Italian guidelines for the risk classification, safety evaluation and monitoring of existing tunnels: An overview

Tunnelling for a Better Life – Yan, Celestino, Thewes & Eberhardt (Eds)

Italian guidelines for the risk classification, safety evaluation and monitoring of existing tunnels: An overview

Andrea Carigi* & Carmine Todaro
Politecnico di Torino, Turin, Italy

Giuseppe Silvestri
Consiglio Superiore dei Lavori Pubblici, Rome, Italy

ABSTRACT: The Italian transport network had a great expansion after World War II and a great number of tunnels were built. After 70 years, those tunnels are approaching their design lifetime. With more than 9000 tunnels extended for 2600 km of underground structures on the Italian national territory, the correct management of this asset is challenging, especially in the context of a complex road network.

To provide an integrated method to monitor and plan the maintenance actions for the different stakeholders on a national scale, a Guideline for the risk classification, safety evaluation and monitoring of existing tunnels has been implemented by the Italian Superior Council of Public Works and is now mandatory for roadways tunnels in Italy.The guidelines are structured in 5 levels with progressively increasing levels of knowledge requirements and detail of the investigation, where level 0 is dedicated to a census of all the available information about the tunnel, level 1 is dedicated to the inspections that have to be carried out with the help a specifically designed defect catalogue. Then, accordingly to the data collected, in level 2 a classification to prioritize further investigations, standard maintenance procedures, or ad hoc designs is regulated through a series of logical operators to ensure that the same classification procedure is used for all the tunnels in the national territory. This last level is subdivided into 6 fields with regard to specific critical phenomena that may lead to a risk to the proper functioning of the tunnel. Then, levels 3 and 4 are respectively dedicated to preliminary and accurate safety evaluations, while the last level regulates the maintenance of tunnels of strategic interest for the nation.

In this paper, a detailed discussion of the structure of the guidelines and about their application is presented.

Keywords: Tunnel, Knowledge, Maintenance, Inspections, Guidelines

1 INTRODUCTION

In the aftermath of World War II, Italy embarked on a plan of infrastructure development, expanding its transport network to accommodate the demands of a growing nation. A crucial component of this expansion was the construction of an extensive network of road and highway tunnels that stretched beneath the complex Italian orography. These tunnels are now nearing the end of their designed lifetimes, having served the nation for over seven decades.

Italian subterranean infrastructure boasts an impressive count, with over 9,000 tunnels spanning an extensive 2,600 km (Pireddu & Bruzzone, 2021). However, the longevity of these critical conduits presents a unique challenge that demands careful consideration and comprehensive management.

As these tunnels have matured over the years, a pressing need has emerged for a holistic approach to their maintenance and safety assessment. The task of ensuring the continued functionality and safety of these subterranean assets has become increasingly complex. In response to this challenge, the Italian Superior Council of Public Works (Italian infrastructure ministery), recognizing the need for a standardized and integrated framework to manage tunnel maintenance, has introduced a Guideline for the Risk Classification, Safety Evaluation and Monitoring of Existing Tunnels (in Italian, “Linee Guida per la Classificazione e Gestione del Rischio, la Valutazione della Sicurezza ed il Monitoraggio delle Gallerie Esistenti”), hereinafter GL2022, adopted by means the Ministry of sustainable infrastructure and mobility Decree 257/2022. This guideline offers

*Corresponding author: andrea.carigi@polito.it

DOI: 10.1201/9781003495505-443

a comprehensive methodology for safety evaluation and continuous monitoring of Italy's existing tunnels. This approach, now mandatory for all road tunnels in Italy, marks a pivotal moment in the nation's commitment to ensuring the enduring safety and efficiency of its underground infrastructures.

In the following pages, we delve into the structure of this guidelines, exploring its structure, fields of applicability and the base philosophy.

2 GUIDELINES 2022

2.1 *Complementary normative*

The GL2022 complement the legislative framework, including Legislative Decree 35/2011 and Legislative Decree 264/2006 which, respectively, address the road and fire safety standards for motorway tunnels. Furthermore, it's worth noting that the technical standards for construction introduced in 2018 (in Italian "Norme tecniche per le costruzioni – NTC2018") remain the primary legislative reference for all design criteria.

2.2 *Field of applicability*

The GL2022 must be implemented comprehensively for all motorway tunnels with a length exceeding 200 meters within the territory of Italy. However, the section pertaining to hydraulic aspects is required also for tunnels with a length less than 200 meters. This exception is primarily driven by the substantial number of underpasses that may be vulnerable to flooding during extreme meteorological events.

