The behavior of support measures applied to the Eupalineio tunnel, 10 years later

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ABSTRACT

The 1036m long Eupalineio tunnel on the island of Samos is an outstanding achievement of science and technology built in the 6th century BCE as part of the water supply aqueduct to the city of Pythagoreion. The tunnel was bored from both ends and the two bores met after many deviations from the straight line using applied geometry. The maximum overburden is 175m. The main tunnel is approximately 1.8x1.8m and the water flowed along the floor of a deep side trench with a width of 0.6m. The tunnel is unlined in most of its length. Masonry lining has been applied in part of its northern section, either during initial construction or later during its operation. The tunnel was fully excavated and documented in the 1970's and some temporary support and protection measures were eventually applied. To improve tunnel stability and to protect against evolving roof collapses, support measures were designed and applied from 2013 to 2016. Applied measures included anchored steel netting, steel mesh and shotcrete in non-visible areas, rock bolts, partial filling of open faults, local dismantling of masonry lining and reconstruction after rock support, steel canopies, steel grate cover of the side trench, etc. All metallic elements were made of stainless steel. The article briefly describes the protection and support measures and presents their behavior over the first 10 years of application. The support measures are in excellent condition. Netting is very tight, rock bolts are well attached, canopies are in perfect condition. Deformations of the masonry linings in general, as well as in reconstructed segments are minimal. Locally, at locations of open geological faults, some debris is accumulated behind the protective netting that will eventually require clearing. Proposals are made for future monitoring and maintenance.

Keywords: Ancient tunnel, rehabilitation, rock support, Eupalinos

INTRODUCTION

The 1036m long Eupalineio tunnel on the island of Samos is an outstanding achievement of science and technology built in the 6th century BCE as part of the water supply aqueduct to the city of Pythagoreion. It is considered unique because it was the first known case where the tunnel was bored from both ends and the two bores met after many deviations from the straight line using applied geometry. It was considered an outstanding achievement in antiquity, as recorded by Herodotus (mid-5th century BCE) who provides a description of its main features and expresses his great admiration. He attributes the construction to Eupalinos, an Engineer from Megara. The aqueduct was operating for 1100 years according to its main investigator Herman Kienast (Kienast, 1995).

The monument has been included in the World Heritage List of UNESCO since 1992 and was declared an International Tunnelling Landmark by the International Tunnelling Association in 2015.

The locations of the spring and the aqueduct were rediscovered in the mid-19th century. At the end of the 19th century its whole length was investigated as reported by Stamatiadis (1884), Synesios (1899) and Kienast (1995). The underground aqueduct is composed of a nearly horizontal access tunnel, approximately 1.8 by 1.8 meters, and a side trench along the Eastern side with a width of appr. 0.6m and depth varying from 4m at the North portal to 8.5m at the South portal. The water was flowing in ceramic pipes placed on the floor of the trench.

The main access tunnel and most of the side trench were cleared from deposits that had accumulated during its long operation, and was fully investigated, documented and studied by the German Archaeological Institute (DAI) in the early 1970's. Kienast (1995, 2005) provides an admirable presentation of the history of the investigations, the tunnel works, and an insight into its method of construction. The southern part of the tunnel was made accessible to visitors for many years.

Although most of the tunnel was in very good condition there were locations where the stability of the walls and the safety of the visitors were inadequate. A major program including restoration, conservation and protection works was carried out between 2013 and 2016. Applied measures included steel netting, steel mesh, shotcrete in non-visible areas, rock bolts, partial filling of open faults, local dismantling of masonry lining and reconstruction after rock support, steel canopies, steel grid cover of the side trench, etc. All metallic elements were made of stainless steel. A summary of the restoration works is presented by C. Zambas (2019).

An assessment of the condition of the restoration and support measures, 10 years after their installation, was made in January 2026 by the authors. They were found to be in excellent condition. The article presents typical cases of rehabilitation and support works and their present condition and proposes required monitoring and maintenance.

GEOLOGICAL CONDITIONS

The geological settings of the Eupalinos Tunnel are documented in detail by Lyberis et al. (2014). Figure 1 illustrates the geological plan and the corresponding longitudinal section along the tunnel axis.

Starting from the north portal, the first 230 m span thinly bedded shales and weak marly limestones (Ho3 unit). From Ch. 200 to Ch. 400, the lithology transitions into massive limestones alternating with clay shales and marls (Ho4 unit). These geological horizons are intensely folded and faulted, exhibiting significant water inflow along the fault zones. Tunnelling through these formations induced severe wall and roof stability issues, which were further exacerbated by the presence of groundwater. Along this specific tunnel section, a substantial length features historic linings: a major segment is supported by large, well-shaped stone blocks fitted without mortar, forming an inverted V-shaped roof (archaic linings), while a section near the North portal consists of mortar walls constructed with small stones and an arched roof (later Roman-period linings). Near the North portal, considerable roof collapses were encountered during the reopening of the tunnel at the end of the 19th century. These apparently occurred after the aqueduct was abandoned.

Between Ch. 400 and Ch. 1000 (36 m prior to the South portal), more competent rock masses are encountered. These consist of thick-bedded limestone (Py1, which is the dominant formation between Ch. 700 and Ch. 1000), platy limestone with marly intercalations (Ho5, occurring between Ch. 450 and Ch. 500), and thin- to medium-bedded limestone featuring marly intercalations (Py2, localized between Ch. 600 and Ch. 700). Several open faults persist along this interval, posing a continuous risk of localized roof or sidewall rockfalls.

Finally, the remaining 36 m leading to the South portal pass through a loose to slightly cemented tectonic breccia (Te). This final section is entirely lined with an archaic masonry structure, which, as revealed during the recent restoration campaigns, was originally constructed utilizing the cut-and-cover method.

REHABILITATION WORKS

During the re-opening of the tunnel in the late 19th century, support and partial reconstruction work was carried out, as reported by Stamatiadis (1884), Synesios (1899) and Kienast (1995).

