The 365 km tunnels assessment along ASPI Motorways Network – Key findings addressing risk analysis procedures and structural conditions evaluation and strategy of interventions

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The 365 km tunnels assessment along ASPI Motorways Network – Key findings addressing risk analysis procedures and structural conditions evaluation and strategy of interventions

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Abstract

An extraordinary assessment plan, performed on 365 km of motorway tunnels, has been carried out in Italy since 2020 starting with detailed inspections and testing. Hundreds of laser scanning kilometres and ground-penetrating radargrams, thousands of concrete compressive strength tests, endoscope inspections and flat-jack tests have been performed so far. Tens of thousands structural defects were detected and several square meters of temporary safety measures installed as well. This allowed to acquire a significant amount of knowledges about the current condition of the asset. According to the process defined by the new Italian Regulations, the dataset analysis provides an insight into the condition of the asset, guiding the entire maintenance process. The visual and detailed inspections frequency is driven by the simplified risk analysis outcome and further safety evaluation are designed based on multidisciplinary criticality. A comprehensive approach, based on in-depth knowledge of the characteristics of the existing tunnel, has been engineered for structural risk, with a focus on tunnel "history" (excavation stages and techniques, construction materials, etc.), design and dimensioning approaches (e.g. Kommerel's graphical method), identified as standard methods for the tunnel construction period from literature review. Additional analyses are carried out for likely local structural failure modes of tunnel lining (punching and flexural strength of residual concrete layers, spalling hazard of concrete thickness anomalies due to temperature variations). When re-lining is needed, the design of a new shell aimed to ensure at least the same structural performance of the original one is addressed, including seismic loads that were neglected in the original design. The

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tunnel assessment, from inspections to re-lining works passing through risk analysis, is an on-going process open to be improved in the upcoming years within a wider asset management strategy.

Keywords: Road tunnels assessment, Detailed tunnel inspection, Asset management dataset, Risk classes, Re-lining works, Existing tunnel analysis

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1. Introduction

Italy has a complex transport system mainly due to its geography and orography. Moving people and goods in the most safe, fast and efficient way is nowadays crucial and strategic at the same time. Road transport mode is historically the most widely adopted in the Country.

In this picture the resilience of the motorway is one of the main objectives that Autostrade per l'Italia S.p.A. (ASPI), the main motorway Concessioner in Italy, is pursuing.

ASPI is actively involved in the maintenance and operation of the asset on behalf of the Ministry of Transport. The main purpose is to ensure travellers, as well as employees, safety and continuity of the operations within a competitive level of service.

An extraordinary assessment plan was launched in 2020 on the road tunnel side, triggering about 365 km of ASPI network (595 tunnels). In 2020, the assessment program was mainly characterized by a reactive approach to maintenance due to few adverse events, one of which is unfortunately well known.

Tunnels were visually inspected and tested through laser scanning (LSC) and ground-penetrating radargrams (GPR) as well as cored to compressive strength of 50 m each.

Many tunnels were visually inspected simultaneously along the motorway. At that time, due to the pandemic, the level of traffic was the lowest ever recorded since many decades and this facilitated construction sites, minimizing the effect on users of the infrastructure.

The reactive maintenance was leading to treatment of structural defects in a short time frame (3 to 6 months) opening several construction sites at the same time, increasing the user related traffic risk when approaching the sites.

A transition from reactive to preventive maintenance approach was then needed among the Organizations and partially promoted by the new Guidelines: 23rd August 2022 "G*uidelines for existing tunnel's risk and safety evaluation and monitoring system installation*", referred to as "LLGG" in the following sections.

The new code comes spread in layers (1 to 4) characterized by an increasing level of detail:

- **Level 0** – Asset information such as location, length, lining material, construction age etc.;
- **Level 1** – Asset conditions in terms of scored defect detected during the visual inspection. In this phase, extension (k_1), magnitude (k_2) and severity (G) of the defects are collected in forms for further analyses;
- **Level 2** – The levels 0 and 1 gathered information feeds a process whose purpose is to assign a simplified risk score to each 20 m long segment of the tunnel for each thematic area (structural global and local, geological, seismic, hydraulic and transport related). The score can be low, mid-low, mid-high or high. The six thematic areas (except for hydraulic) are then combined into a global risk rate. Level 2 defines the visual inspection frequency of the asset, by the risk rate associated to structures (both for global and local mechanisms).
- **Level 3 & 4** – Whenever risk rate coming from level 2 is mid-high a preliminary safety evaluation is performed to better investigate the parameters which lead to such rate of risk in the specific thematic area. If the risk rate is confirmed engineering judgement and calculation are put in place to identify the mitigation measures, or eventually monitoring systems, needed to keep the risk acceptable (Level 4). When the risk rate is higher Level 3 is glossed over. At Level 4, the engineered process to residual level of safety evaluation includes calculation and approaches, in some cases, directly derived from the past.