Additionally, it's important to note that the GL2022 does not automatically apply to transnational tunnels. The decision is entrusted to the international security committee to establish a consistent method for managing tunnels subject to the regulations of the two nations sharing the infrastructure. This collaborative approach ensures the harmonization of safety standards across international boundaries.

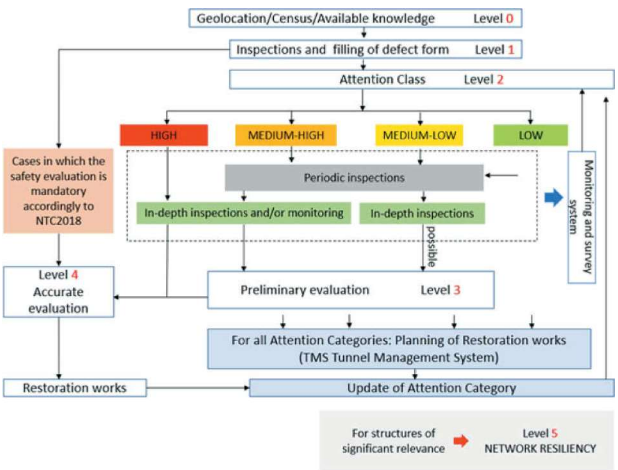

Figure 1. Overall structure of GL2022.

2.3 *General structure*

The articulated structure of LG2022 is summarized with the flux diagram given in Figure 1 and an in-depth analysis is provided in the following sections where are described the various steps (i.e. levels) to be developed.

2.4 *Level 0 – Census*

The acquisition of data for the tunnel census, that constitutes Level 0 of the multilevel approach, involves cataloguing all structures within the guideline's scope. The goal is to obtain detailed information about tunnel geometry, structural elements, and existing analyses to better understand their condition, the surrounding road network, and their location. Data collected by managing entities contribute to creating a national database of tunnels, which must be consistently updated in accordance with the guidelines. The census goes beyond a simple count and aims to achieve a comprehensive understanding of existing tunnels, including all available data related to their condition. Tunnel condition is not solely influenced by structural aging but also by various factors, including environmental conditions, initial design choices, construction methods, and maintenance interventions over time. This process helps prioritize initial visual inspections and initiate Level 1 activities. Moreover, the data collected and subsequent visual inspections allow for identifying cases requiring in-depth safety assessments beyond the Level 2 classification. The acquisition of data for the tunnel census is based on analysing available information and documentation. Retrieving technical and administrative documentation related to the tunnel is crucial to gather necessary information for subsequent preliminary risk assessment. Processing and summarizing these data represent a way to capitalize on resources used in previous studies and investigations during the tunnel's design, construction, and operation phases, and become part of the tunnel's technical documentation. It is essential to conduct thorough research of both technical documents (design, construction, subsequent interventions, etc.) and administrative and accounting documents that document the tunnel's evolution over time. Additionally, it is important to search for data documenting the tunnel's role in the transportation system and its socioeconomic implications, including the road or transportation networks the tunnel is part of, traffic volumes, and available alternatives in case of limitations or closures.

2.5 *Level 1 – Inspections*

Level 1 involves conducting initial inspections on all tunnels catalogued in Level 0 of the census. These inspections are tailored to the specific characteristics of each tunnel and the existing level of knowledge. The primary goal of these initial inspections is to check and to contextualize the data collected during Level 0, gather additional information about the tunnel's geometric and structural features, evaluate the structural condition, especially for tunnels with limited available information and low knowledge levels. These inspections provide an objective assessment of the tunnel's conditions, including its interior and key structural elements, and require thorough visual examination, which may involve cleaning surfaces for effective assessment of any damages, defects, or infiltrations. The inspection also covers tunnel access areas and non-structural elements such as installations and vertical signage. Visual examinations, supported by portable instruments where necessary, aim to build upon the Level 0 findings and address initial concerns related to the tunnel's characteristics and natural conditions. The Tunnel Officer, with specialist support based on the tunnel's specific features and initial visual inspection findings, should assess whether further, more detailed experimental investigations are needed for defect reconstruction, planning their quantity and location, potentially leading to subsequent in-depth inspections. If specific conditions for the tunnel require additional investigations in terms of quantity and type, as outlined above, the Level 1 phase can still be completed, considering the knowledge gap as a factor that contributes to raising the attention class. This class may be re-evaluated based on the outcomes of subsequent investigations, aligning with the initial attention class priority. During the initial inspection, along with comprehensive photographic documentation and geometric measurements of key tunnel dimensions (where possible), the structural condition is assessed to identify, highlight, and report existing degradation phenomena and defects. Specialized forms or suitable data management systems are utilized for data collection and assessment. These records help identify specific degradation phenomena, their intensity, and extent, which are vital parameters in the Level 2 classification method.