When the tunnel was cleaned by the German Archaeological Institute (Deutsches Archäologisches Institut, DAI) from 1971 to 1973, some canopies were installed to protect against roof collapses (near the North portal), and some limited lining rehabilitation works were constructed. Eventually a grill was built to cover the side trench at the southern part of the tunnel, and more canopies were later installed near the South portal.

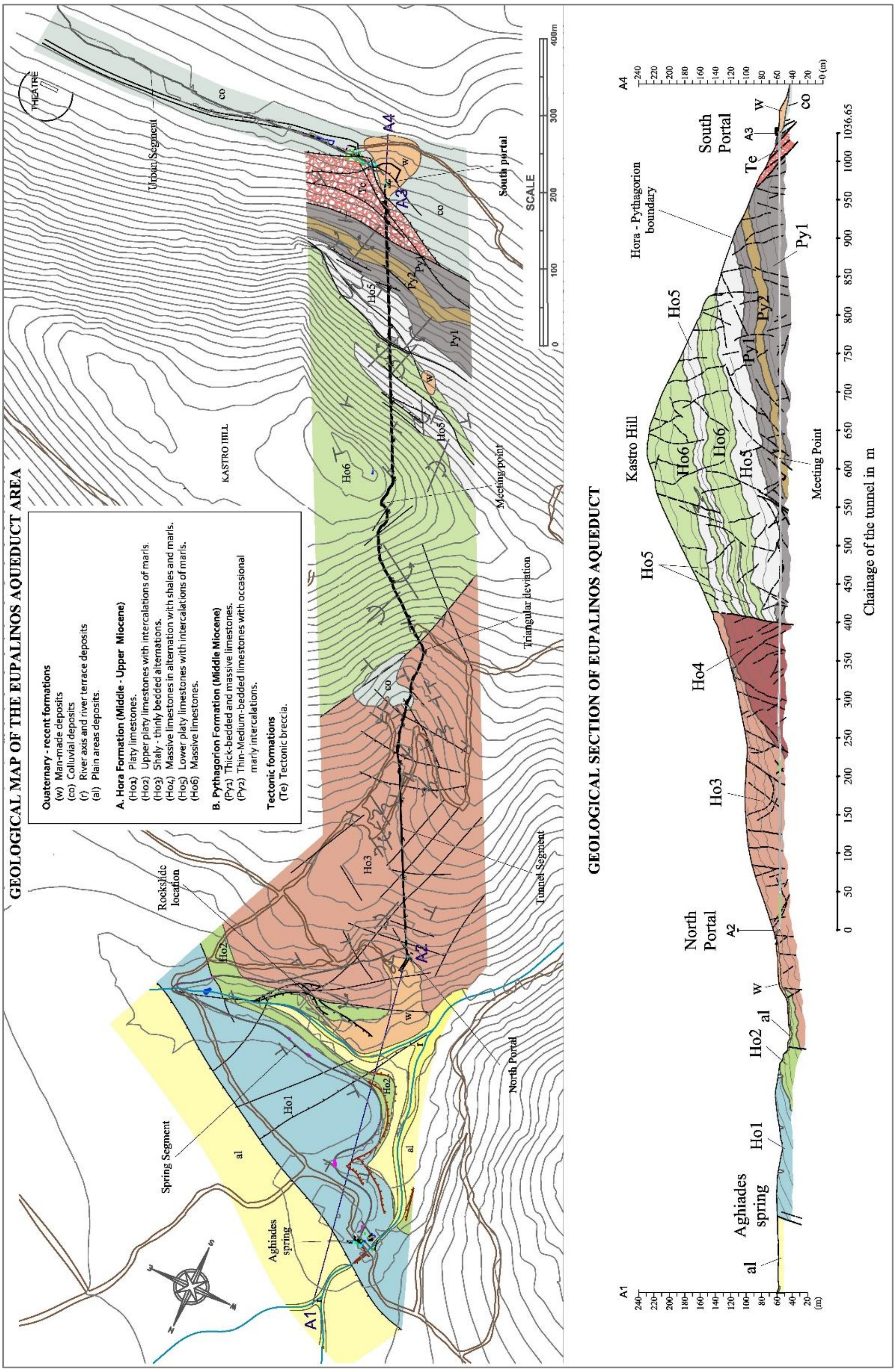


Figure 1. Geological map and Section of the Eupalinos Aqueduct (Lyberis et. al., 2014).

In 2009, an extensive study of the tunnel was carried out by Egnatia Odos SA which, after being approved by the Ministry of Culture, was implemented between 2013 and 2016.

The studies, supervised by Egnatia Odos SA, were undertaken by a multidisciplinary group consisting of Dr C. Zambas office, Team coordinator, EDAFOS S.A., K. and P Tokmakides, G. Tsokas and V. Konstantinides. The Directorate of Conservation of Ancient and Modern Monuments of the Greek Ministry of Culture studied and performed the conservation and protection of the ancient marks and writings, the masonry linings, the rock surfaces etc. The construction was undertaken by EDRATEC S.A. under the supervision of the Directorate for the Restoration of Ancient Monuments of the Ministry of Culture. The Local Ephorate of Antiquities performed limited archaeological excavations and advised on the construction of the works. EDAFOS SA and Dr C. Zambas office acted as Technical Consultants for the duration of the works.

The studies for the restoration works and their application are presented by Lyberis et. al. (2014), Angistalis and Kouroumli-Arend (2014), Zambas et. al. (2016), Angistalis et. al. (2018) and Zambas (2017).