The LLGG multilevel approach helps Organisations like ASPI, with a very large asset portfolio, in prioritizing maintenance and expenditures.

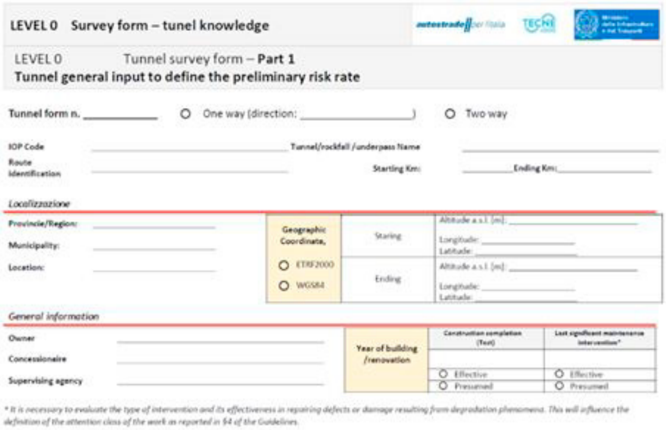
In the following sections the assessment program is described starting from the guidelines approach going through the treatment strategies with an insight to the asset management.

Nomenclature

$k_{1,i}$	single defect extension used in the calculations
$k_{1,t}$	extension of defect type in the section
$k_{2,i}$	single defect intensity used in the calculations
$k_{2,t}$	intensity of defect type in the section
G_i	single defect severity
$G_{i,t}$	severity of defect type in the section
H	hazard
V	vulnerability
E	exposure
CdA	preliminary risk rate or "*Class of Attention*"

2. Asset information

Risk evaluation and treatment prioritization start from a deep knowledge of the asset. Level 0 is the first step of the assessment process where tunnels affected by the guidelines are analysed to collect the minimum amount of information about (but not limited to) location, owner, designer, length, number of lanes, construction age, structure layout and materials, surrounding conditions of the soil, average number of vehicles per day, percentage of commercial vehicles etc.. Data are collected and printed in standard spreadsheet (Fig. 1).



LEVEL 0 Survey form – tunel knowledge

LEVEL 0 Tunnel survey form – **Part 1**
Tunnel general input to define the preliminary risk rate

Tunnel form n. ____________ ○ One way (direction: ________________) ○ Two way

IOP Code ____________ Tunnel/rockfall /underpass Name ____________
Route identification ____________ Starting Km: ________ Ending Km: ________

Localizzazione

Provincie/Region: ____________
Municipality: ____________
Location: ____________

Geographic Coordinate, ○ ETRF2000 ○ WGS84	Staring	Altitude a.s.l. [m]: ________ Longitude: ________ Latitude: ________
	Ending	Altitude a.s.l. [m]: ________ Longitude: ________ Latitude: ________

General information

Owner ____________
Concessionaire ____________
Supervising agency ____________

Year of building /renovation	Construction completion (Test)	Last significant maintenance intervention*
	○ Effective	○ Effective
	○ Presumed	○ Presumed

** It is necessary to evaluate the type of intervention and its effectiveness in repairing defects or damage resulting from degradation phenomena. This will influence the definition of the attention class of the work as reported in §4 of the Guidelines.*

Fig. 1 Standard printout data for Level 0.

The amount of data required is quite large, more than 600 parameters, but the level of detail can be coarse at this early stage. The set of data gained at this stage will be deepened during the subsequent levels. Some of the parameters are directly involved in the simplified risk evaluation of the asset promoted by Level 2 and in the safety analysis of Level 3 and 4.

The Level 0 activity does not require the fulfilling of the 600 requested parameters in a row, it can be accomplished by subsequent runs of digging for knowledge.

3. First inspection

When it comes to Level 1, of the multilevel approach, a first visual inspection is carried out on the asset.

The purpose of the first inspection is to confirm and deepen the data collected at the Level 0, gather further information about the actual geometry and structural characteristics of the tunnel, in addition to assess the degree of deterioration of the liner.

First inspection starts with high pressure water cleaning of the lining surface. In fact, the inner road tunnel environment is quite aggressive and the exposure of the liner to vehicles smog makes hard to notice any possible evolution of structural defects. Any screen and water-sheet are dismounted in order to have free access to the surface of the concrete (or to inspect the masonry in some other cases).

