THE CONTRIBUTION OF CIVIL – GEOTECHNICAL ENGINEERS
TO THE INFRASTRUCTURE OF GREECE

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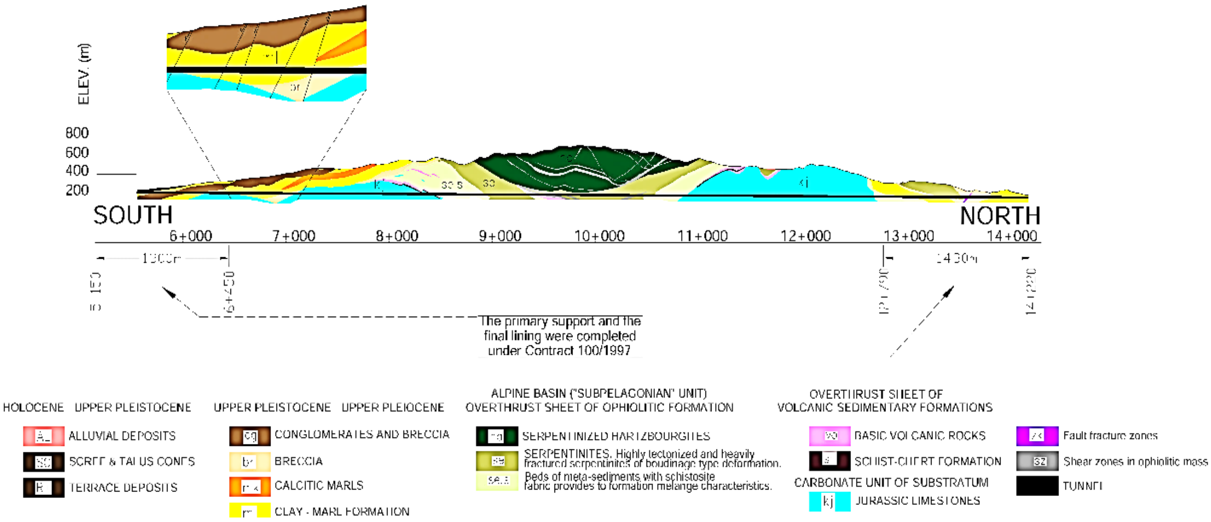
In most of the 20th century, Greece experienced the early history of geotechnical engineering but towards the end of the century and during the first decades of the 21st century geotechnical engineering in Greece entered with force its mature, important stage.

The first lessons on foundations were taught at the NTUA (National Technical University of Athens) before WWII, soil mechanics after the War. In 1982 in civil engineering the geotechnical direction was established in NTUA and by 1998 the graduate degree on Planning and Construction of Underground Works was established (together with the School of Mining Engineering). Currently all schools of civil engineering in Greece offer a geotechnical direction.

Many tunnels were designed and built, including the 9km long **Kallidromon tunnel** designed in 1994-'96. It was built in metalpic deposits, excavated using the method of Yielding – Double Support and closely followed by extensive use of movement measuring devices.

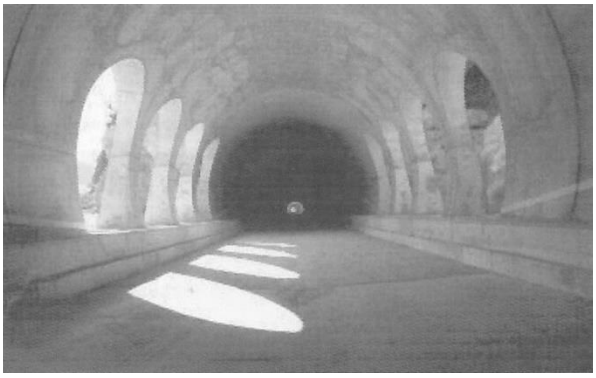


Cross-section of Kallidromon tunnel

Kallidromon tunnel

The **railway tunnel at Tempi** designed between 1995 and 1998 (main section of 4km) was excavated in limestone formations.

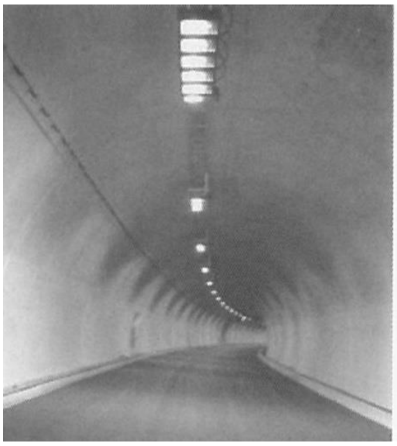
Tempi tunnel during excavation phase



Tempi tunnel

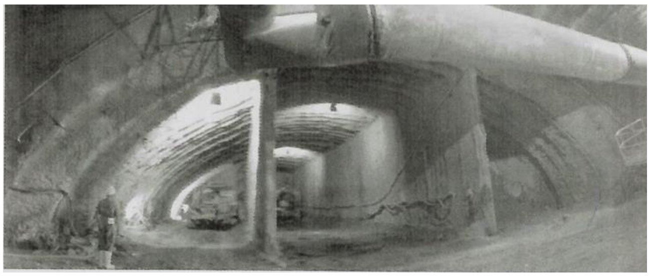
The rather shallow **twin tunnels to bypass the town of Ag. Konstantinos** designed between 1995 and 1998 go through marls and conglomerates.

Twin tunnels of Ag. Konstantinos



Ag. Konstantinos tunnel

An important underground structure during the construction of the **Athens Metro was the Cavern of the Aegaleo Station**. The Cavern was 110m long, 28m wide and 18m high, only 8m underground and was designed in 2001-2002.

