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ScienceDirect

Procedia Structural Integrity 62 (2024) 1105–1111

Structural Integrity Procedia

www.elsevier.com/locate/procedia

II Fabre Conference – Existing bridges, viaducts and tunnels: research, innovation and applications (FABRE24)

# Anti-icing using the heat recovered in the Lagoscuro tunnel

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**Abstract**

In the context of promoting local energy sources with low environmental impact, energy geostructures are more and more being explored. This paper will describe an example of a technological system able to achieve the anti-icing of the motorway pavement through the exploitation of heat from the adjacent tunnel. Taking advantage of the current motorway refurbishment plan fostered by Autostrade per l'Italia (ASPI) and the activities planned for the Lagoscuro tunnel, located along the A26 motorway in the Genova province, the opportunity for geothermal energy exploitation is being tested in a full-scale prototype. The details of the experimental site setup will be revealed together with the characteristics of the pavement anti-icing solution.



*Keywords:* Tunnel rehabilitation; Existing tunnels, Geothermal energy; Anti-icing.

## 1. Introduction

Over the last decades, global warming has become one of the major issues to cope with. Human activities are responsible for a global surface temperature increase of approximately 1.1°C since the pre-industrial age, thus leading to changes in weather extremes and irreversible losses to ecosystems. This is the consequence of massive greenhouse gas emissions: as of 1750, $CO_2$, $CH_4$ and $N_2O$ concentrations in the atmosphere have increased by

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2452-3216 
10.1016/j.prostr.2024.09.146

+47%, +156% and +23%, respectively (IPCC, 2023). Nowadays, the building sector plays a non-negligible role, thus taking part in about 18% of the global $CO_2$ eq. direct and indirect emissions (IPCC, 2014). Towards the 1.5°C Paris climate goal, the paramount purpose is the reduction of such emissions through, but not exclusively, renewable energy supply, sustainable land management, green transportation and energy-efficient buildings.

In this context, energy geostructures could play a relevant role. These are ground-contact structures engineered to accomplish the twofold aim of structural support and heat exchange (Brandl, 2006; Laloui & Di Donna, 2013). The thermal activation of such structures is achieved by embedding heat exchanger pipes inside them. The circulation of a heat carrier fluid within these pipes, usually water or water-glycol mixtures, allows the extraction or the injection of heat from or into the surrounding ground.

Starting from the 80s, energy geostructures have been successfully constructed, taking advantage of a variety of geotechnical structures, such as foundation piles (Pahud & Hubbuch, 2007; Prodan et al., 2021), retaining walls (Sterpi et al., 2018; Barla et al., 2023), tunnel linings (Adam & Markiewicz, 2009; Barla et al., 2019), shallow foundations (Baralis & Barla, 2021) and anchors (Adam, 2008). Recently, road pavement structures have been used to exchange heat, too (Motamedi et al., 2021). Among them, the thermal activation of tunnels has raised increasing interest in the past few years. Indeed, compared with other energy geostructures, energy tunnels reap the benefits of a larger surface in contact with the ground, thus improving heat exchange. Furthermore, tunnel intrados lies in contact with the underground environment. Depending on its aerothermal conditions, this could act as a heat source or a heat sink, thus affecting the thermal efficiency of energy tunnels. However, full-scale implementations have only dealt with new tunnelling projects so far.

Taking advantage of the current motorway refurbishment plan fostered by Autostrade per l'Italia S.p.A. and the activities planned for the Lagoscuro tunnel, located along the A26 motorway in the Genova province, the opportunity for geothermal energy exploitation is being tested in a full-scale prototype. The heat harvested and stored from and into the Lagoscuro tunnel is being exploited to anti-ice the road pavement outside the tunnel portal.

To the best of the Authors' knowledge, the prototype to be installed in the Lagoscuro tunnel constitutes the first worldwide example of thermal activation of an existing tunnel during refurbishment.

