Design and Construction of Underground Works: December 2012 Greece Technical Tour

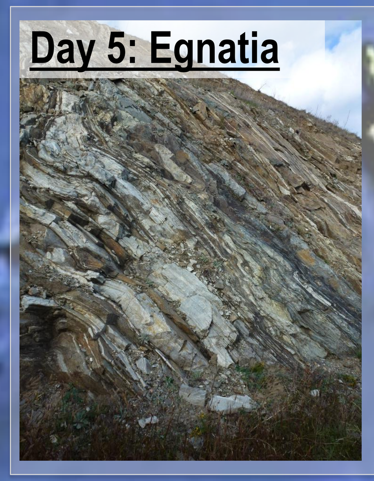
C. Palleske, M. van der Pouw Kraan

Department of Geological Sciences and Geological Engineering, Queen's University, Kingston, Ontario

Introduction

This poster provides an overview of the sites visited as part of a technical tour focusing on the design and construction of tunnels in Greece. Photos from each stop on the tour are shown and a brief discussion of issues pointed out on site are included. The tour started in Athens and went north to Kamena Vourla, Platamonas and Thessaloniki, with a day trip to Chalkidiki to the Olympus mine, before heading west towards Metsovo, and then back to Athens. The route is shown in red on the background map. Sites are laid out loosely according to their relative geographic locations.

Day 5: Egnatia



As the main east-west portion of Egnatia Odos has been completed, rock conditions are visible only in road cuts and outcrops. To illustrate typical tunneling conditions in gneiss, the outcrop shown at left was used. A GSI assessment was carried out and the impact of the strength and weathering on rockmass behaviour under different stress conditions was evaluated. The close-up at right shows the foliation with a pen for scale.

Day 5: S3 Tunnel

The 230 m long S3 tunnel crosses a landslide noted after construction began. Inclinometers were installed and a shallow-seated failure plane was located. Stabilization works were undertaken; however, movement continued and a more deeply seated failure mechanism had to be assumed. A small bench was cut in to the slope above the slide, and a buttress constructed at the toe. Monitoring is ongoing.

Olympus Mine River Diversion

A 1.14km km long tunnel is being built to divert a portion of the Kokkinolakkas River to allow construction of the tailings ponds. Water is expected to flow through the 4.26m wide, 4.13m tall tunnel at up to 17 m/s. The tunnel is currently being excavated through fresh to brecciated amphibolite gneiss. The photo at left shows the intake portal with reinforced concrete log-deflection posts.

Day 4: Olympus Mine

Olympus Mine, located on the Chaldikidi Peninsula in northern Greece, is currently building two access tunnels to expand their gold mining operation. Currently under construction, the main access horseshoe shaped tunnel is 5m wide by 5m high.

At the time of visit, the 10.5km long secondary access tunnel was being advanced in 1m rounds using an excavator, with ground support consisting of rock bolts, steel sets, lattice girders, shotcrete, and forepoles. The presence of clay-filled karst pockets in the marble unit made excavation difficult. As shown to the right, the contact between a marble and gneiss unit had just been exposed, resulting in a collapse of the face and crown.

The tunnel has reached 500m of the 8.77km long drive through blocky sericite and biotite gneisses (shown at left) and is advancing in 1.5m drill and blast rounds. The expected geology consists of 8 units along the alignment - 4 gneiss and 2 marble units of varying GSI, and 2 fault units of various thickness – with a prescribed support class for each. Currently, as the GSI ranges from 60 – 75, the ground support consists of 8-10 grouted fibreglass bolts spaced along the crown and walls, and 15cm of shotcrete.

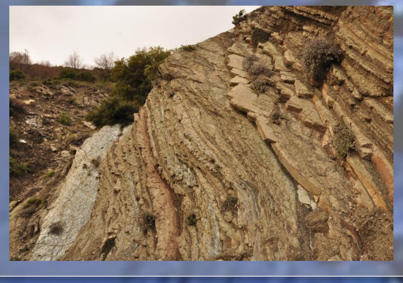
Day 5: Ieropigi

The Ieropigi Tunnel is located near the Albanian border and will be part of a north-south road that will provide access to the Egnatia Highway. The tunnel is being excavated in molasse – thickly bedded conglomerate, sandstone and siltstone – which is competent at depth, but prone to severe weathering near surface. The photo below left shows the tunnel face about 15m past the portal; the rock is transitioning between near-surface conditions and improved conditions at depth. The preferential weathering follows coarser-grained units which provide a preferential transport path for water, as indicated by oxidization in the conglomerate, but not in the siltstone as shown below. Above left, a photo of the portal shows extremely degraded rock at surface requiring significant stabilization measures for portal stability.

Due to substantial weathering of molasse at surface, heavy support is required in the portal area. The photo above shows installed support including:
steel sets with elephant feet at 1m spacing, 25cm of shotcrete, 6m grouted rock bolts, and 6m long, grout-filled forepoles. As the effects of surface weathering reduce with depth, and rock quality improves, support requirements will be decreased.