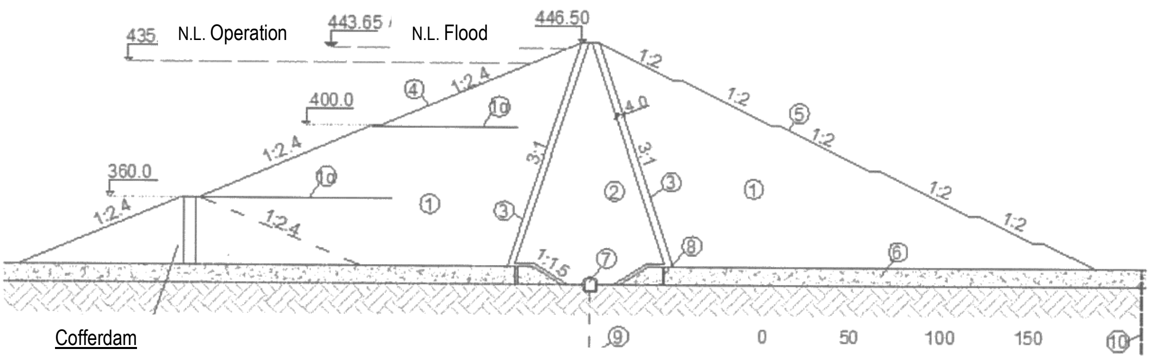


Aegaleo station cavern

Aegaleo station cavern

Several dams were built and continue to be built. Most importantly the **Mornos Dam** (135m max height) which was finished by 1979 in the Fokis region for the water supply of growing Athens. It has a clay core, filter zones and shells of sand-gravel and rockfill on the upstream side. Cement grouting of approx. 90000m was implemented for the curtain. Grout was injected through a 2170m long tunnel constructed for this purpose. The dam is founded on flysch formations.

Mornos Dam



LEGEND

1 Sandgravel shoulders
1a Gravel drain
2 Impermeable core
3 Filter
4 Protection rip-rap
5 Vegetation cover
6 Sandgravel alluvia
7 Grout and visit gallery
8 Plastic diaphragms
9 Grout curtain
10 Drain shafts

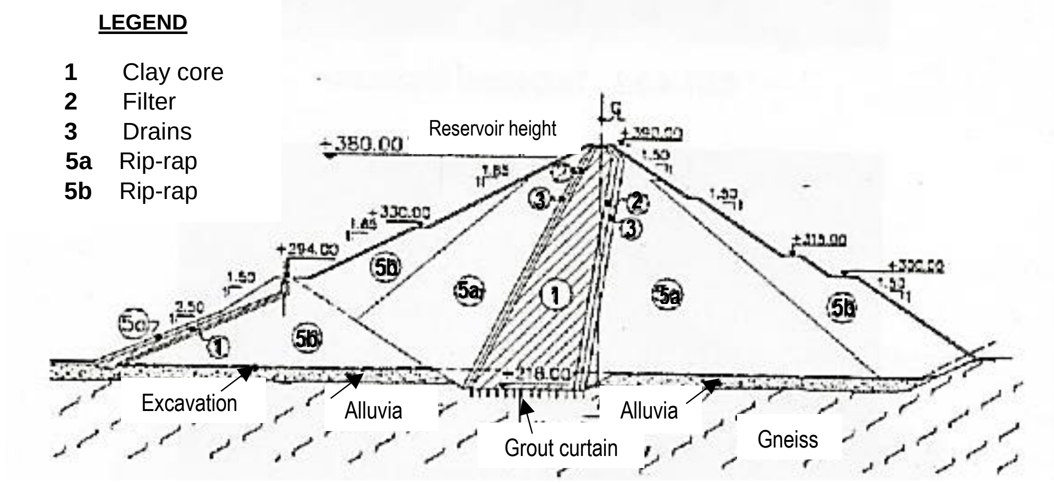
Typical cross-section of Mornos Dam

The **Evinos Dam** in Nafpaktia Region started to be built in 1992 and was finished in 2001, after having to deal with two main landslide events. The dam is 126m high and is composed of a central clay core and sand gravel and rockfill shells. The remedial works for the landslides included extensive drainage works (tunnels etc.).

Evinos Dam

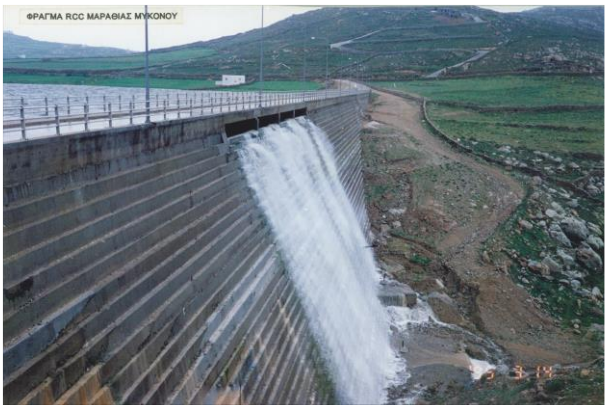
The **Thissavros Nestos Dam**, whose construction finished in 1996, has a height of 168m and is founded on gneiss, granitic gneiss, schist with mica with numerous pegmatic veins associated with shear zones. Grouting as well as drainage galleries reached a length of 5000m. A serious rockslide that occurred was remedied with anchoring and drainage works.

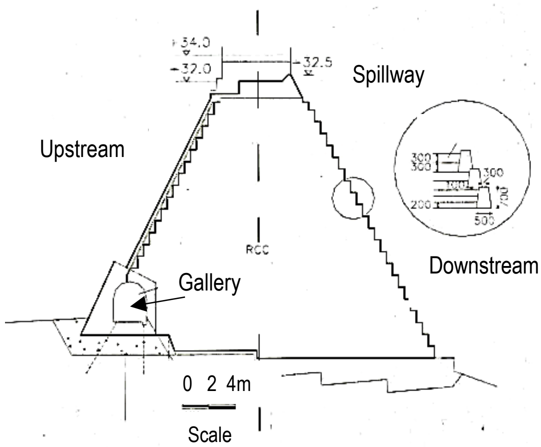
Thisavros Dam



Typical cross-section of Thisavros dam

The **Marathia Dam** on the touristy island of Mykonos, the first RCC dam to be built (in Greece), finished in 1992. It has a height of 30 m and was intensively followed with instrumentation for years after the first filling.