The restoration, maintenance and protection measures applied to the tunnel included:

- Limited Reconstruction of masonry linings.
- Partial filling of open faults with stones and mortar.
- Combination of stainless-steel mesh with stainless steel rock anchors to enhance the stability of the tunnel crown.
- Lightly anchored stainless-steel mesh to protect against micro rock falls.
- Anchored mortar mantle reinforced with stainless steel mesh to enhance the stability of the roof or tunnel sides. This was applied above lined sections in areas non-visible by the visitors.
- Earth bags filled with lightweight dry concrete for the protection of sides of roof collapses in non-visible areas.
- Stainless steel canopies for the protection of visitors against rockfalls.
- Heavy-duty stainless-steel grates to cover the side trench, protect the edges of the trench and allow safe walking over it.
- Rehabilitation of both North and South entrances.
- Lighting along the tunnel.

Use of shotcrete mantles was avoided in areas visible by visitors. The viewing of the unique geological formations was safeguarded as the tunnel is not only a technical but also a geological monument.

Pins were installed at various locations for measuring convergence of the tunnel walls, particularly along the masonry lined sections.

THE INSPECTION OF 2026

General

The inspection was conducted in January 2026. The whole tunnel was inspected and photographed, and spot checking of conversion measurements were made. A comparison of the current conditions with conditions in 2016 was made. The rehabilitations, the support measures and the protection measures were found to be in excellent condition. The condition along some selected characteristic locations is presented.

Support of cavern above Roman lining (Ch. ≈15-50)

This type of intervention was applied exclusively in one section, between Ch. 15 and Ch. 50, where a robust Roman lining had been installed. This lining was primarily designed to safeguard the functionality of the aqueduct from the continuously collapsing roof and sidewalls rather than to provide active structural support, effectively acting as a canopy (analogous to the modern ones installed during the recent restoration works, see next paragraph).

The collapse of a low-strength, thinly bedded rock mass, composed of platy, marly limestones alternating with marls, above the vault of the Roman lining formed an impressive cavern—a "chimney failure" in tunneling terminology—along this section of the Eupalinos Tunnel (see Figure 2). This failure is not visible to visitors moving within the Roman lining, and its exact dimensions were fully revealed only during the restoration works. The geometry and scale of the cavern were also influenced by the presence of major longitudinal and transverse discontinuities relative to the tunnel alignment, as well as by the broad bending of the bedding planes, which facilitated rock mass detachment. Notably, recent archaeological evidence indicates that during the Byzantine period (6th–7th centuries AD), this cavern served as a refuge. The maximum height of the cavern reached approximately 7.5 m above the Roman vault, while the thickness of the collapsed material was on the order of 5 m. Prior to its partial removal, this debris pile left an open space of about 2.5 m below a crown formed in an extremely poor rock mass with numerous unstable, overhanging blocks (see Figure 2). Roof collapses were apparently evolving risking a probable daylighting of the “chimney”.

Considerable measures were applied comprised of: (a) rock scaling; (b) application of a shotcrete mantle (7–30 cm thick), reinforced with stainless steel mesh (Ø6/200 mm) and 2m-long, Ø16 mm stainless steel rock bolts installed in a nominal 1x1m grid pattern to enhance the stability of the cavern roof and walls; (c) partial unloading of the Roman lining through the removal of approximately 1.7 m of the 5m-thick collapsed debris; and (d) placement of bags filled with lightweight dry concrete to provide confinement and additional support to the lower part of the cavern sidewalls.

Finally, the protection of the area was supplemented by reinforcing the mortared, arched, stone masonry of the Roman lining—which bears the load of the remaining fallen debris—using pins and grout injections.

During the 2026 inspection, the interventions were found to be in pristine condition. There were no signs of deformation in the cavern roof or walls, such as shotcrete cracking or overloading of the anchor plates, while the light concrete bags remained intact (see Figure 2).

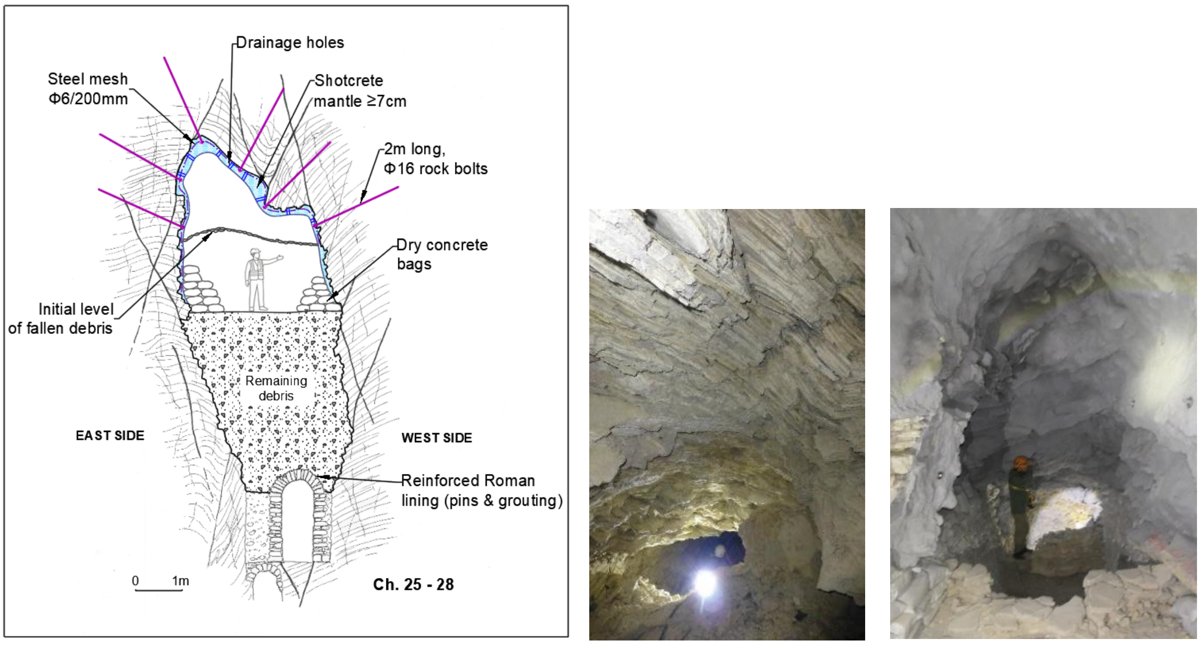
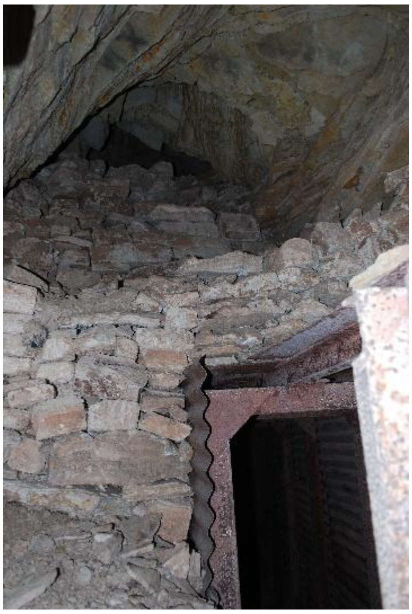