Day 6: Near Metsovo

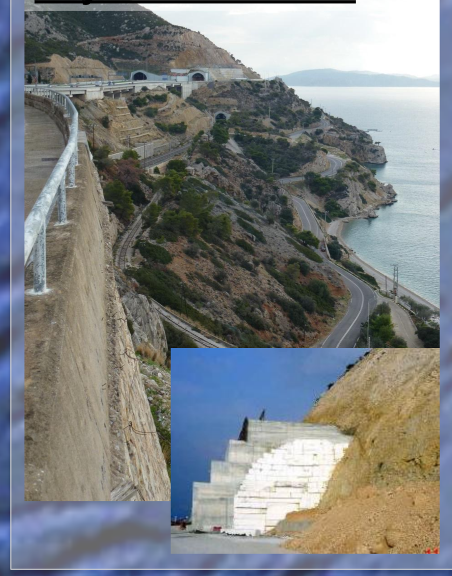
A suspension bridge with ground anchors was originally envisioned to connect Metsovo to the Egnatia Odos. However, a review of the ground conditions indicated that the ground anchors were not possible, as the rock near the proposed anchoring locations varied from a flysch, with GSI 20 – 25, to a flysch-melange, with a GSI from 10 – 15 and nearly no structure remaining. As a result, the bridge foundation was changed from ground anchors to a gravity foundation. Flysch from an outcrop in the area is shown to the left. An oblique view showing bedding surfaces is below left. Below right is an outcrop of highly disturbed melange, with only traces of structure still visible.



The final location of the Aniliou tunnel shown above had to be relocated due to a landslide in the original alignment. The approximate limits of the slide mass are outlined in yellow. The tunnel was moved behind the instability into the more competent rock mass behind.

Monument at Thermopylae, the Last Stand of 300 Spartans soldiers who held off the invading Persian army in 480 BC.

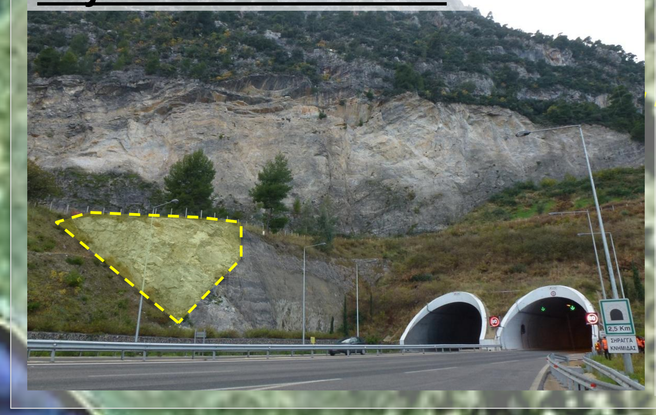
Day 1: Kakia Scala



Twin highway tunnels were conventionally excavated parallel to the 15 – 20 km long active Kakia Scala fault system, in karstic limestone. The tunnels have been designed to allow for 0.3 to 0.5m of vertical movement along the fault plane.

Left: twin tunnels constructed parallel to the Kakia Scala fault. Left inset: a false portal was built to construct the outer tunnel. Right: fault planes result in 40 – 50m high steep cliffs. Above: the tunnels were constructed through karstic limestone (voids up to 3m wide, 2 m deep) and heavily faulted rock (pen for scale).

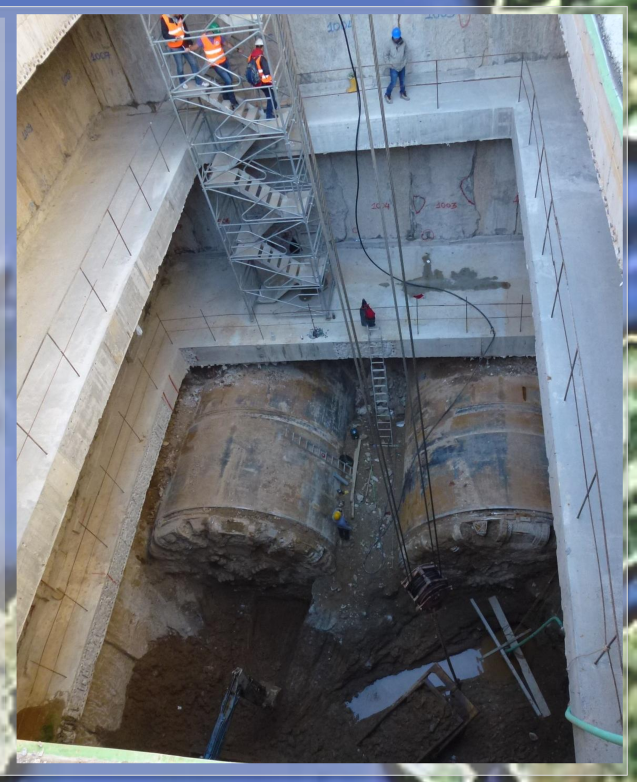
Day 1: Knimidas Tunnel



The 2.5km long Knimidas tunnel, part of the Greek National Road 1, had to consider tectonic displacements as part of tunnel design. Up to 0.15m of displacement is expected across the fault zone over the tunnel design life. Over-excavating the tunnel and back-filling the excavation with material will accommodate this movement and require minimal repair work following a tectonic event. The photo at left shows the portal area, with an exposed fault surface highlighted in yellow.