The inspection is not limited to the tunnel lining only, the access areas of the tunnel and non-structural support elements are analyzed as well.

Before Engineers inspect the tunnel, some tests are performed:

- Ground-Penetrating Radargrams (GPR) – a transmitter is used to generate electromagnetic waves across the concrete liner. Waves travel time is measured and distances from obstacles or anomalies inside the concrete detected. The test is used to evaluate the thickness of the liner, the presence of voids or steel rebars and the presence of hidden defects.

The test is performed by longitudinal sections (**Errore. L'origine riferimento non è stata trovata.**). across the tunnel in central top position and on the sides. A minimum of 3 sections are required for two lanes tunnel, 5 for three lanes one.

- Laser Scanner (LSC) – the travel time of the light emitted by a source, hitting the lining surface and coming back to the receiver is recorded. The output is a cloud of points representing the actual geometry of the tunnel (Fig. 2b,c,d**Errore. L'origine riferimento non è stata trovata.**).

coring for concrete strength – concrete is cored and specimens collected each 50 meters for simple compression testing. The strength of the liner has an impact on the evaluation of the simplified structural risk for local mechanism as well as for the subsequent safety evaluations.

During inspection, defects are recorded by position, relative dimensions k_1 (from 0 to 1), intensity k_2 (0.2 – 0.5 – 1.0) and severity G (from 1 to 4).

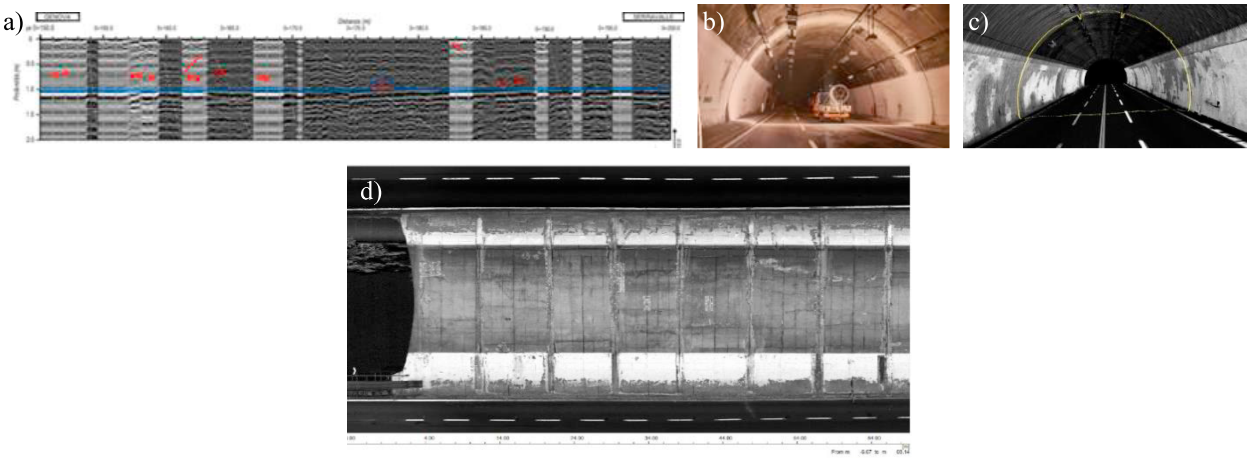
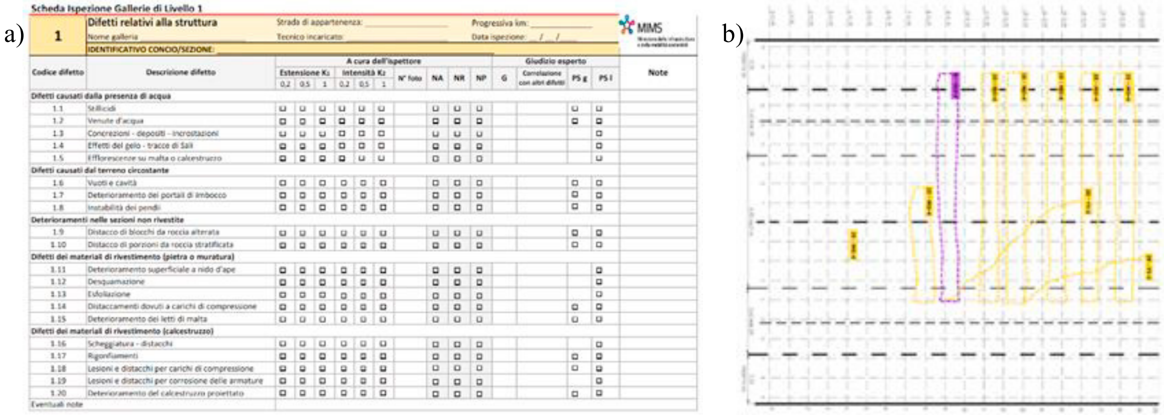


Fig. 2 a) GPR section layout, b), c) and d) LSC.