2.6 *Level 2 – Attention category classification*

The classification of tunnels on a territorial scale involves estimating the "risk" factors associated with these structures. In this phase, the risk estimation is simplified and expedited, conducted by expert judgment (the decision-making process, generally multidisciplinary, coordinated by Tunnel Officer) on the basis of data collected in Level 0 and Level 1. The risk associated with tunnels is approximated using the "Attention Class" (CdA). It's important to note that this isn't a comprehensive risk analysis, which should require more complex investigations.

CdA is a tool for setting priorities for further investigations, verifications, controls, and maintenance planning.

The guidelines include four Attention Classes (CdA):

- High
- Medium-High
- Medium-Low
- Low

The CdA value is determined by evaluating hazard, exposure, and vulnerability, based on available knowledge and Level 1 inspections. The CdA cannot be lower than Low Attention Class or higher than High Attention Class.

Various risk types are considered relevant for tunnels, considering their characteristics and the contexts they're in. These risk types include:

- Global structural and geotechnical risks, such as tunnel and geological interactions.
- Local structural issues within the tunnel, including non-structural elements.
- Seismic risk.
- Road-related risk.
- Geological risk related to landslides.
- Hydraulic risk.

These risks independently and define a separate Attention Class for each are analysed. Each Attention Class is uniquely defined based on the three parameters: hazard, exposure, and vulnerability.

The methods for evaluating and classifying these different CdAs are based on logic flowcharts.

After determining the relevant CdAs, they are combined to obtain the overall CdA of the tunnel, which forms the basis for subsequent actions. The classification method is inspired by risk assessment principles.

Each of the primary and secondary parameters required to define the CdA are determined through expert judgment of the Tunnel Officer, considering both the data collected during knowledge gathering and Level 1 visual inspections. Depending on the primary parameter values a class – among Low, Medium-Low, Medium-High, and High – is assigned, with specific criteria for each parameter. Then, these classes are then adjusted based on secondary parameters, which may have two or more classes.

When hazard, vulnerability, and exposure classes are identified, the Attention Class is derived by combining them according to the general scheme shown in Figure 2, applicable to all risk aspects.

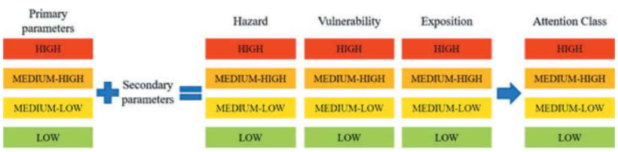

Figure 2. General scheme for the CdA determination.

The tunnel divided in stretches with length about 20m and for each of these segments the Attention Class is defined.

The tunnel's Attention Class corresponds to the most critical segments along the route and then a diffusion index (the percentage of tunnel length for each CdA) is added to further characterise the obtained CdA.

It has to be highlighted that a High Attention Class does not mean directly that there is a risk. Rather, it is a condition where additional investigations and analysis have to be carried out to understand if a risk is present or not.

In Tables 1 to 6 the primary and secondary parameters used for the definition CdA for the different risk types are given.

The Global Structural and Geotechnical Attention Class concerns the possibility of a global collapse of the tunnel as a consequence of the interaction of the structure with the surrounding soil. It involves considering key parameters that influence the structural behaviour of the tunnel, especially concerning the final lining, at a global level, and its interaction with the surrounding rock mass or soil. This entails evaluating parameters related to the magnitude and variations of the applied loads compared to the design predictions for the final lining, as well as factors related to the structural characteristics of the tunnel linings and their level of defectiveness.

Furthermore, due to the global nature of a potential collapse, the potential exposed subjects have been considered, which include both the tunnel users and any structures and infrastructures above the tunnel that may be affected by ground movements.

Table 1. Parameters for the evaluation of Global structural and geotechnical CdA.

	Primary parameters	Secondary parameters
Hazard	Level of knowledge of geotechnical, hydrogeological, and hydraulic characteristics of the mass and reliability of the geomechanical model	Geomechanical characteristics of the rock mass and/or soil, external factors interacting with the tunnel structure.
Vulnerability	Level of defectiveness, type of tunnel, constituent materials, and construction issues	Rate of degradation, presence of circulating water or infiltration, and presence of the waterproofing layer
Exposure	Level of average daily traffic and tunnel length	Heavy vehicles (mass ≥ 3.5 tons), maximum design speed, alternative routes, interference with buildings and infrastructure

For the Local Structural Attention Class, the primary concern is the possibility of a portion of the lining or any non-structural component detaching and posing a danger to tunnel users. Unlike the previous Attention Class, which only considers local detachments without consequences for overall stability, this class focuses on conditions, including widespread ones, where portions of the lining may interact with the roadway but do not result in global structural instability.