## 2. Thermal retrofitting of the existing tunnel heritage during rehabilitation

A schematic of a tunnel standard life cycle is shown in Fig. 1. Following their planning, design and construction, tunnel infrastructures require routine inspections and ordinary maintenance to guarantee service continuation in safe conditions. As a function of the evolution in time of the tunnel attention class (MIMS, 2022), routine inspections could highlight the need for deep inspections. These are deep fact-finding surveys aimed at localizing, identifying and quantifying every single defect affecting the tunnel lining. Based on the defect quantity, typology and seriousness, an appropriate strategy is identified among:

- rehabilitation, which involves major repair works aimed at extending tunnel nominal service life. E.g., tunnel vault and/or invert integral/partial replacement (Agresti et al., 2022),
- upgrading, which involves major repair and construction works aimed not only at extending tunnel nominal service life but also at changing the intended use. E.g., existing tunnel enlargement to host more motorway lines or railway tracks (Lunardi et al., 2011),
- disposal, which involves repurposing existing operating or abandoned tunnels. E.g., hosting art exhibitions (De Feudis et al., 2023b), bicycle ways, etc.

Despite being resilient, the increasing ageing and decay affecting tunnel infrastructures require refurbishment to guarantee service continuation in safe conditions (De Feudis et al., 2023a). Therefore, the increasing need for rehabilitation/upgrading interventions, as well as disposal plans for reusing abandoned and disused ones, could represent an opportunity to investigate and develop solutions to retrofit the existing tunnel heritage not only from the structural but also from the sustainable viewpoint.

Just as for new tunnelling projects (Barla et al., 2019), thermally activating existing tunnels while rehabilitating or repurposing represents an opportunity to take advantage of ground-trapped energy that would otherwise remain unexploited.