Defects are listed in a spreadsheet (Fig. 3a) and represented into a 1 m by 1 m grid plan layout (Fig. 3b).



a)

Scheda Ispezione Gallerie di Livello 1

1 **Difetti relativi alla struttura**

Nome galleria ____

Strada di appartenenza: ____

Tecnico incaricato: ____

Progressiva km: ____

Data ispezione: __/__/____

IDENTIFICATIVO CONCIO/SEZIONE: ____

Codice difetto	Descrizione difetto	A cura dell'ispettore										Giudizio esperto				Note
		Estensione K_1			Intensità K_2			N° foto	NA	NR	NP	G	Correlazione con altri difetti	PS g	PS l	
		0.2	0.5	1	0.2	0.5	1									
Difetti causati dalla presenza di acqua																
1.1	Stillicidi	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
1.2	Venute d'acqua	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
1.3	Concrezioni - depositi - incrostazioni	☐	☐	☐	☐	☐	☐		☐	☐	☐				☐	
1.4	Effetti del gelo - tracce di Sali	☐	☐	☐	☐	☐	☐		☐	☐	☐				☐	
1.5	Efflorescenze su malta o calcestruzzo	☐	☐	☐	☐	☐	☐		☐	☐	☐				☐	
Difetti causati dal terreno circostante																
1.6	Vuoti e cavità	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
1.7	Deterioramento dei portali di imbocco	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
1.8	Instabilità dei pendii	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
Deterioramenti nelle sezioni non rivestite																
1.9	Distacco di blocchi da roccia alterata	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
1.10	Distacco di porzioni da roccia stratificata	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
Difetti dei materiali di rivestimento (pietra o muratura)																
1.11	Deterioramento superficiale a nido d'ape	☐	☐	☐	☐	☐	☐		☐	☐	☐				☐	
1.12	Desquamazione	☐	☐	☐	☐	☐	☐		☐	☐	☐				☐	
1.13	Esfoliazione	☐	☐	☐	☐	☐	☐		☐	☐	☐				☐	
1.14	Distaccamenti dovuti a carichi di compressione	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
1.15	Deterioramento dei letti di malta	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
Difetti dei materiali di rivestimento (calcestruzzo)																
1.16	Scheggiatura - distacchi	☐	☐	☐	☐	☐	☐		☐	☐	☐				☐	
1.17	Rigonfiamenti	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
1.18	Lesioni e distacchi per carichi di compressione	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
1.19	Lesioni e distacchi per corrosione delle armature	☐	☐	☐	☐	☐	☐		☐	☐	☐				☐	
1.20	Deterioramento del calcestruzzo proiettato	☐	☐	☐	☐	☐	☐		☐	☐	☐			☐	☐	
Eventuali note																

Fig. 3 a) Annex C2, b) Defect representation.

k_1 and k_2 are assigned during the inspection whilst G is under the Engineering judgement responsibility who will tag a defect with high severity (G=4) when this could lead to collapse of the structure, mid-high severity (G=3) when leading to an out of service of the asset.

Defects are then grouped by type in each tunnel element[1] evaluating the size and intensity of the cluster as follows:

$$k_{1,t}=\sum_{i=1}^{n} k_{1,i} \tag{1}$$

$$k_{2,t}=\sum_{i=1}^{n} \left(k_{2,i}\cdot k_{1,i}\right)/k_{1,t} \tag{2}$$

$$G_t = \sum_{i=1}^{n} G_i \cdot k_{1,i}/k_{1,t} \tag{3}$$

These parameters are then combined, at Level 2, to have a vulnerability rate (low to high).

4. First inspection

The background of knowledge coming from Level 0 and 1 is analyzed at Level 2 to have a simplified indicator of the risk. The preliminary risk rate (CdA) of the tunnel is computed combining hazard, vulnerability and exposure of six different disciplines:

$$CdA = H\ x\ V\ x\ E \tag{4}$$

global structural and geotechnical risk (SGG), local structural risk (SLO), seismic risk (SIS), landslide risk (GEO), transportation risk (STD) and hydraulic risk (IDR). To do so about 60 indicators (primary and secondary) are gathered and combined. Primary and secondary parameters are characterized by a rate (low, mid-low, mid-high, high).