Figure 2. *Cross section with the implemented support measures within the cavern above Roman lining (left). Pre-intervention rockmass condition in the cavern (middle). Post-intervention state during the 2016 inspection, displaying shotcrete, rock anchors, and dry concrete bags (right).*

Stainless-steel canopies

In three specific sections—between Ch. 49–63.7, Ch. 397–399, and Ch. 530–533—where the tunnel had suffered major roof and sidewall collapses resulting in a considerable enlargement of its cross-section, stainless-steel canopies were installed in addition to anchored stainless-steel netting (see the dedicated section below). In these cases, the protected walkways provide additional security by shielding visitors from potential large-scale instabilities; heavier stabilization would have required a shotcrete mantle that would obscure the visibility of the geological formations. The observation of the tunnel's original form and its geological features constituted a core design criterion.

Figure 3 illustrates the canopy installed by the German Archaeological Institute (DAI) between Ch. 49 and Ch. 63.7, where the failure mechanism mirrored that observed between Ch. 15 and Ch. 50, resulting in a chimney failure with a crown extending more than 3 m above the original tunnel roof. The rusted canopy was removed, the area was cleared and the walls and roof of the opening were stabilized by an anchored netting (Figure 4). Then, a new stainless-steel canopy was installed. The canopy is 1.4 m wide and serves as an extra protection against roof collapses. Locally it was adopted to also act as support of partially detached rock wedges (Figure 4).



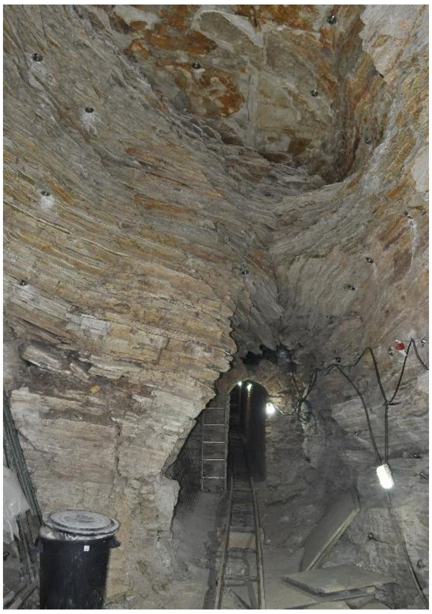


Figure 3. *Pre-intervention sheltered walkway constructed by the DAI (left); the same location during installation of rock support measures after clearing (right).*

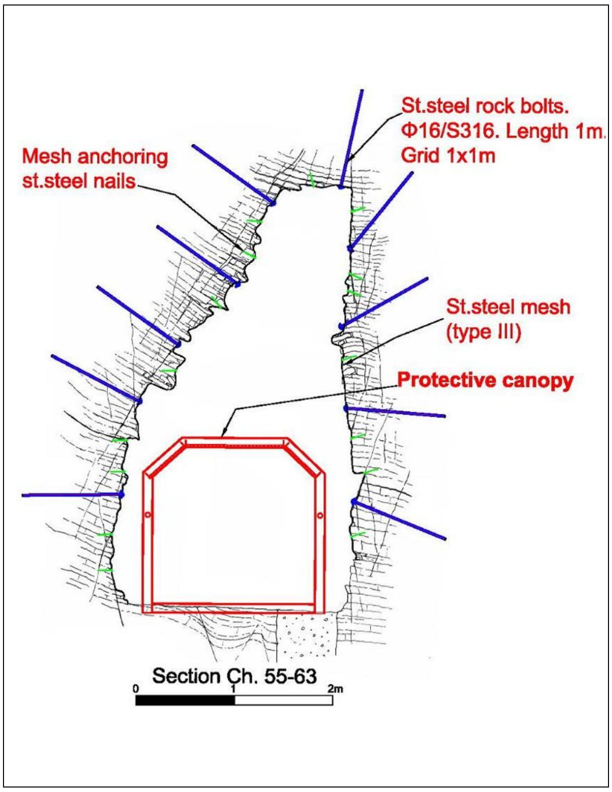


Figure 4. *Cross section detailing the protective canopy and the rock support measures at the section between Ch. 49 and Ch. 63.7 (left). View of the installed canopy during the 2026 inspection (down right). Detail illustrating canopy protecting the visitor walkway from active rock falls (up right).*