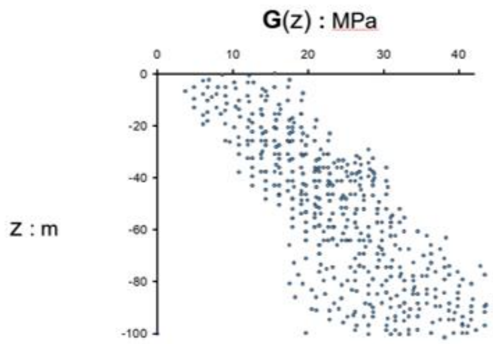


Marathia Dam

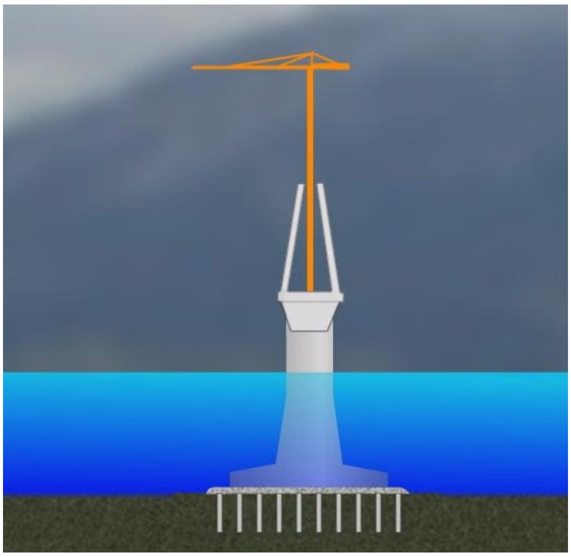
Typical cross-section of Marathia dam

Many important bridges were built in the last 50 years which had serious geotechnical aspects regarding their pier foundations. Most important is the **Rion - Antirion bridge**, bridging the Peloponnese with mainland western Greece. It not only travels over deep water (-65m) but its design -and consequent construction- had to deal with the increased seismicity of the region due to crossing over a major fault zone. Important geodynamics were employed for the successful design of the pier foundations.

Rion-Antirion bridge



Soil profile in terms of shear modulus

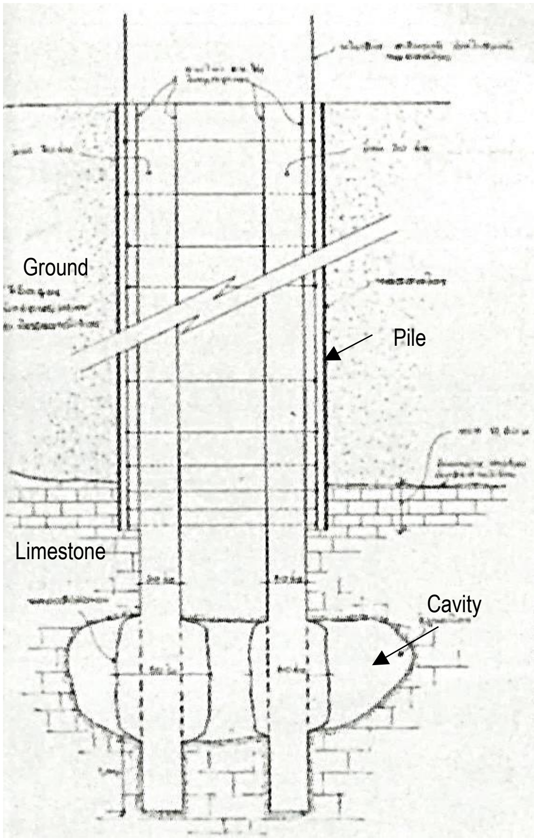


Sketch of pier foundation (Rion-Antirion bridge)

The **bridge of Servia over the Aliakmon River** was redesigned in early '70's -after an initial design- to take into account the particular foundation soil conditions, which, most importantly, consisted of a, rather rare for Greece, highly sensitive marl. The re-design led, among others, to an increase of the approach fills to decrease the bridge's total length.

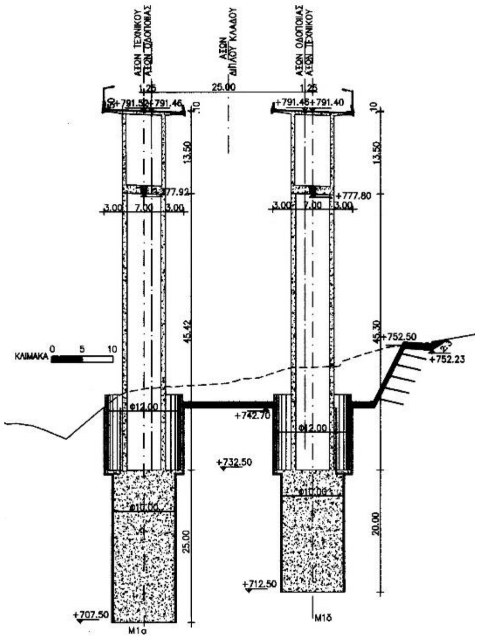
Servia Bridge

The **Aheron bridge on the Preveza – Igoumenitsa Highway** had to deal with the problem of sizeable karstic cavities in the foundation ground. A rather original but simple method for the extension of the piles below the cavities was designed and used in construction, in the late ‘70’s.



Cross-section of large diameter pile of Aheron bridge with smaller diameter piles passing through cavity.

The foundation of the **Votonossi bridge** piers of the Egnatia Highway was designed and constructed in thick layer Pindos sandstones -with siltstone in-layers of varying thickness. For the pier foundations shafts were designed and constructed in approx. 2001, one of the first such cases in Greece.



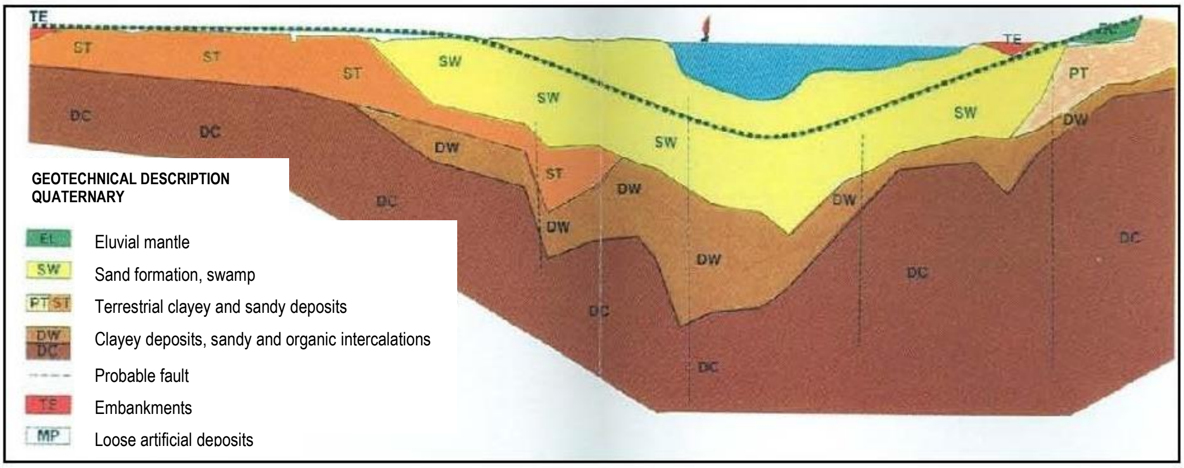
Votonossi bridge during construction phase

Section of pier foundation

The foundation of the underwater tunnel bridging **Preveza with Aktion** was investigated (1997), designed, and constructed using gravel -piles to avoid possible liquefaction.