The specific disciplines risk rates are then consecutively combined according to (5) to have the representative risk of the tunnel.

$$CdA = \{[(CdA_{SGG} + CdA_{SLO}) + CdA_{GEO}] + [(CdA_{SGG} + CdA_{SLO}) + CdA_{SIS}]\} + CdA_{STD} \tag{5}$$

---

[1] A tunnel is usually broken down into 20 m long elements unless geological or structural discontinuities are identified.

Hydraulic stands separately (Fig. 4**Errore. L'origine riferimento non è stata trovata.**).

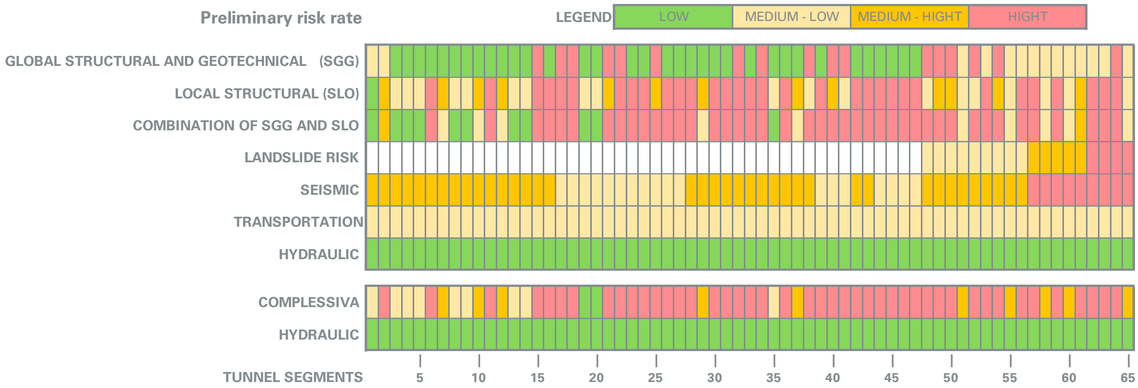


Fig. 4 CdA.

The overall risk of the tunnel is represented by the worst one among its sections. The percentage of sections in a specific risk rate classification is calculated and called "*index of diffusion*".

Level 2 allows to preliminary shortlist tunnels based on specific risks. Mid-high to high values of risk lead the disciplines involved to undergo safety evaluation respectively in Level 3 and 4.

In both cases a detailed inspection, including testing, is planned within a year.

Level 3 is focused on the re-evaluation of the CdA concentrating on deepening the board of knowledge gathered at Level 2 whilst, in Level 4, accurate evaluations are carried out to estimate the safety factor of the involved risk disciplines.

During these activities (Level 3 and 4) the asset, is constantly monitored proportionally to its structural criticalities (briefly SGG+SLO CdA) which drive the subsequent visual inspection frequency (both ordinary and detailed).

LLGG also includes a Level 5 analysis, which only applies to strategic tunnels. At this stage, advanced models are put in place to evaluate the resilience of the infrastructure considering the logistic importance of the tunnel itself, analysing the interaction between the tunnel and the transport system of the geographic area and finally studying the consequences of a closure on the social and economic context.

5. Detailed inspection and safety evaluation

5.1. Detailed inspection

Detailed inspection has characteristics similar to visual first inspection; nonetheless, it includes some tests previously requested by the company in charge of the activity and results are gathered before entering the tunnel.

Testing is mainly addressed in deepening the knowledge of the areas suspected of hidden deterioration of the concrete liner. Heritage from Level 1 is driving test plans including:

- endoscope (VE) - when GPR provides clues for potential defects under the concrete lining, VEs are then performed by drilling small diameter holes through the liner down to the rock surface. A cctv equipped probe and a tape measure are used to report the layers where concrete, voids or deteriorated concrete are encountered;
- flat jack - stress state of the liner is a needed information for further safety analyses. The concrete surface is cut to measure the displacement of the edges. The original edges position is then restored by applying a flat-jack load;

- pacometer test - a digital tool enabling the detection, the direction and the diameter of the rods in the reinforced concrete in a non- destructive way. It consists of a probe generating a magnetic field and a controller measuring the power dissipated by the metallic object as result of the magnetic induction from the probe. This test can be used to confirm the presence of rebars in specific tunnel sections.

During detailed inspection on site, if any criticality is detected, additional tests and an accurate safety evaluation may be requested to the Process Owner[1].

Level 3, based on the detailed inspection results, investigates deeper the parameters which led to a mid-high specific level of risk.

If the risk is confirmed Level 4 is activated for further safety evaluation. In the following sections some of the methods adopted for structural global and local risk are described.