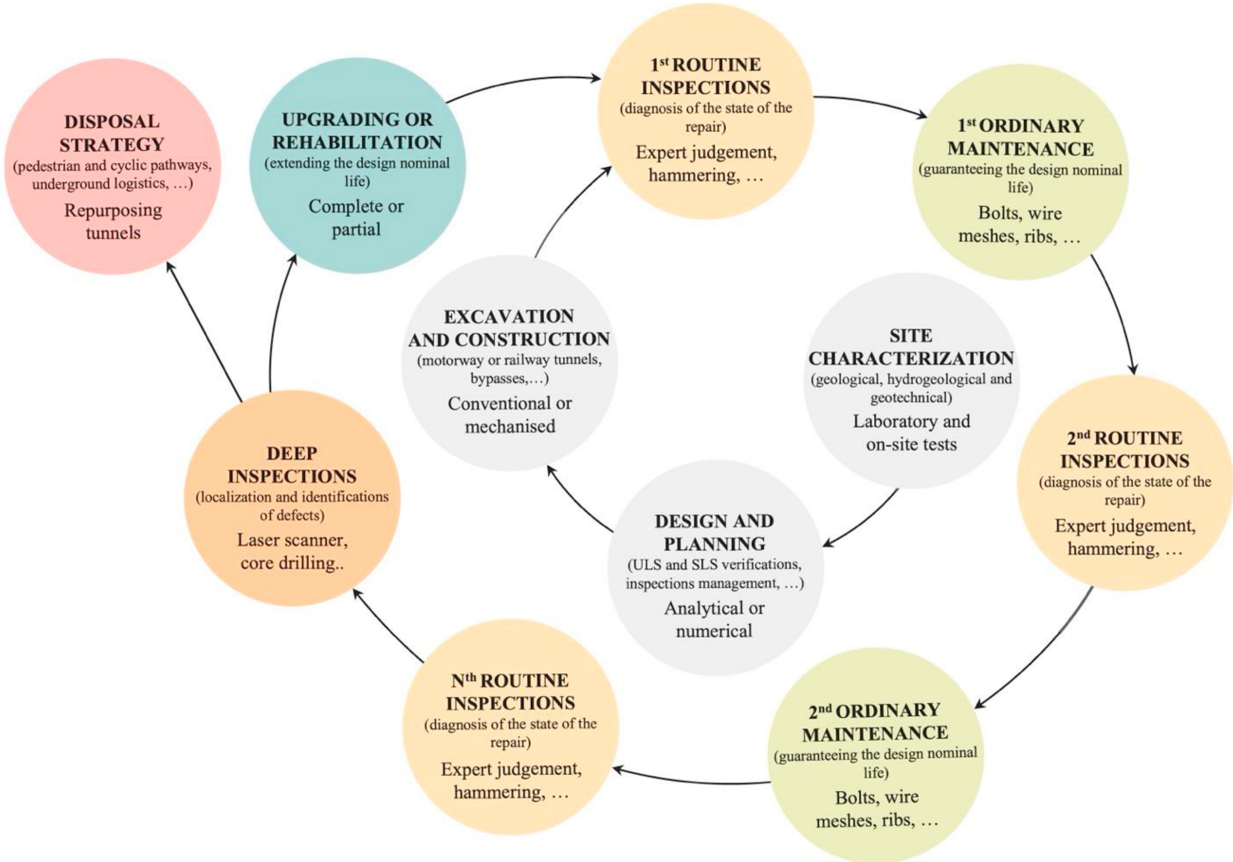


Fig. 1. Schematic of a tunnel infrastructure standard life cycle.

## 3. The thermo-structural retrofitting solution for the Lagoscuro tunnel

### *3.1. The Lagoscuro tunnel rehabilitation workflow*

The Lagoscuro tunnel is a twin-tube motorway tunnel located on the A26 motorway, in the Genova province. Deep inspections revealed a widespread ageing status of the right tube. In particular, together with other superficial defects (honeycombing, gravel pockets, voids in the lining, etc.), complex and ramified crack networks were identified that could potentially trigger the detachment of concrete blocks with volumes larger than 1.0 $m^3$. Additionally, these cracks represent a preferential way out for groundwater. Indeed, being built during the '70s, the Lagoscuro tunnel lacks any impermeabilization systems, thus hastening the process of concrete degradation in time.

Therefore, deep inspection outcomes highlighted the need for a massive refurbishment process. Accordingly, the Lagoscuro right tunnel rehabilitation work envisages spraying a reinforced concrete intrados shell and installing an impermeabilization system, thus extending its nominal service life by 50 years. The realisation phases are depicted in Fig. 2 and listed in the following:

- pre-consolidation of the existing tunnel vault through fiberglass dowels (Fig. 2b), thus ensuring worker safety towards local block detachments,
- partial demolition of the existing lining through punctual milling or hydro-demolition for an overall thickness of 35.0 cm (Fig. 2c),
- after having removed potentially unstable blocks, regularisation of the tunnel wall through a 3.0 cm thick shotcrete layer (Fig. 2d),

- installation of the waterproofing, consisting of a TPO (thermoplastic polyolefins) sheeting coupled with a double geotextile layer, and the drainage systems (Fig. 2e),
- positioning of steel lattice structures (working as reinforcement) and casting-in-place of the reinforced concrete intrados shell through sprayed concrete (Fig. 2f).

In such a rehabilitation workflow, the partial demolition of the tunnel vault would allow limiting the milling or hydro-demolition thickness to a minimum extent, thus achieving a threefold aim. Firstly, the residual portion of the existing lining would join the pre-consolidation, acting as short-term support during the rehabilitation process. Secondarily, as the Lagoscuro tunnel runs through a serpentinite formation, this modus operandi would avoid any interaction with the rock mass behind the lining. Finally, the shorter the demolish extent, the lower the related costs.