Drilling at sea (Aktion-Preveza)

Aktion side Preveza side



Geological longitudinal section of seabed (Aktion-Preveza underwater tunnel)

The construction of the **new ports of Igoumenitsa (2014) and Patras (2012)** faced the problem of very soft foundation clay and sand silts with extremely low shear strength. The solutions implemented included – apart of using light weight quay walls – preloading, use of gravel piles, speeding consolidation rates.

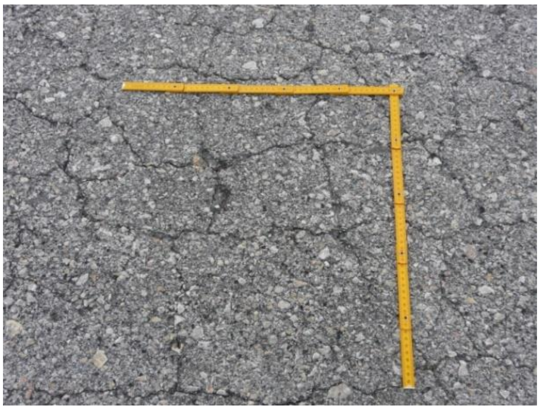

Port of Igoumenitsa

Port of Patras Port of Patras

One of the latest infrastructure projects in Greece, which started in 2017 and is still going on, is the upgrading of several **airports** most importantly in the airside areas. This included extensive investigation of the pavement conditions, including the subgrade and foundation ground. Increased difficulties had to be overcome due to the time allowance for investigation in airports in operation. Increasing the length of the corridor 10/28 of the Thessaloniki **(Macedonia) airport** (1997-2001) designed in the sea water, was based on the use of granular material using the method of deep dynamic compaction and monitored by an extensive system of vibrating wire electric piezometers.

Macedonia airport

Drilling rig working at night next to the airport take off corridor



Heavily stressed concrete and asphalt pavements

The fill of the **Athens – Thessaloniki Highway near Thermopylae** had to be re-designed in 2006 using prefabricated blocks 1mx2m min size made of expandable polysterine EPS100. Polyethylene geomembranes as well as light reinforced concrete was also used.

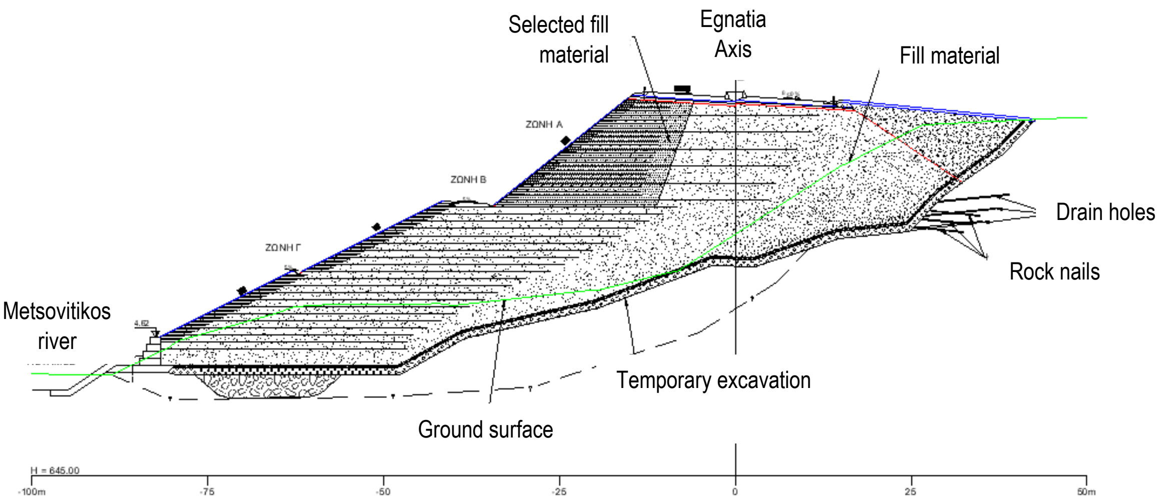
Crack and settlement (Athens-Thessaloniki highway)

A reinforced earth fill was designed (in 2014) and constructed in **the Ionian Highway bypassing the town of Amfilochia**. The technique of wrap-around facing of the geosynthetic reinforcement was used in the design as well as uniaxial geogrids.

View of reinforced earth fill with wrap-around technique of the reinforcement (Ionian highway)

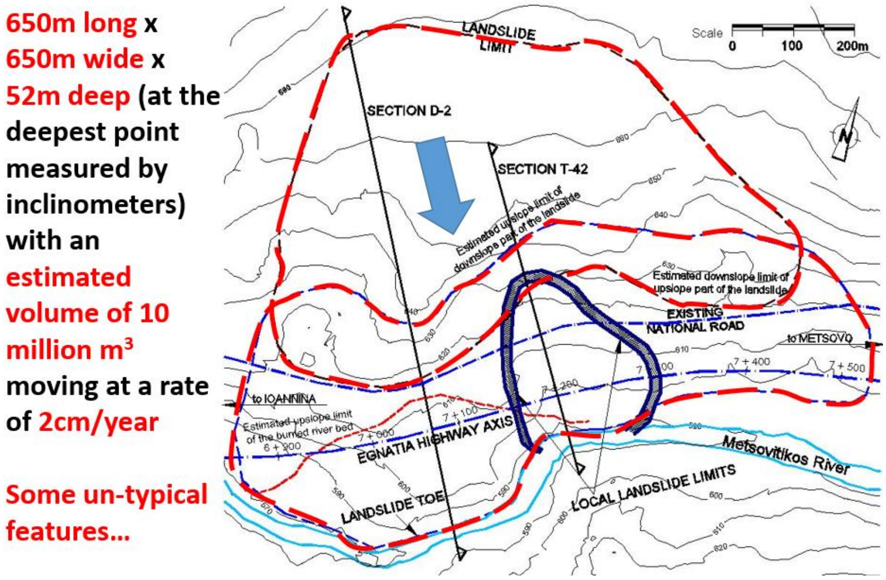
Uniaxial and biaxial geogrids were also designed around 2003 and used in several reinforced earth fills along the new Egnatia Highway in Northern Greece especially in the **Metsovo** area.