5.2. Global safety evaluation

The methods to evaluate the residual safety factor associated to a global mechanism of failure of the structure is strictly linked to the context (presence/absence of primary concrete liner, geological conditions etc...). When the tunnel liner is unloaded, the surrounding soil has good properties (sound rock) and the cross-sectional model is almost symmetric an historical approach to assess liner performance can be adopted. Conversely, finite element analysis is needed to replicate the actual condition of the liner in terms of stress and strain. Here the historical method of "*Kommerell*" is presented, which was widely adopted before '70 to design tunnels in Italy. It is based on a graphic procedure to evaluate the load, and its eccentricity, among the arch sections (Fig. 5a).

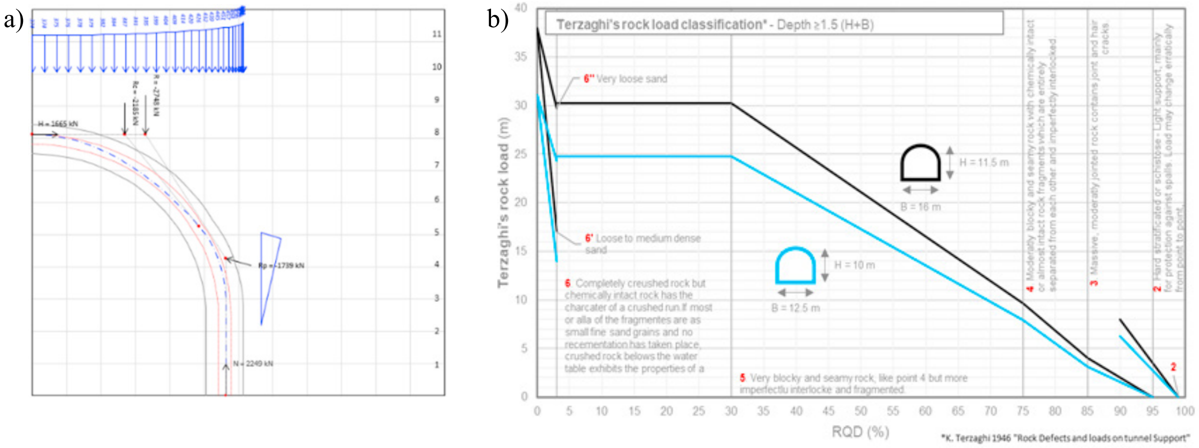


Fig. 5 a) Kommerell method, b) Terzaghi's rock load classification (2, 3 lanes tunnel).

The method is based on three main assumptions:

- symmetry of the model (load and geometry);
- sides distributed reaction of the surrounding soil to balance the vertical loads;
- compression of the arch only – the load shall be included in the central t/3 where t represents the thickness of the lining.

---

[1] Supported by the Engineering Judgement.

The method has been implemented in a user-friendly spread sheet to iterate the calculation increasing vertical loads to the highest compatible with the structure. The thus found load is then compared with the expected one (Fig. 5b) based on rock mass quality designation (RQD) (Bieniawski).

When the expected load is lower than the maximum one the performance of the lining is adequate and the global failure mechanism unlikely.

5.3. Local safety evaluation

The methods to evaluate the residual safety factor associated to a local mechanism of failure of the structure is strictly linked to the local condition of the lining (construction and exogenous defects). Three methods are used to assess the influence of the anomalies of the concrete lining:

- punching check on the residual thickness;
- bending check on the concrete plate;
- critical temperature variations influence (Aiello et al.).

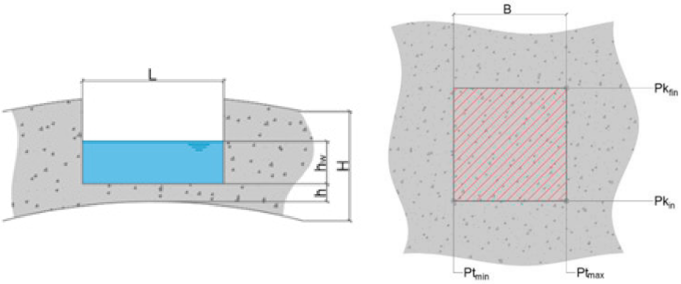


Fig. 6 Under thickness of the concrete.

In all cases a thin concrete layer is investigated for likely failures mode and mitigation measures consequently prescribed. Furthermore, that a more comprehensive approach is adopted by the Engineer who is in charge of evaluating the level of deterioration of the asset. Defects distribution, presence of cracks or water leakages and their combination feed a more complex engineering judgement process that leads to the definition of a monitoring and/or treatment plan on the tunnel.