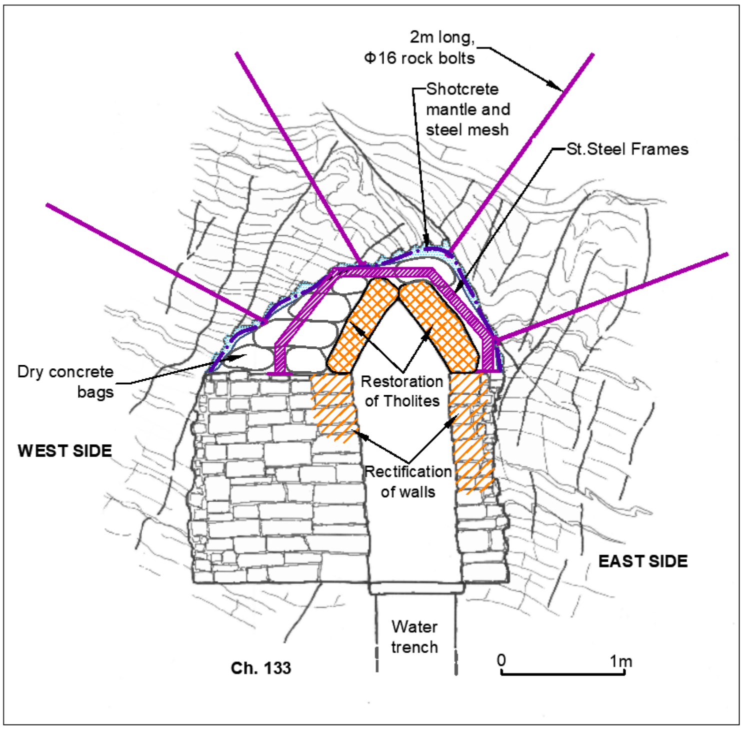
During the 2026 inspection, the canopy was found to be in perfect condition (Figure 4). Small, detached rock fragments were successfully retained by the anchored netting.

Local reconstruction of archaic lining

During the Archaic period, possibly immediately following the completion of the tunnel excavation (Kienast, 2005), a heavy lining had to be constructed along three distinct sections characterized by highly unstable geotechnical conditions. The total length of this Archaic lining spans 165 m.

The lining was constructed using voluminous stone blocks that demonstrate a superb level of stonemasonry, forming an elegant, inverted V-shaped arch at the crown—composed of precisely fitted "tholites" (arch stone blocks)—positioned below the crown of the tunnel. The masonry lining touches the sides of the excavation but leaves some space on the crown as, most probably, roof collapses occurred along the lined sections.


Figure 5. *Distorted section between Ch. 130 and Ch. 136 prior to reconstruction (left). Representative view of the restoration process following the removal of the tholites (right).*



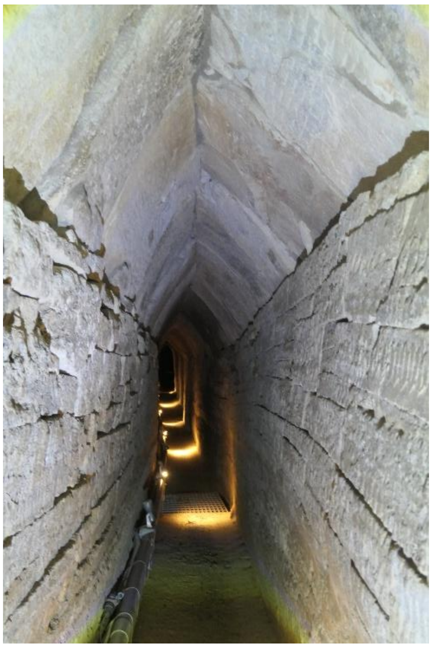


Figure 6. *Cross section with the implemented support measures for the reconstruction of the archaic lining (left). Finalized view of the section during the 2026 inspection (right).*

While the greater part of this Archaic lining was preserved in excellent condition, five sections—between Ch. 96–100, Ch. 109–117, Ch. 130–136, Ch. 178.6–183.0, and Ch. 1030–1036—suffered excessive deformation, characterized by severe tunnel convergence and structural distortion and fractured masonry blocks, alongside extensive rock fracturing. The section between Ch. 96 and Ch. 100 was partially reconstructed during past interventions by the DAI (Jantzen et al., 1973; Zambas, 2017). Three sections (Ch. 130–136, Ch. 178.6–183.0, and Ch. 1030–1036) were reconstructed during 2013-16 restoration works. These interventions aimed to improve tunnel functionality and mitigate the risk of a potential structural collapse.

The reconstruction of the archaic lining posed significant engineering challenges for both the Consultant and the Contractor. It required continuous adaptation of design during construction, as actual conditions of the rock were revealed. Critical factors included the structural condition of the existing lining, the quality of the surrounding rock mass, and the limited space available for the interventions.

Figures 5 and 6 illustrate the case between Ch. 130 and Ch. 136 of the archaic lining. Within this section, twelve pairs of tholites exhibited significant inward displacement—reaching up to 34 cm—accompanied by severe fracturing and the opening of construction joints. These deformations were driven by the gravitational collapse of a highly weak, thinly bedded to shaly rock mass. This lithology consists of platy, marly limestones, marls, and green tuffaceous alternations with sheared argillaceous shale intercalations. Structurally, the zone is characterized by a synclinal fold axis and conditions of increased moisture. After the dismantling of the tholites and the debris removal it was revealed that a cavern, up to approximately 1 m in height, had formed directly above the original tunnel crown.

During the 2026 inspection, the restored Archaic lining was found to be in excellent condition, fitting seamlessly with the remaining lined sections (see Figure 6). No signs of visible deformation were observed.

For the monitoring of tunnel convergence, stainless-steel reference pins were installed on the tunnel walls, and the distance between them was measured using a vernier-type measuring device. From the completion of the restoration works in 2016 until 2022, systematic monitoring of convergence was carried out along the tunnel. Convergence exceeding 1 mm, with a slightly increasing trend, had been recorded at the monitoring stations located at Ch. 128, Ch. 133, Ch. 134, and Ch. 178.