Reinforced earthfill of Egnatia Highway in Metsovo area

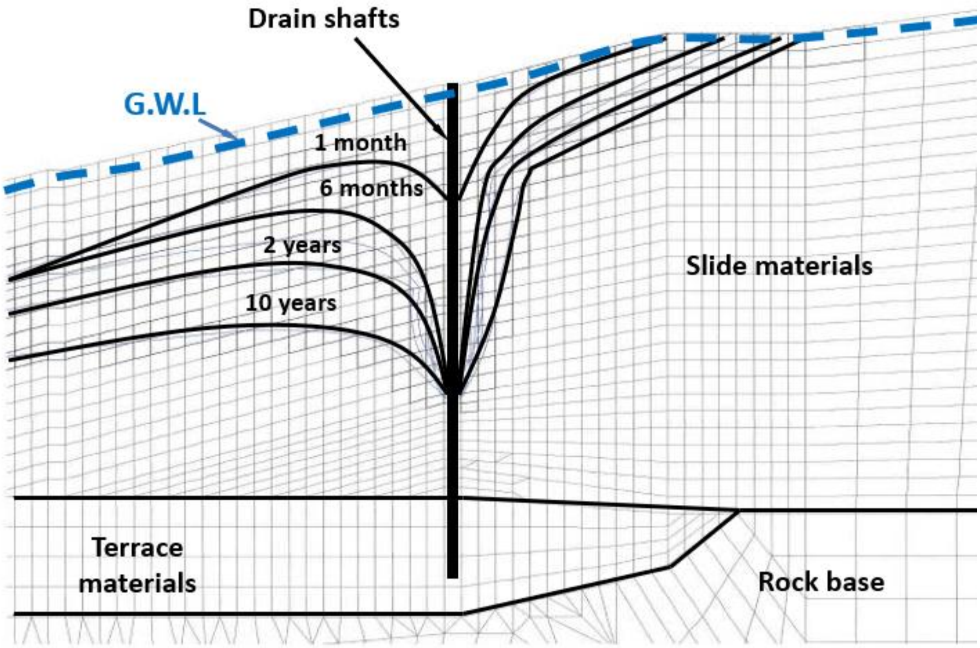


Cross-section of the reinforced earthfill in Metsovo area

Facing old or new landslides is a main aspect of geotechnical contributions to the infrastructure. In the **Peristeri region, the Egnatia Highway** had to pass by the toe of old natural landslides with a perpetual movement due to the erosion caused by the **Metsovitikos River**. Drainage wells leading water to the permeable, covered, old riverbed led to significant decrease down to the zeroing of pore pressures on the sliding surface. This in turn also increased the available shear strength. Construction took place in the first decades of the 21st century.



Plan view of landslide in Peristeri region (Egnatia highway)

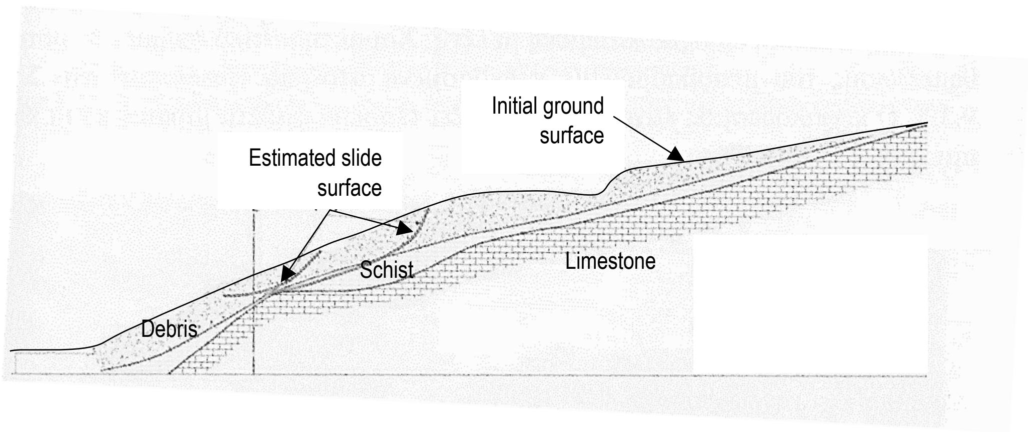


Numerical simulation of pressure distribution (Peristeri-Egnatia highway)

Twin tunnel of Metsovitikos River with berm above it stabilizing one landslide to the north (left side) and to the south (right side). Picture taken by drone from downstream of the river.

The **Ikonion landslide** in early 21st century, was over passed by a train bridge that was founded outside its lateral boundaries, following a geotechnical investigation that identified the lateral limits of the slide.

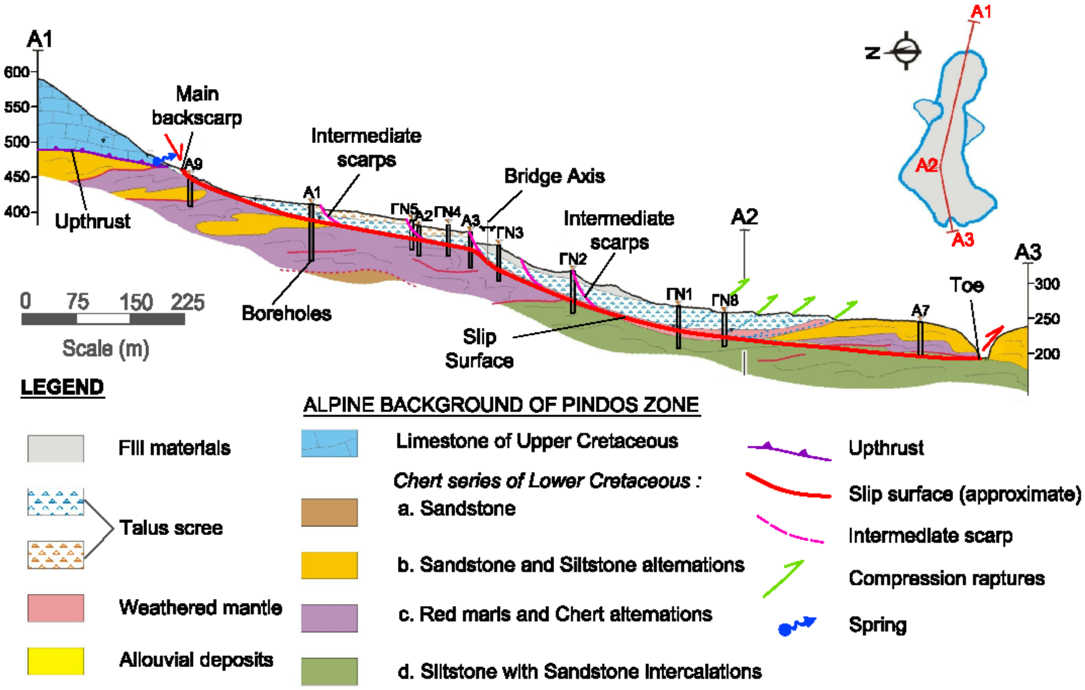
Bridge with railway line over the Ikonion landslide, during construction phase