6. Tunnel intervention strategy

Level 4 purpose is to highlight the criticalities and possible solutions in terms of monitoring systems or intervention strategies. Tecne S.p.A., engineering company of Autostrade per l'Italia S.p.A., tends to group intervention strategies with the effect these have on asset conditions:

- IMS – is the treatment approach closer to extraordinary maintenance "*Intervento di Manutenzione Straordinaria*". The aim is to reduce vulnerability for mainly local mechanisms of failure without increasing the strength of the structure.
- IRS – stands for structural reinforcement "*Intervento di Rinforzo Strutturale*". In this, the aim is to reduce vulnerability for global mechanisms and increase the structural strength of the system.
- TRS – stands for "Tunnel Renewal Strategy". The renewal solution is aimed to extend the tunnels life cycle of at least additional 50 years, through the construction of new lining, able to replace the structural function of the existing one and to ensure waterproof condition and suitable performance under seismic events.

The optimal solution to be implemented mainly depends on Organization culture about preventive maintenance, existing lining conditions, impact on traffic, time, costs, waterproofing effectiveness, job-site organization, reusability of the solution, propensity to innovation.

On a higher organizational level, decision making on tunnel maintenance strategy is moving to a more robust asset management approach also by developing a dedicated tool to compare several alternative intervention scenarios in terms of risk, costs and residual value of the asset.

7. Tunnel renewal strategy

Due to the early stage tunnel assessment experience mainly based on reactive maintenance, the TRS approach was developed since end of 2021 by the following main steps:

1. analysis of the assessment program and technical solutions applied during 2020/2021;
2. collection of existing tunnel industry state of the art, including bibliographic research, looking for solutions adopted around the word for tunnel rehabilitation both in continuity of operation and closure;
3. definition objectives and requirements of relining works (§7.1);
4. definition of a set of typological interventions and related design methods and verification criteria (§7.2);
5. involvement of construction market to develop mechanized and technologically innovative solutions (§7.3);
6. organizing field tests and application of pilot projects (§7.4);
7. standardization and recurrent applications based on return of experiences coming from pilot projects (§7.4);
8. continuous improvement (§7.5).

7.1. Objectives and requirements

The main objectives and requirements defined in the TRS context are:

- safety for operation, especially in case of alternation of works/traffic operation and works during traffic operation;
- safety for workers (protection, mechanization);
- minimization of impact on traffic (protection, mechanization);
- quickness of intervention (mechanization);
- high structural performance (pre-casting operations, high-performing concrete mix);
- installation of an effective and durable waterproofing system;
- sustainability and conservation of the asset by recycling, use of green machine and materials.

Key role to ensure safety conditions and reduce time and traffic impact is played by the minimization of the existing concrete milling, especially when a not negligible stress state is detected in the lining during detailed inspection. This allows also to reduce the supports and soil treatment needed to fulfill the required safety standard during concrete demolition, maintaining low uncertainties regarding rock mass stability.

The minimization of existing concrete milling can be obtained by lowering the road pavement and reducing new lining thickness resorting to high performance materials.

Once the new lining is built, the maintenance of its structural capability is ensured by the mandatory installation of a waterproofing system and drainage system is mandatory to take out water from deterioration root causes during the operational stage.

Every project is accompanied by environmental performance of the works, assessed by LCA methodology, which has become an additional item for designing and choosing between engineering solutions.

7.2. Typological interventions

Nine different typological interventions were defined:

A. complete demolishing of existing lining and cast in place of new concrete shell;
B. partial existing lining milling and concrete relining casted in place by precast concrete shell formworks (Fig. 7a);

C1. partial existing lining milling and relining by high performance shotcrete (Fig. 7b,c, Fig. 8a,b,c);
C2. partial existing lining milling and concrete relining by casted in place by modular steel formwork (Fig. 8d);
D. shallow existing lining milling and relining by implementation of liner plates (Fig. 9a);
E. existing lining milling and relining by implementation of precast concrete segments (Fig. 9b);
F. steel liner coupled to existing lining;
G. installation of steel ribs and shotcrete, with or without existing lining milling;
H. platform remodulation (lowering) to avoid existing lining milling combined with inner lining based on previous typological interventions.

Each intervention has been detailed evaluated to define its proper field of application based on a pros and cons analysis and the specific design methods and verification criteria are developed correspondingly.

7.3. Involvement of construction market

As part of TRS, the construction market was approached by engaging specialized players by issuing the challenge regarding the development of innovative solutions.