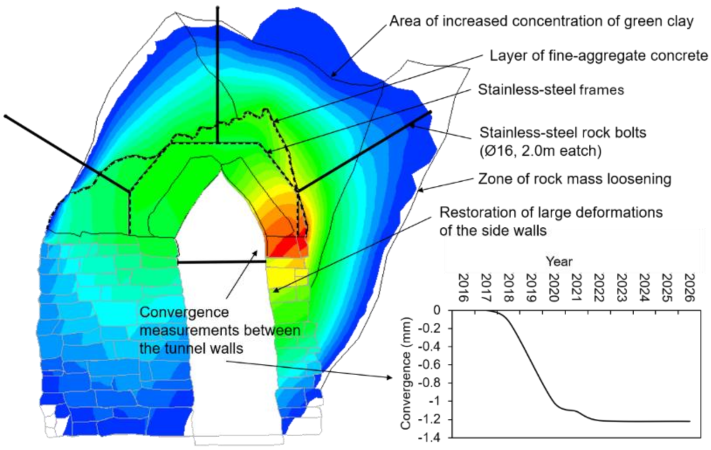


Figure 7. *Performance of the restoration works, based on numerical simulation and field measurements.*

During the 2026 inspection, new convergence measurements were performed at selected representative locations along the lined sections of the tunnel, one of which was located at Ch. 134. Figure 7 presents the monitoring results at this location for the period 2016–2026 (Xenophon Briolas was monitoring the tunnel and kindly provided the convergence measurements for the period 2016 to 2024). The corresponding convergence at the monitoring location prior to the restoration works was of the order of 14 cm, of which approximately 7 cm were geometrically restored by horizontal jacking during the restoration works. According to the measurements, the convergence after restoration appears to have been stabilized at 1.2 mm. This displacement is very small and may be associated either with post construction contact deformations between masonry blocks that were gradually mobilized, or with the rebound of the sidewalls, which were jacked back horizontally to widen the passage by up to 7 cm.

To investigate the performance of the stabilization measures and of the reconstructed lining, a numerical analysis was carried out using the finite element method. Explicit joint elements were introduced to simulate the individual stone blocks of the Archaic masonry lining. Back analyses were first performed to reproduce the deformation mechanism of the archaic lining. The analyses considered the local geological conditions and the initial lining geometry. The phenomenon was associated with the development of loads from the surrounding rock mass, particularly from the right-hand side of the lining, where an increased concentration of green clay is present.

Then, an analysis of the applied restoration measures was performed to investigate the relaxation of the rockmass required to produce the measured convergence of 1.2mm. This relaxation is significantly lower than the one that caused the deformations before the application of the support measures.

Figure 7 presents the calculated displacement distribution after relaxation of the rock mass, calibrated to reproduce the final measured convergence of approximately 1.2 mm at the monitoring location. The performance of the restoration works appears to be satisfactory, as the loads transferred from the rock mass to the lining are significantly reduced compared with those that the lining had been required to withstand before the restoration measures.

The largest calculated displacements remain concentrated along the right-hand side of the section, owing both to the local geological particularity and to the structural configuration of the lining itself.

Partial filling of geological faults

A wide range of major faults and large-scale discontinuities are encountered throughout the tunnel—particularly within the limestone formations—which are either open or exhibit significant cave-like voids along their strike.

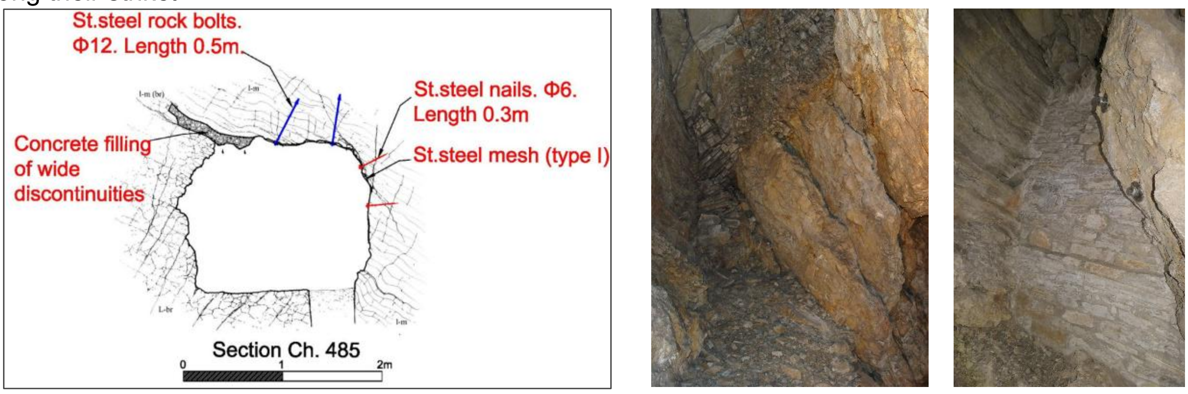


Figure 8. *Design cross-section detailing the geological fault backfilling (left). Pre-intervention view (middle), and Post-intervention view during the 2026 inspection of the fault zone at Ch. 531 after infilling with mortared masonry (right).*

Figure 9. *Pre-intervention view (left), and Post-intervention view during the 2026 inspection of the fault zone at Ch. 626 stabilized by pressure grouting (right).*

These zones are characterized, to varying degrees, by rock mass loosening, the presence of cataclastic zones, and of unstable rock fragments.

While many of these zones were mitigated through the installation of anchored wire mesh (see below), many cases required pressure grouting (see Figure 9), whilst some larger voids necessitated backfilling with mortar (Ch. 621-625), or even the construction of a masonry wall (Ch. 509 and 531, see Figure 8). For these interventions—such as at Ch. 621-625—stones were sourced from the material stockpiled by the DAI between Ch. 49 and Ch. 63. These were bound using a color-tinted lime mortar, in full compliance with the provisions of the Conservation Study.

During the 2026 inspection, the backfilled faults were found in pristine condition, fitting well with the surrounding rockmass. No signs of deformation or fracturing were found.