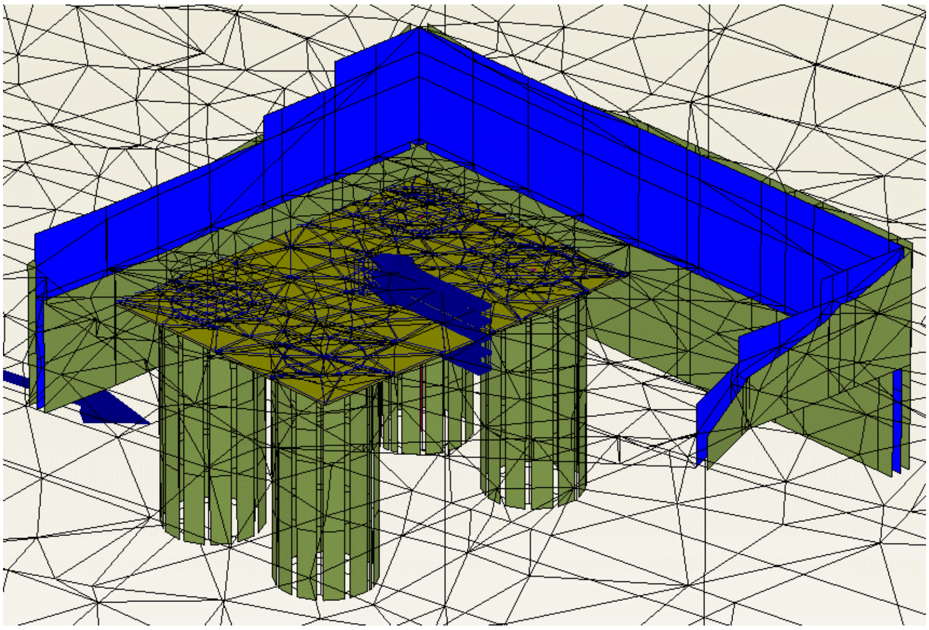
Cross-section at the Ikonion landslide location

Similar was the solution for the **Tsakona landslide**, which occurred in 2003, where the piers of the main part of the designed bridge were founded about 300m apart to avoid the landslide. Moreover, special measures were designed and implemented for the initial (temporary) solution for the road to be operational while sliding continued at a low rate.

View of Tsakona landslide



Geological cross-section across the Tsakona landslide

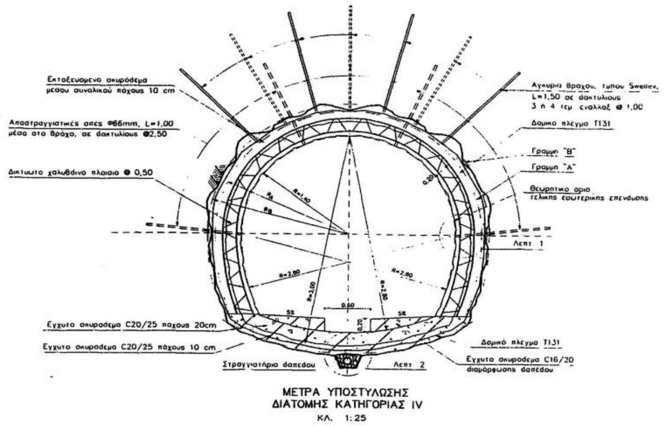


3D Finite element analysis of Shaft-raft bridge foundation over the Tsakona landslide

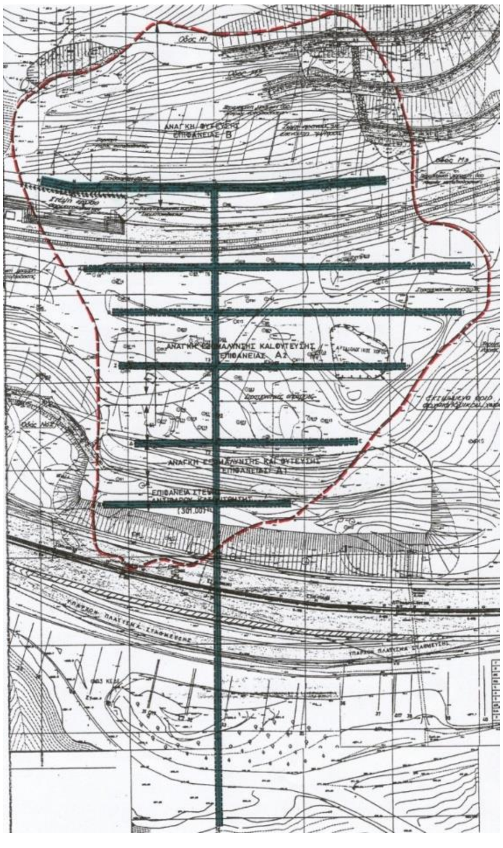
The **Malakassa landslide** of 1995 destroyed the Greek south – north train line and reduced the width of the south - north motorway. The slide was formed by uniting old shear zones and was triggered by a sizeable increase of water pressures. The extensive geotechnical investigation was followed by both two and three - dimensional analyses. The design -and following construction- mainly included an extensive dewatering system through boreholes leading to a series of drainage tunnels constructed under the slip surface. A tall toe fill was also part of the remedial measures.