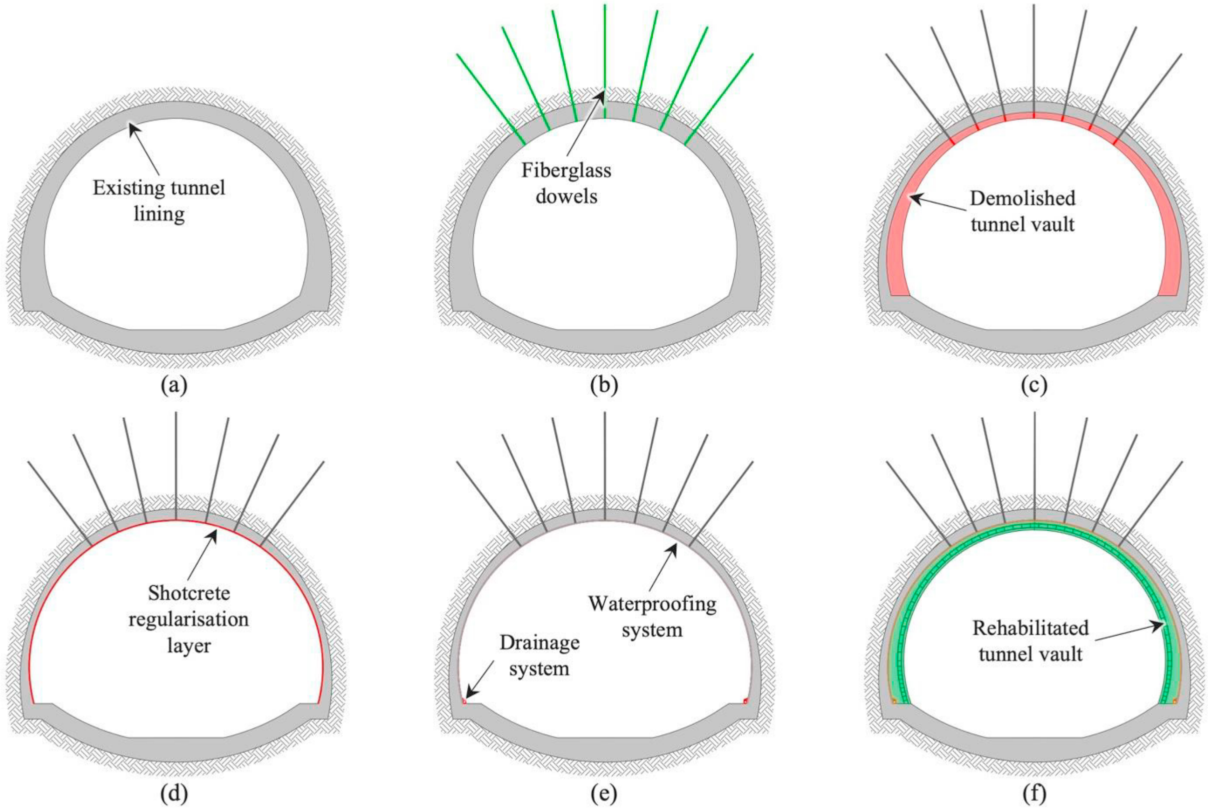


Fig. 2. Lagoscuro tunnel rehabilitation phases: a) status quo, b) pre-consolidation through fibreglass dowels, c) partial demolition of the existing tunnel vault, d) milled walls regularisation through shotcrete, e) installation of the waterproofing and drainage systems, f) cast-in-place of the reinforced concrete intrados shell through spritz beton and steel lattice structures acting as reinforcements.

### *3.2. The thermal activation of the Lagoscuro tunnel while rehabilitating*

Throughout the above-mentioned rehabilitation workflow, a 14.0 m long section of the Lagoscuro tunnel is being instrumented for heat exchange by hand-clamping heat exchanger pipes on the tunnel wall after the completion of the demolishing phase. These would be subsequently embedded in the shotcrete regularisation layer, thus being arranged between the existing and the renovated vault and adding only one phase more to the realisation workflow.

Furthermore, being pipes located behind the waterproofing and drainage systems, negligible thermal stresses and strains are expected to be induced to the reinforced concrete intrados shell. Indeed, waterproofing sheeting acts as a thin insulation layer and additionally it would allow the pipe circuit to be less affected by underground environment airflow, too. This generally reveals to be essential whether a so-called cold tunnel is getting instrumented for geothermal exploitation. Due to the scarce length, limited overburden and large diameters, the underground environment of cold tunnels is generally strongly affected by the outdoor climate, thus not embodying an additional heat source. Commonly, motorway tunnels fit into this category.

Lastly, the pipe arrangement discussed so far would allow handling unlikely disruptions easier since potential losses of the heat carrier fluid would be funnelled towards the drainage tubes by the waterproofing sheeting.

A 3D view of the thermo-structural retrofitting solution is depicted in Fig. 3.