Table 2. Parameters for the evaluation of Local structural CdA.

	Primary parameters	Secondary parameters
Hazard	Presence of water	Characteristic compressive strength of the lining
Vulnerability	Fracture condition, slab thickness (resulting from construction defects) or presence of internal discontinuities in the lining (such as cold joints, casting inhomogeneities)	Presence of reinforcement, lining history and existing deteriorations
Exposure	Level of average daily traffic and tunnel length.	Heavy vehicles (mass ≥ 3.5 tons), maximum design speed, alternative routes

The Seismic Attention Class assesses the potential risks associated with seismic activity on the tunnel, taking into consideration potential local amplification phenomena. In its definition, it was considered that an underground structure, except for portal areas and in case of interference with active faults, is not particularly sensitive to seismic phenomena. It's worth noting that has been included the strategic importance of the structure as an exposure parameter. This is because damage to the tunnel could also affect the emergency response capability for the surrounding area in the event of a seismic event.

Table 3. Parameters for the evaluation of Seismic CdA.

	Primary parameters	Secondary parameters
Hazard	Presence of active faults, susceptibility to landslides, unfavourable geological conditions, Seismic acceleration	Potential local amplification phenomena
Vulnerability	Morphological position, overburden	-
Exposure	Level of average daily traffic and tunnel length	Alternative routes, heavy traffic, strategic importance of the structure

The definition of the Road-related Attention Class considers the key parameters that influence the safety and functionality of the tunnel under normal operating conditions. These parameters encompass aspects related to the tunnel's geometric characteristics, the efficiency of the road surface, its degradation over time, and the volume and composition of vehicular traffic. Additionally, it includes parameters associated with the operation and management of the road network to which the tunnel belongs.

Table 4. Parameters for the evaluation of Road-related CdA.

	Primary parameters	Secondary parameters
Hazard	Road accidents	Fires
Vulnerability	Road surface defectiveness level, pavement materials	Rate of degradation evolution, design standards
Exposure	Level of average daily traffic and tunnel length	Heavy vehicles (mass ≥ 3.5 tons), maximum design speed, alternative routes

The definition of the Geological Attention Class associated with landslide risk takes into consideration specific parameters indicating the level of the structure's involvement in potential landslide phenomena, both spatially and temporally. In general, artificial tunnels and underpasses in sub-flat areas are excluded from this classification. On the other hand, particular attention should be given to tunnels with low cover and portal areas.

Table 5. Parameters for the evaluation of Geological risk related to landslides CdA.

	Primary parameters	Secondary parameters
Hazard	Slope instability (magnitude, velocity, state of activity)	Mitigation measures or monitoring
Vulnerability	Relationships between the tunnel and morphological conditions: deep instability along the alignment or at the portals, model uncertainty/reliability of the assessment	-
Exposure	Level of average daily traffic and tunnel length	Heavy vehicles (mass ≥ 3.5 tons), maximum design speed, alternative routes, interference with buildings and infrastructure

The Hydraulic Attention Class considers the possibility of aquaplaning caused by flooding of the road, which can result from meteoric contributions and infiltrations from the lining. This class also considers control strategies, focusing on the reliability of capture systems and early alert systems for users. It analyses the causes and identifies the parameters influencing potential flooding phenomena in the structure, defining flooding as any phenomenon that could compromise the functionality and safety of users.

Table 6. Parameters for the evaluation of Hydraulic CdA.

	Primary parameters	Secondary parameters
Hazard	Precipitation intensity, water table level	Contributing surface at access points, hydraulic conductivity of soils, waterproofing deficiency
Vulnerability	Capture system, conveyance system, gravity or lift return system	Capture system blockage, flammable/hazardous liquid collection system, automatic traffic signal system
Exposure	Level of average daily traffic	Transportation of flammable/hazardous liquids, maximum design speed, exposure reduction systems

After defining CdA values for each 20-meter segment of the tunnel, the various CdAs associated with different risk types are aggregated to calculate an overall CdA for each segment. Subsequently, the tunnel's Attention Class is determined by selecting the highest CdA value found (Figure3). A qualification index is then assigned based on the percentage of tunnel segments falling within this highest CdA category.

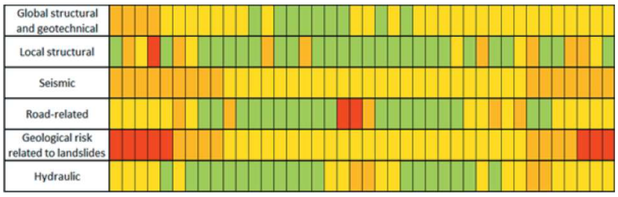

Figure 3. Example of representation of the CdAs along the tunnel.

