly laminated (< 6 mm) to thinly bedded (60 to 200 mm). Bedding surfaces are mainly smooth and planar (JRC 2 to 6) with occasional clayey coatings. Joints have a very low persistence (< 1 m). Intact rock strength varies considerably (1 to 77 MPa).
- RMT 4: Brownish-grey or red siltstone - sandstone alternation. The characteristics of siltstone

Fig. 7 Bimrock developed along a thrust fault in "Red Flysch". Blocks of sandstone varying in size and shape are surrounded by clayey gouge.

Bild 7 *Bimrock-Bildung entlang einer Aufschiebung im „Red Flysch". Unterschiedlich große und geformte Blöcke werden von tonigen Kataklasiten umflossen.*

are similar to RMT 3. Sandstone interlayers are thinly bedded and more persistent.

- RMT 5: Tectonic block-in matrix rock consisting of mainly red siltstone - sandstone alternations ("Red Flysch"). The rocks are intensely sheared and folded. Competent blocks of sandstone and siltstone varying in size and shape occur in silty to clayey gouge matrix. Main characteristics are a heterogeneous, chaotic structure and very low strength properties of the matrix, larger blocks may be heavily fractured.
- RMT 6: Rock mass dominated by weak, clayey fault gouge, occasionally fault breccia and heavily fractured rocks, characterized by extremely low strength properties.
- RMT S (Engineering soil): The engineering soil includes non-compacted Quaternary sediments, slope debris and residual soil.

Definition of support classes

The definition of support classes which includes support quantities and round length, is adjusted to the anticipated behaviour of the rock mass during excavation. Rock mass types (physical condition of the rock mass) and rock mass behaviour correspond largely but not necessarily.

All descriptions below are based on the assumption of a sequential tunnel excavation subdivided into a top and bench heading.

Support class A

This support class is used for stable conditions. The stable rock mass allows round lengths of 2 to 3 m. Only local small discontinuity controlled failure is expected.

10 to 15 cm of wire mesh reinforced shotcrete in the top heading and 5 cm shotcrete without reinforcement in the bench are provided. Spot bolting with Swellex bolts in the crown prevents rapid loosening and detachment of single blocks.

Support class B

This support Class is used for blocky rock mass with overbreak potential. Rock mass failures are clearly controlled by discontinuities.

The round length is kept at 2 to 3 m. The support as selected for support class A is increased by one set of lattice girder per round, 10 cm shotcrete lining in the bench and grouted bolts in the top heading will prevent the development of overbreak.

Support class C

This support class is designed for weathered, loosened rock with low overburden (portal areas).

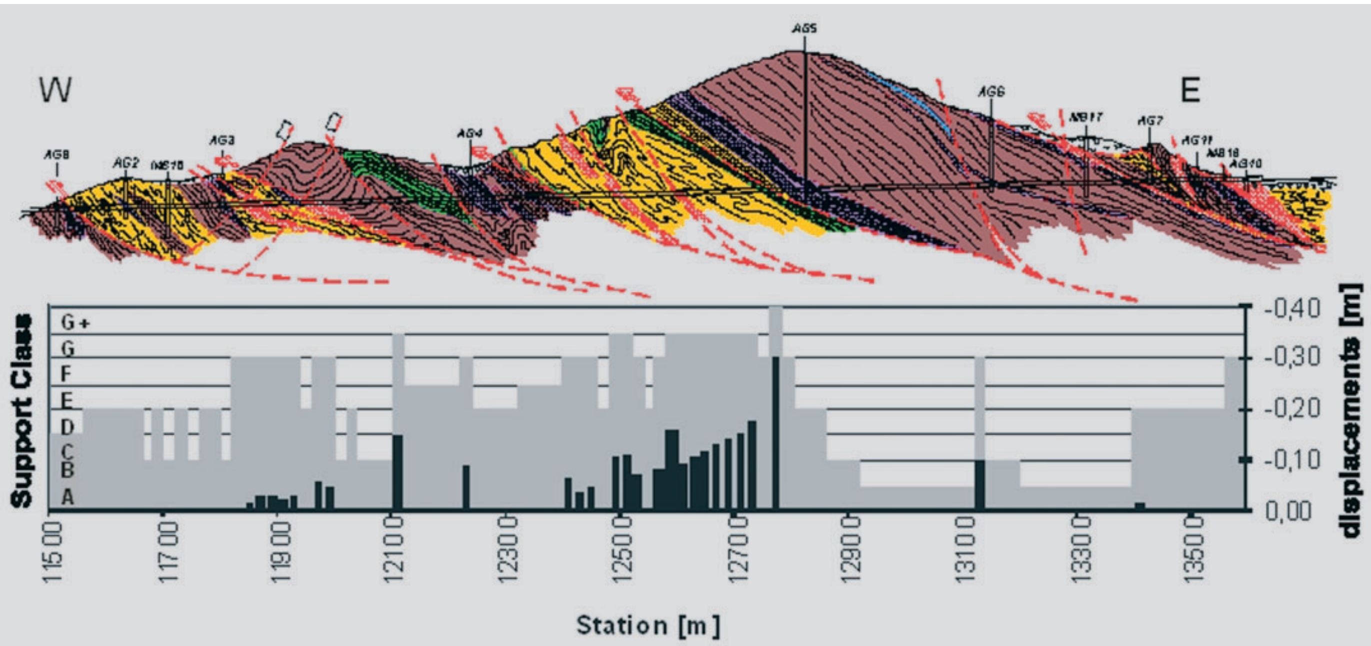


Fig. 8 Geological longitudinal section with radial displacements and distribution of support classes.