View of Malakassa landslide

View of landslide crest



Typical cross-section of drainage tunnel with category IV support measures



Plan view of drainage tunnels

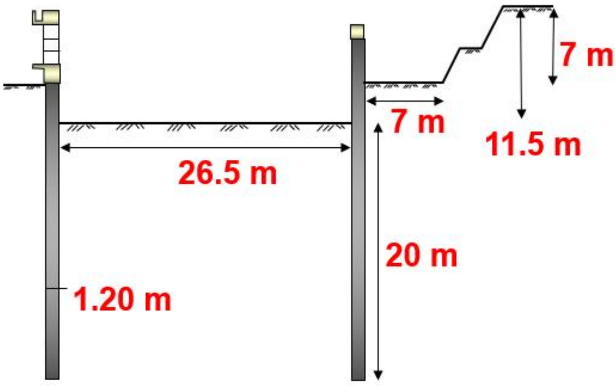
Environmental infrastructure requirements tend to increase. Characteristic cases with increased geotechnical input are those of sanitary landfill sites such as those on the islands of **Lemnos** and **Lesbos.** Such sites are expected to increase drastically over the next years.

Sanitary landfill, Lemnos

Sanitary landfill, Lesbos

The building of sports infrastructure was accelerated due to the Athens Olympics of 2004. The foundation soil of the **Olympic Sports Center of Athens** was thoroughly investigated to provide input for the geotechnical design of the foundations of the various structures of the whole complex.

Olympic Sports Center

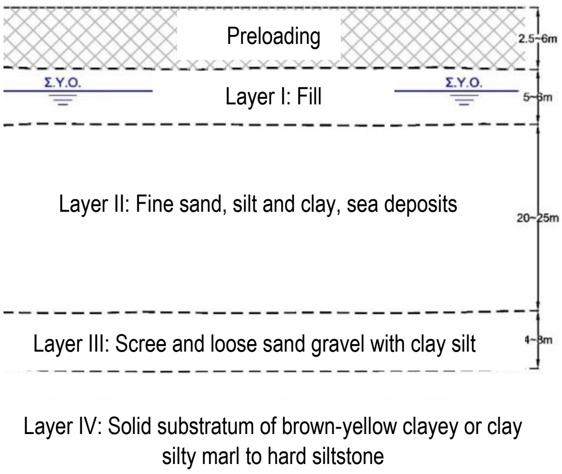


- **December 2003**
  Excavation around the shaft down to -7m
- Excavation in the shaft down to - 11.5m
- Placement of the first row of drains at -9m

Shaft excavation at the Olympic Sports Center

The foundation of the **Peace and Friendship Stadium** near Athens required drastic improvement of the foundation soil which consisted of preloading and heavy dynamic compaction (1982-’83).

Peace & Friendship Stadium

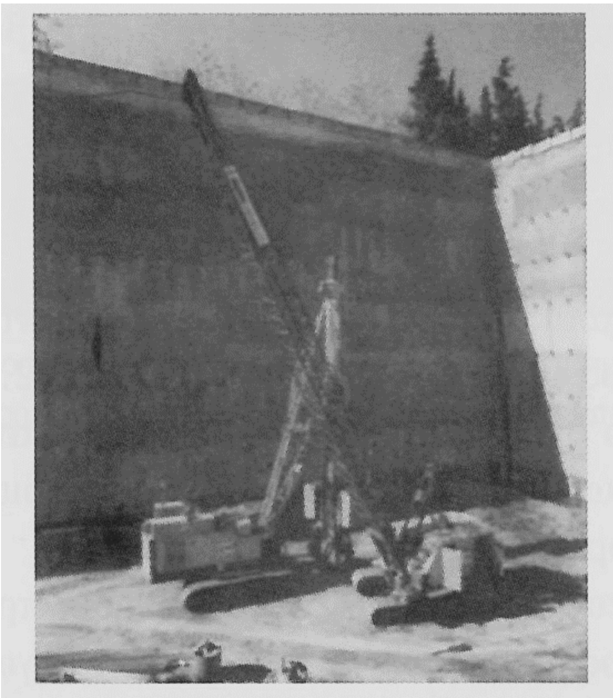


Typical soil profile at Peace & Friendship Stadium site

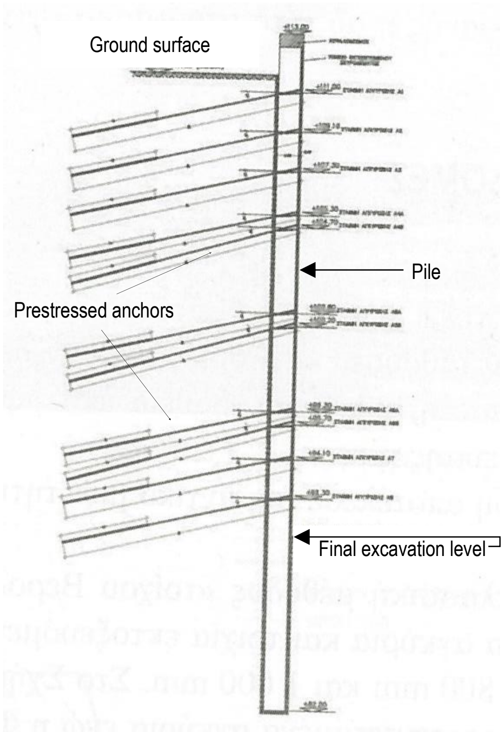
In the north of Greece for the **Indoor Stadium of Thermi** preloading with prefabricated drainage was designed in 1998 to 2000 to avoid possible liquefaction, decrease expected settlements as well as avoid negative friction on the piles. The solution involved an area of 160000m^2 with drainage holes down to 26m.

Soil improvement. Preloading with drains for the Indoor Thermi Stadium.

The **Athens Concert Hall (Megaron)** which was inaugurated in 1991 is a primary cultural infrastructure for Athens. The required deep excavation was assisted by “Berlin walls” with piles of 80 to 100 cm diameter, gunite and prestressed anchors. The excavation reached a max. depth of 33m, all in the Athenian schist.

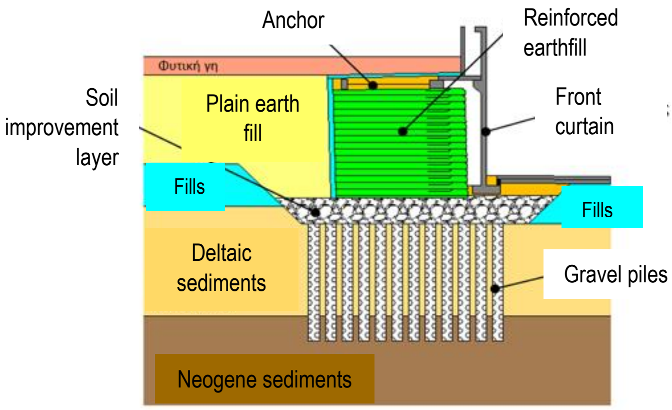


Excavation support during construction of the Athens Megaron



Pile cross-section with prestressed anchors for temporary excavation support (Athens Megaron)

The **Stavros Niarchos Cultural Center** near Athens, by the sea, was founded after an extensive soil investigation with boreholes, pressuremeter holes, penetrometer holes, test pits and test pumping. The investigation also included special large diameter shear tests for coarse grained material.