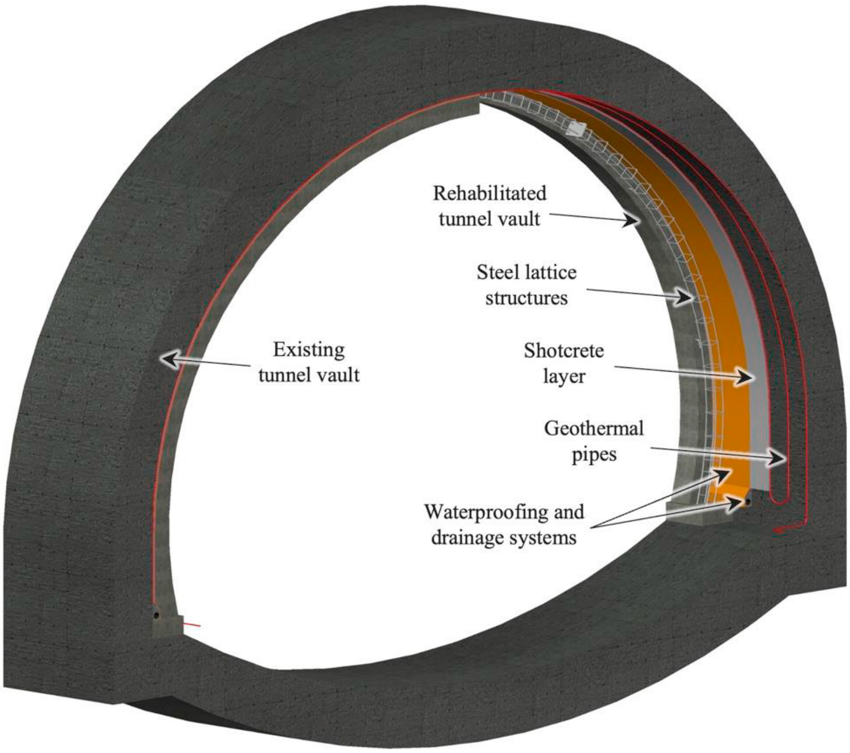


Fig. 3. Conceptual 3D view of the thermo-structural retrofitting solution proposed for the Lagoscuro tunnel.

## 4. The anti-icing system for the road pavement

Together with the tunnel lining rehabilitation, the refurbishment of the motorway pavement is envisaged, too. Taking advantage of this, the geothermal energy exploited in the Lagoscuro tunnel is being used to cool down in summer and heat up in winter part of the rest area outside of the Ovada tunnel portal. For this purpose, a second circuit of pipes is planned to be embedded in the base layer of the newly renovated pavement, at a buried depth of 12.0 ÷ 14.0 cm, thus virtually not undermining the structural stability of the outward wearing and binder layers. To the same end, heat exchanger pipes are planned to be arranged perpendicularly to the direction of traffic so that the “U” bends are localised towards the verges of the motorway. These bends, indeed, were revealed to be the weakest part of the overall structure (Zhou et al., 2021).

Hence, during winter, the above-mentioned pavement would behave as a hydronic heated pavement (H.H.P.) to the end of avoiding the deposition of hoar frost on the paving surface. On the other hand, during summer, this would behave as a pavement solar collector (P.S.C.) to the end of gathering solar thermal energy to be stored in the rock mass surrounding the tunnel and to be reused for the upcoming winter season. Additionally, this could also slow down the development of rutting damages during summer seasons.

An operating schematic of the overall system is provided in Fig. 4.