Bild 8 *Geologischer Längenschnitt mit Radialverschiebungen und der Verteilung von Stützmittelklassen.*

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Due to the deficiency of side pressure the round length varies between 1.2 to 1.5 m. 20 cm of reinforced shotcrete, one set of lattice girders per round, and grouted bolts at the sidewalls with a length of 6 m in the top heading and 4 m in the bench are provided. Forepoling should be applied to prevent overbreak. Bench round length and shotcrete thickness correspond with the top heading. Each second lattice girder is extended down to the invert. Face protection by a thin layer of shotcrete is required.

Support class D

This support type should be applied for RMT 3 with low overburden and adverse influence of ground water.

The round length does not exceed 1.5 m. The support is based on support class C, but bolts are additionally applied in the crown. Protection of the top heading invert will be required by presence of groundwater. An invert protection (geotextile, drainage and backfill) is provided under such circumstances.

Support class E

This type of support is provided for rock mass types with unfavourable orientation of bedding planes (steeply dipping, and striking subparallel to the tunnel axis).

To prevent large overbreak, possibly developing into chimney failures, and to prevent shearing and buckling along bedding a dense rockbolt pattern is designed. Bolt orientation shall be adjusted to the discontinuity orientation to achieve maximum effect. Due to the steeply dipping bedding, special care has to be taken for bolting in the top heading to avoid major problems during bench excavation. Round length in the top heading is 1.5 m. The round length in the bench is 3 m.

Support class F

This support type is used in sections, where stresses considerably exceed the rock mass strength, but magnitude of displacements still allows a stiff type of support with a lining thickness of 25 cm. A temporary top heading invert, forepoling, face sealing, and occasionally face bolting is provided. An invert arch is mandatory for this type of rock mass. The round length amounts to 1 to 1.2 m in the top heading and somewhat longer in the bench.

Support class G

Class G is used in fault zones, where displacements exceed the deformability of the conventional lining. The type of support is similar to support class F, but yielding elements (LSC) will provide a flexibility of the lining (7). Rock bolts have a length of 6 m, in general. Face support, temporary invert in the top heading and an arched, deep invert is required. Round length amounts to 1 m for the top heading and to 2 m at the bench.

Support class G+

This support type is provided for extremely poor rock conditions under high stress. The type is based on type support class G, but shotcrete thickness is increased to 30 cm, yielding elements are adjusted to the thicker lining, and the rock bolt density is increased by 30 to 40 % compared to type support class G.

Prediction of displacement magnitudes and support class distribution

The prediction of support class distributions was primarily based on the assessment of displacement magnitudes and depth of broken zones.

For a first rough appraisal of the depth of the broken zone, the magnitude of displacements and the influence of support an analytical approach suggested by Feder (8) was used. Modifying Feder's procedure systematic nonnumeric calculations were performed stepwise in 20 m sections along the tunnel axis. The efficiency and suitability of the selected support was additionally confirmed by numerical calculations (UDEC 3.0) at selected cross sections.

The procedure which finally resulted in the prediction of support class distributions along the tunnel included as essential input the geological alignment architecture, the distribution of rock mass types and relevant mechanical parameters from laboratory tests and geophysical surveys (UCS, φ, c, E_{stat}, E_{dyn}). Further inputs were influencing factors, such as primary stress (calculated by the height of overburden, using 2.7 t/m^3 as specific weight, and simplified with $k_o = 1$), the orientation of discontinuities, and groundwater.

Figure 8 displays the result of this procedure which includes the distribution of support classes along the alignment (shaded), as well as the expected displacements in each section (black single columns). It can be clearly seen that fault zones, in particular tunnel sections in the tectonic melange of siltstone – sandstone alternations (“Red Flysch”) with increased overburden have a high potential for displacement and development of deep reaching broken zones. With the chosen support expected displacements remain within tolerable limits. At the transition from “Red Flysch” to the competent sandstone (approximately Station 12 750 m) displacements exceed 20 cm. In this crucial section with high overburden a thrust zone is predicted.

Concluding Remarks

This article presented an investigation approach which can be used for the preliminary design of tunnels in a complex geological environment, such as usually found worldwide in Alpine fold-and-thrust belts. The authors recommend to put utmost care on detailed geological field studies, in particular on a comprehensive structural geological analysis which should exceed the immediate vicinity of the tunnel alignment.

Of great importance is the selection of geotechnical relevant key parameters as input for the definition of rock mass types and mechanical calculations (9). It is the authors´ experience to begin the analytical procedure stepwise with relatively simple calculations and to check the results by numerical calculations at selected sections (10). Significant data for the appropriate assessment of support classes are radial displacements and the depth of the broken zone. However, due to various simplifications in input parameters and boundary conditions displacements and depths of broken zones calculated by the analytical procedure can not be very accurate. Nevertheless, the calculated results, combined with experiences from previous projects, can be used for the preliminary design of a technically sufficient and economical support.

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