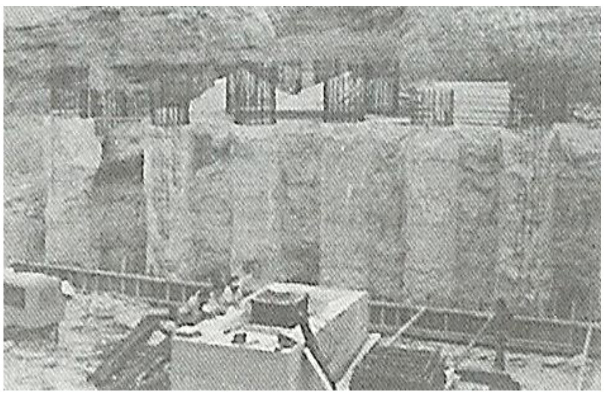


Schematic foundation profile at Stavros Niarchos Cultural Center

Large diameter direct shear test apparatus

Recent infrastructure construction was accompanied by the re-design and additional construction of old or ancient works. The **Corinth Canal**, which was constructed in the 19th century, acquired a new bridge with special bearings for seismic insulation and large diameter piles in 1997. The sides of the Canal are treated to avoid rockfalls or slides.

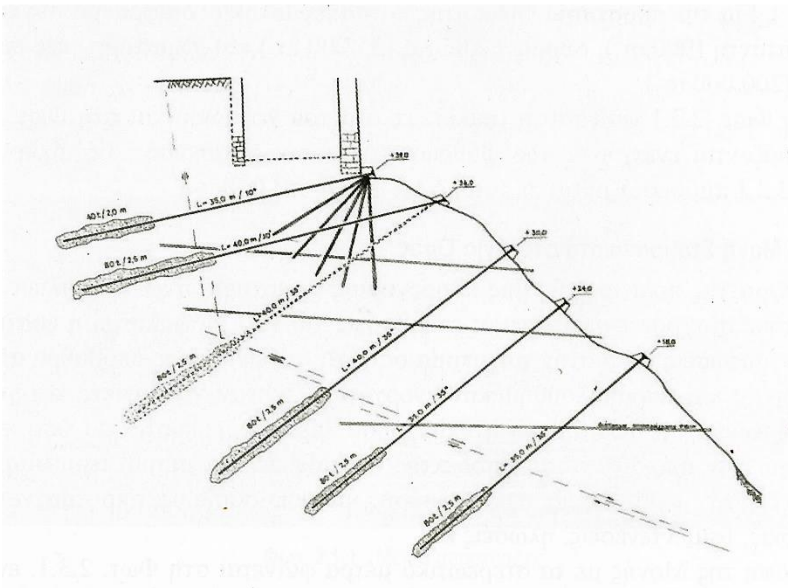
The Corinth Canal



Placement of seismic insulation bearing (Corinth Canal)

The **Stavronikitas Monastery on Mount Athos**, visited by thousands every year, was submitted to substantial geotechnical works to restore its stability which included prestressed anchors, micropiles, nailing, cement grouting, drainage holes etc.

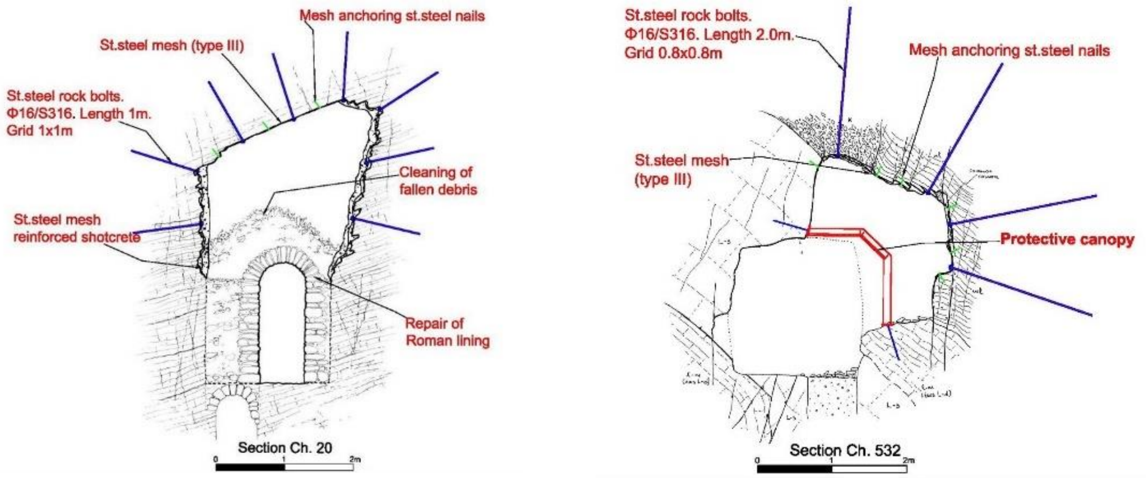
Stavronikitas Monastery



Characteristic section of southeast slope in Stavronikitas Monastery. Permanent prestressed anchors, micropiles and drainage holes are discerned.

A recent major rehabilitation of the ancient **Eupalinos aqueduct** on the island of Samos enables visitors to admire the remarkable work dated in the 6th century B.C. Rock anchors, grids, cement grouting and other works were designed and built providing safety to visitors. The design was performed in 2009.

Support measures of Eupalinos aqueduct



Cross-sections of Eupalinos aqueduct

The projects included in this write up are indicative of the infrastructure works that took place in Greece in the last decades, for which Greek geotechnical engineers provided important to crucial input for the design and construction. Judging from the current and anticipated projects, geotechnical engineers will continue with increasing involvement to provide their services for the investigation, design, and construction of infrastructure in Greece. The future possible massive use of instrumentation in conjunction with the use and treatment of big data electronic technology highlight the future of geotechnical engineering in Greece.

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