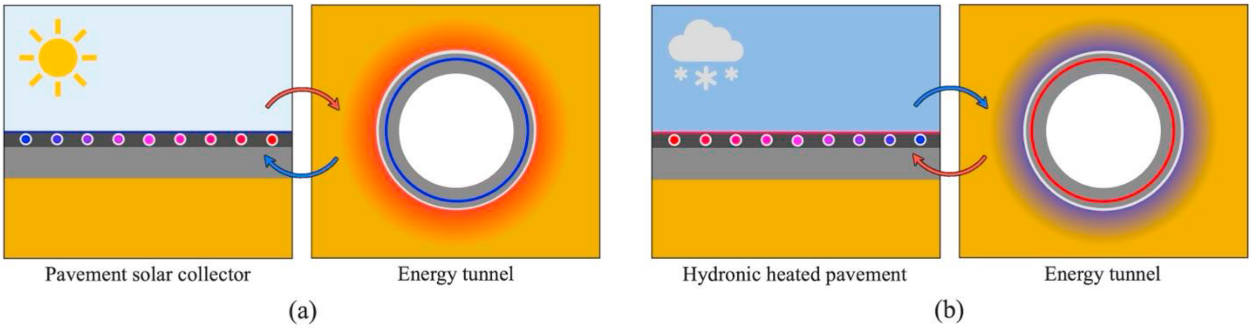


Fig. 4. Operating schematic of the overall system during (a) summer and (b) winter to be applied in the Lagoscuro tunnel.

## 5. Monitoring and control systems

The entire geothermal system is planned to be monitored and remotely governable through an online platform. Concerning the thermo-structural behaviour of the reinforced concrete intrados shell, strain gauges and thermistors are being tied to the steel lattice structures to monitor their deformations during the operativity of the system. The aerothermal conditions of the underground environment are planned to be investigated, too. To this end, outdoor temperature transducers and a hot wire anemometer are being installed along the thermo-active section of the tunnel. It is envisaged to arrange other temperature transducers in the rest area pavement, thus allowing the verification of the functionality of the system. Energy and flow rate counters are planned to be arranged on both supply and return hydraulic collectors to quantify the amount of heat extracted from or injected into the rock mass and dissipated into or collected from the pavement in winter and summer respectively.

The monitoring system was designed to be wholly wireless. Sensors are being wired up to dataloggers that, in turn, communicate wirelessly with a router. This, besides allowing the online stock and share of data on an online dedicated platform, was designed to communicate with a smart hydraulic pump such as to activate the entire system only when needed, depending on the monitoring outcomes.

## 6. Summary and further developments

This paper focused on disclosing some details related to the first worldwide conversion of an existing tunnel into an energy geostructure. The Lagoscuro tunnel is being thermally activated during the realisation of its rehabilitation intervention which consists of spraying a reinforced concrete intrados shell after having milled or hydro-demolished part of the existing lining. Throughout the rehabilitation workflow, a solution to instrument the Lagoscuro tunnel for heat exchange was suggested. This corresponds to hand-clamping heat exchanger pipes on the tunnel wall after the demolishing phase and subsequently embedding them in the shotcrete regularisation layer. The geothermal energy exploited through the thermo-activation of a 14.0 m long section of the tunnel will be used to heat up or cool down the pavement of the rest area outside of the Ovada tunnel portal. Hence, this pavement will behave as H.H.P. during winter and as a P.S.C. during summer. The entire system will be monitored and automatically controlled through a smart hydraulic pump that activates based on the monitoring outcomes.

This full-scale experimental site will be paramount to:

- directly test the applicability of the thermo-structural solution that has been identified for the Lagoscuro tunnel and understand the related installation issues, if any,
- check the proportion between the length of the thermo-active tunnel and the effectively anti-iced road surface and assess the economic attractiveness of the system,
- calibrate a thermo-hydraulic numerical model to investigate the functionality of the system based on different outdoor climatic conditions (air temperature, solar irradiance, humidity, etc.).

Finally, beyond producing clean renewable thermal energy, anti-ice, or even de-ice, road pavement through geothermal systems would allow shelving traditional salt-spreading trucks, thus reducing aquifer pollution and avoiding salt-corrosion to customer cars. In the long-term, moreover, as a result of higher initial investments, these systems are generally revealed to be more effective (if well-managed) and cheaper (in the entire life cycle) with respect to traditional systems.

## Acknowledgements

Funder: Project funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.3 - Call for tender No. 1561 of 11.10.2022 of Ministero dell'Università e della Ricerca (MUR); funded by the European Union – NextGenerationEU.

Award Number: Project code PE0000021, Concession Decree No. 1561 of 11.10.2022 adopted by Ministero dell'Università e della Ricerca (MUR), CUP - to be indicated by each Beneficiary, according to attachment E of Decree No. 1561/2022, Project title "Network 4 Energy Sustainable Transition – NEST".

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