The search for these solutions was mainly directed in the area of materials, seeking innovative materials with high structural performance, as well as in the area of mechanization for the installation of the components of the new lining shell. Not Disclosure Agreements have been signed with the selected companies and suppliers to ensure the exclusive use of the information shared in the design phase, then followed by specific agreements in order to manage future patent developments of original solutions as well.

7.4. Testing, pilot projects and recurrent applications

Less than two years from the statement of TRS main steps, all the typological interventions have been preliminary tested and the application of the related pilot projects completed or ongoing.

Deep involvement in the design and testing stage have been extended to members of Construction Company and all the technicians included in the process. It is also demonstrated mandatory training sessions and the availability of detailed method statement for each innovative technologies introduced by the design.

In addition, the daily technical support ensured by design teams during the progress of the works has been crucial to refine typological interventions, fix issues, record feedback and improve products and application processes. In this regard, it is worth to be noticed that the Construction Standards do not provide any facilitation for pilot projects, therefore the process entails unavoidable technical refinement during the works and possible related additional costs.

To date, seventeen TRS projects are under construction and almost half of them are already recurrent applications of the corresponding pilot project.

Fig. 7 a) “*Colle Marino*” tunnel construction site – relining by high strength shotcrete b) and c) “*San Fermo*” tunnel - Field test of shotcrete application

Fig. 8 a) and b) "*Manfreida*" tunnel construction site – relining by high strength shotcrete, c) Relining by high strength shotcrete - Pilot application at "*Manfreida*" tunnel, d) Relining by high strength fibre reinforced plain concrete - Pilot application at "Colle" tunnel

Fig. 9 a) Relining by liner plates - Pilot application at "*Castello*" tunnel, b) "*Poderuzzo*" tunnel - Field test of pre-cast concrete shell implementation

7.5. Continuous improvement

The next developments of TRS are aimed to the following main goals:

- implementation along the second tube of "*Colle Marino*" tunnel of shields system, to ensure relining works during the process of two lanes of motorway traffic (Fig. 10a);
- implementation along the second tube of "Colle" tunnel of the innovative steel formworks able to cast in

place concrete by continuous extrusion system, in order to speed-up the relining stage (Fig. 10b);

- finalization the strength tests campaign promoted by construction player involved in TRS process to qualify geopolymer concrete for implementation in relining works (Fig. 10c).

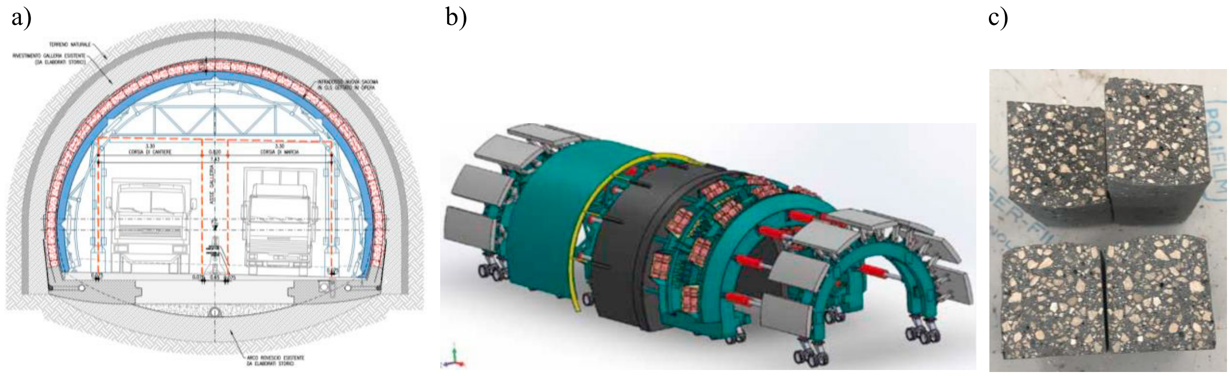


Fig. 10 a) Cross section of shields system, b) Perspective drawing of the continuous extrusion system, c) Geopolymers specimens involved by strength tests to the next implementation of geopolymer concrete in relining works

8. Conclusions

Tunnel assessment is an on going process for Autostrade per l'Italia S.p.A. The amount of information and experience acquired by its Engineering company (Tecne S.p.A.) and all the Operators involved in the activities, is constantly growing.

The monetary and economic value of the asset make any effort needed and worthy.

The reactive approach to maintenance has been overtaken and the Tunnel Renewal Strategy is now starting the standardization and recurrent applications stage to extend the tunnels life cycle of at least additional 50 years.

Beyond that, the company is looking forward to embrace a comprehensive tunnel asset management approach including data management, asset condition evaluation and tunnel tailored best intervention strategy going from corrective to preventive maintenance approach.

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