Anchored stainless steel net

To mitigate instability risks and prevent the detachment of rock blocks or fragments from the tunnel crown and sidewalls, an anchored stainless steel wire mesh system was installed at approx. 30 locations along the tunnel. A primary advantage of this stabilization method is that it maintains the full visibility of the tunnel surfaces. This exposure allows for continuous visual inspection of the significant geological formations while preserving the heritage value of this ancient engineering achievement.

Depending on the volume of the potential rockfalls, three types of stainless steel rock anchors were utilized, featuring diameters of Ø 6, 12, or 16 mm, and lengths ranging from 0.3 to 2.5 m. The design of the spherical anchor heads was further modified at the onset of construction to achieve the lowest possible profile, thereby minimizing protrusion from the rock face while securing the mesh or wire ropes. Additionally, they incorporated a custom-designed circular bearing plate to ensure the specified clamping force.

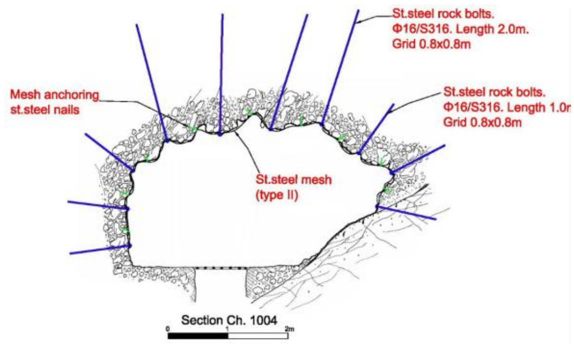


Figure 10. *Design cross-section detailing the anchored stainless steel netting system between Ch. 999 and Ch. 1007. Pre-intervention view of the cataclastic rock mass of the section structure showing the temporary protection measures (right).*

Three types of flexible wire-rope nets were deployed based on the severity of the localized instabilities, classified by rope diameter and grid spacing (Ø / mesh size in mm): Type I (Ø 1 / 30 mm), Type II (Ø 2 / 40 mm), and Type III (Ø 3 / 60 mm). These wire-rope nets were secured to the anchor plates using steel cables (diameters ranging from Ø 3 to Ø 5 mm), complemented by specialized end connectors and wire-rope clamps.

The lighter Type I net was deployed to mitigate minor rockfalls and spalling. It was paired with Ø 6 mm dowel pins (0.3 m in length), the primary function of which was to secure the netting to the rock face. It was implemented at 12 locations. For larger instabilities, Type II nets (implemented at 15 locations) and Type III nets (implemented at two locations) were utilized in conjunction with longer anchors (0.5-2.5 m). These anchors designed for the dual purpose of rockmass stabilization and net retention. In addition, intermediate threaded Ø 6 steel rod anchors and auxiliary wire ropes were installed within cave-in zones. This configuration optimized the profile conformity of the mesh against the irregular rock face, thereby minimizing voids.

Finally, Ø 6 mm (0.3-m-long) dowel pins and Ø 12 mm (0.5-m-long) short anchors were utilized without netting. These were typically combined with the sealing of open rock discontinuities and joints using lime mortar—and occasionally grout injection—to stitch overlapping bedding planes along the tunnel crown.

During macroscopic observations conducted in 2026, all rock bolts exhibited excellent structural integrity, showing no indications of plate deformation, loosening, or displacement. The wire-rope nets remained fully functional, effectively retaining detached fragments derived primarily from fault zones and weak shale–marl intercalations, though localized sections required minor clearing and retensioning.

Figures 10 & 12 illustrate the tunnel section between Ch. 999 and Ch. 1007, which intersects a tectonic breccia zone developed within the limestone host rock along a major fault bounding the 'Kastro' hill (see also Figure 1). This zone is characterized by a highly irregular morphology resulting from previous roof collapses, intense fracturing, and structurally unstable rock masses. To protect this section, a Type II steel wire-rope net was deployed in combination with 1.0-m and 2.0-m-long Ø 16 mm rock anchors. In highly unstable zones, a double-layered net was installed. Mitigation measures also included the scaling of highly unstable blocks, selective grouting, and the sealing of wide discontinuities.

Figure 11. *View of the installation of the support system during the 2026 inspection (left). Close-up detail illustrating the wire netting retaining detached rock fragments (right).*

Stainless-steel grates

To optimize monument accessibility, the side trench was covered with heavy-duty, removable stainless-steel grates, expanding the visitor walkway area. In addition, recessing the grate deck slightly below the adjacent tunnel floor—in order to align with the gallery "bridges" between the open trenches—establishes a continuous pedestrian lane with increased clearance headroom (Zambas, 2017). The load-bearing framework consists of transverse beams anchored into the opposite trench walls, supporting pairs of longitudinal beams. Furthermore, the degraded western shoulder of the trench—previously stabilized with temporary concrete—was cleared and meticulously reconstructed using hydraulic lime mortar, preserving the ancient rock-cut geometry.

Figure 12. *View during construction showing the installation of the transverse steel beams supporting the grates (left). Completed structural grates during the 2026 inspection at Ch. 945 (right).*

During the 2026 inspection, the authors verified the robust and still flawless condition of the grates. Their installation has drastically improved both the overall appearance and functionality of the tunnel. Figure 12 illustrates a typical example of the grates application and Figure 13 compares the old trench protection with the new grates.

Figure 13. *The pre-existing steel grill prior to the intervention at Ch. 568 (left). Installed structural grates during the 2026 inspection at Ch. 960 (right).*

CONCLUSIONS

The Eupalineio tunnel on Samos is a globally recognized masterpiece of ancient engineering. The extensive stabilization, restoration, and protection works implemented between 2013 and 2016 successfully mitigated long-term geological hazards, ensuring the monument's preservation and visitors' safety. Based on the site assessment conducted in January 2026—marking a full decade of operational monitoring—the following major conclusions can be drawn:

(a) Excellent Structural Condition: The applied rock support measures remain in excellent condition. High-tensile stainless steel netting is tight, rock bolts remain firmly attached, and the protective steel canopies are in pristine condition.