Day 3: Thessaloniki Metro

A 9.5km long metro system with 13 stations is currently under construction in Thessaloniki. The majority of the twin tunnel lengths are constructed using two 6m diameter Seli EPBM's (right), with small cut and cover lengths at either ends of the alignment, and the NATM for one street crossing. The stations are built top-down, once the approximately one meter wide diaphragm walls are excavated up to 40m deep and backfilled with tremie concrete (top left). The majority of the tunnel and station excavation works are in a stiff, red clay (below, left). Once completed, the €800 million project will transport 18,000 people per day per direction in 18 trains, and will be one of the most modern metro systems in Europe.



Day 2: Tunnel T3 - Platamonas

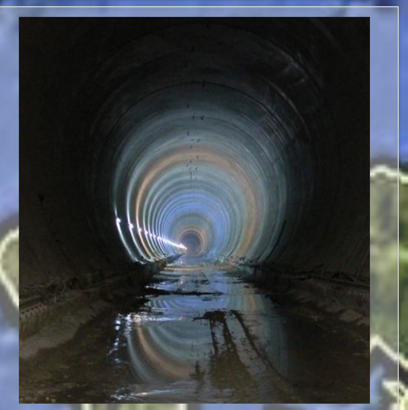
During construction in the highly sheared serpentinite unit with a GSI of approx. 15, a 40m long fall-out in the crown resulted in 0.5m of settlement at the surface 17m above. Consequently, the excavation methodology was redesigned in this section to use 12m long forepoles filled with grout spaced approx. 0.3m apart, for a 60m tunnel length (below). The tunnel diameter was also narrowed, thereby creating a additional excavation stage. Extensometers currently monitor this section for indications of further ground movement.

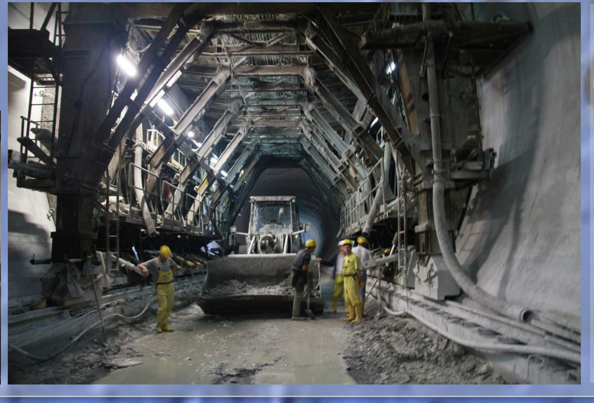
Twin 13m high, 2.8 km long rail tunnels part of the Athens to Thessaloniki highway. The tunnels are constructed using the NATM, with a heading and bench excavation. Major rock units are faulted and sheared ophiolites and limestones. Initial support includes welded wire mesh, steel sets, elephant feet,12m bolts, and shotcrete. Final lining is also completed using a 'turtle', with layers of geotextile (grey) and geomembrane (yellow) placed against the shotcrete for a watertight seal (inset, upper middle). Each 12m long cast-in-place segment is independent, in the event of an earthquake.

Day 2: Kallidromo Tunnel

The 9km long twin Kallidromo Tunnels are currently under construction as part of the Athens to Thessaloniki high speed railway line. A heading and bench excavation sequence is used, with the top bench 15m ahead of the bottom bench. The differing deformation characteristics of the three major geologic units along the alignment (ophiolites, silty clay, and limestone) required different levels of initial support stiffness. While the silty clay exhibits swelling behavior (up to 0.25m of convergence was recorded in 1 month), and requires yielding support (typically a longitudinal strip is left unsprayed (shotcrete) along the tunnel walls), the limestone units are stiff in comparison – i.e. the invert does not need to be closed with shotcrete to prevent heave.

Right: 12m long fibreglass bolts and shotcrete are used to support the 58m^2 face in between excavation rounds. Bolts, mesh, steel sets, and shotcrete support the walls.





Upper left: green geomembrane is placed against the initial shotcrete liner prior to rebar installation for the cast-in-place concrete liner. Left: nicknamed the 'turtle', this machine is used to pour the top bench cast-in-place final liner in sections. The top heading is tied in to the bottom bench has previously been excavated, poured, and backfilled. Top: finished tunnel section.