(b) Protection against rockmass instabilities: The support measures function properly, providing high-level stabilization to the tunnel's roof and sidewalls. All the main problematic sections of the rockmass, which were recorded in detail during the design phase and addressed during construction, do not show any signs of deformation. The localized accumulation of rock debris behind the protective netting is strictly restricted to intensively fractured and very weak zones, a behavior that was entirely expected and is currently safely contained.

(c) Minimal Lining Deformation: There are no signs of active deformation across the reconstructed masonry linings and the supported section above the Archaic lining. Interpretation of the convergence measurements confirms this stability, revealing only minimal deformation, of the order of 1.5 mm. This minor movement was observed in the section between Ch. 130 and Ch. 136 and, according to the 2026 measurements, appears to have been stabilized. Displacements of a similar magnitude have also been recorded in the section between Ch. 178.6 and Ch. 183; however, their stabilization remains to be confirmed through future measurements. This very limited displacement is attributed to the initial response of the support system to the imposed stress conditions immediately after construction.

(d) Material Sustainability: The systematic use of stainless steel for all metallic support elements (and titanium for the restoration of the tholite blocks) has proven highly successful, offering excellent durability against the humid, underground microclimate of the tunnel.

(e) Side Trench Grates: The stainless-steel grates covering the side trench are in excellent condition after a decade of service. They have proven highly effective in ensuring visitor safety while maintaining the visibility of the historic water supply channel.

To maintain the structural integrity of the monument and ensure visitor safety, continuous inspection and monitoring is recommended. Periodic clearing of debris accumulated behind the netting and occasional re-tensioning is required.

Finally, continuous lighting has caused the growth of algae on some of the tunnel walls. The installed lighting requires frequent part replacements. The installation of a new modular lighting system is recommended, operating briefly only when visitors are crossing the relevant section of the tunnel.

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Dr C. Zambas office coordinated the group of designers including EDAFOS S.A., Geotechnical and Geological Studies, Prof.K. Tokmakides, Aristotle University of Thessaloniki and P. Tokmakides, Surveyors, Prof. G. Tsokas, Aristotle University of Thessaloniki - Geophysical investigations and V. Konstantinides & Associates, Electrical installations.

K. Papastamatiou and his team from the Directorate of Conservation of Ancient and Modern Monuments of the Greek Ministry of Culture prepared studies for the conservation and protection of the ancient marks and writings, the masonry linings, the rock surfaces etc.

The Archaeological Ephorate of Samos, headed by Maria Viglaki, greatly assisted during the design. Panagiotis Hatzidakis, who succeeded Maria Viglaki, assisted in the construction.

The Directorate for the Restoration of Ancient Monuments with D. Svolopoulos, Director (succeeded by Th. Vlachoulis), P. Hadjimitros, Head of the Constructions Section, A. Kalfas, V. Soulis, G. Soras and S. Spyropoulou as supervisors, managed the construction works carried out from 2013 till 2016.

The construction was undertaken by EDRATEC S.A. headed by A. Tampakopoulos. Xenophon Briolas was the Foreman of the worksite and V. Spiliadis, S. Tampakopoulou and Ch. Iliakopoulos were the main company executives.

EDAFOS SA and Dr C. Zambas office in cooperation with Dr K. Papantonopoulos acted as Technical Consultants for the construction.

Pavlos Triantafillidis, acting Director of the Samos Archaeological Ephorate, instituted the current inspection of the tunnel.

REFERENCES

Angistalis, G., Dounias, G., Tsokas, G., & Zambas, C. (2018). “The Walls of Eupalinos Aqueduct, Samos Island, Greece -Description, Pathology and Proposed Restoration Measures”, Bulletin of the Geological Society of Greece, Vol. 53(1), 193-228. doi:http://dx.doi.org/10.12681/bgsg.18710

Angistalis, G., Kouroumli Arend, Our. (2014). Outline of the Restoration Designs of Eupalinos Tunnel, Samos Island, Greece. 2nd Eastern European Tunnelling Conference. 28 September - 01 October 2014. Athens. Greece.

Jantzen, U., Felsch, R. C. S., Hoepfner, W. & Willers,W. D. (1973). Samos 1971, Archäologischer Anzeiger 1973, 72 ff.

Jantzen, U., Felsch, R. C. S. & Kienast, H. (1973). Samos 1972, Archäologischer Anzeiger 1973, 401 ff.

Kienast, H. (1995). Die Wasserleitung des Eupalinos auf Samos, DAI, Samos XIX, Bonn.

Kienast, H. (2005). The aqueduct of Eupalinos on Samos, Translation from German by David Hardy, Archaeological Receipts Fund, Directorate of Publications, Athens.

Lyberis E., Dounias, G., Ntouroupi, A., Sotiropoulos L. & Angistalis, G. (2014). The geology of Eupalinos Aqueduct, Samos Island, Greece, 2nd Eastern European Tunnelling Conference, 28 September - 01 October 2014, Athens, Greece.

Stamatiades, E., (1894) On the Eupalinos tunnel on Samos (Περί του ορύγματος του Ευπαλίνου εν Σάμω), Samos 1884, (in Greek)

Synesios, (1899) Treatise on the Eupalineio tunnel (Πραγματεία περί του Ευπαλινείου ορύγματος), Samos 1899, (in Greek)

Zambas, C., Dounias, G. and Angistalis, G. (2016), “The Aqueduct of Eupalinos on Samos, Greece and Its Restoration”, Chapter 5 in Underground Aqueducts Handbook, Edited by A. N. Angelakis, E. Chiotis, S. Eslamian & H. Weingartner, CRC Press – Taylor & Francis, 2016, pp 63-80

Zambas, C. (2017) More light in the tunnel of Eupalinos. Mitteilungen des Deutschen Archaologischen Instituts - Athenische Abteilung, Band 131/132, 2016/2017, pp. 99-145