Table 7. Qualification indexes.

Risk type	CdA	Qualification Index
Global structural and geotechnical	Medium-High	10%
Local structural	High	2.5%
Seismic	Medium-High	40%
Road-related	High	5%
Geological risk related to landslides	High	20%
Hydraulic	Medium-High	10%

2.7 *Level 3 – Preliminary evaluation*

Level 3 preliminary assessment primarily aims to verify the Attention Class assigned to the tunnel in Level 2. It involves a deeper examination of the information obtained in the previous levels, typically based on existing knowledge and data.

The results of the preliminary assessment can lead to two outcomes:

1. Confirmation of a significant risk for the specific context, as previously attributed to the tunnel. In this case, a detailed assessment is necessary.
2. Redefinition of the Attention Class.

If the level of knowledge and available data are deemed insufficient to arrive at a reliable estimate of safety margin, it will be necessary to proceed with an in-depth knowledge assessment and a Level 4 detailed assessment.

2.8 *Level 4 – Deep evaluation*

Level 4 detailed assessment aims to provide a reliable evaluation of the safety margin associated with specific portions of the tunnel or ancillary works, including portals. It also determines whether any mitigation measures are necessary for a specific risk. The reliability of these assessments must be ensured through an adequate level of knowledge. To achieve this, it will often be necessary to plan and carry out additional investigations and measurements, in addition to the data available from previous levels and from the monitoring systems that will be addressed in chapter 2.11.

2.9 *Level 5 – Strategic infrastructures*

Level 5 applies to tunnels considered of significant importance within the road network. For such structures, it is useful to conduct more sophisticated analyses, such as network resilience assessments, by evaluating their transport relevance, analysing the interaction between the structure and the road network to which it belongs, and assessing the consequences of a possible disruption of tunnel operations on the socio-economic context in which it is situated. Due to the importance and the specificity of each of these tunnels, the approach to be used is not specifically regulated by the GL2022 to not constrain the approach of the owner in the management of the infrastructure.

2.10 *Regulatory compliance*

Three main figures are identified in the GL2022: the Tunnel Manager, that is the Body that owns the road or the concession holder, the Tunnel Officer and the Inspector.

The Tunnel Manager must appoint a Tunnel Officer with specific expertise in tunnel management and maintenance. This Officer will oversee and coordinate activities based on the guidelines, under the Operator's supervision.

The Tunnel Officer can oversee multiple tunnels but must have an adequately staffed and skilled operational structure. Also, has to plan activities per the guidelines and coordinate inspections, involving specialists from various disciplines. They must also provide data for the annual tunnel condition report.

Inspections come in different types, as described in Annex 4 of LG2022, and frequencies based on the assigned attention class to the tunnels as described in Table 7.

Table 8. Inspection frequencies.

Inspection	Low	Medium-Low	Medium-High	High
Initial	At the beginning of the Level 1			
Detailed	6 years	4 years	2 years	1 year
Regular periodic	1 year	6 months	3 months	2 months
Post-incident	After a relevant event			

Operators must document inspections with records listing participants and their evaluations. Inspections also cover tunnel-adjacent spaces and specific external zones. If the lining prevents visual inspection, temporary removal procedures should be adopted.

The inspection program considers maintenance and inspection needs from other regulations and aims to minimize impacts on traffic.

Inspections are carried out by competent technical personnel under the Tunnel Officer's coordination. In the absence of in-house expertise, the Operator may engage external entities with competence.

2.11 *Monitoring and investigations*

Monitoring programs must be based on a comprehensive examination of existing information and should be tailored to the specific tunnel's issues, utilizing both direct and indirect types of surveys. Indirect surveys offer the advantage of collecting widespread and non-specific information along the tunnel, usually with relatively quick field operations (high-performance surveys), which is significant for minimizing traffic disruptions.

Measuring indirect physical quantities to correlate with material characteristics and natural formations, as well as assessing their relationships, always requires recourse to direct calibration surveys. This considers the reliability of survey results, which is influenced by the data acquisition phase along with calibration and calibration of the acquisition system relative to the specific conditions and environments in which it operates. It also depends on the processing phase and the representativeness of the adopted reference models and the interpretation phase of the overall measurements, considering direct surveys.

Monitoring programs should also be prepared with specific reference to individual situations, graded, and deepened in relation to the nature and importance of the safety issues identified.

The preparation of investigation and monitoring programs will be coordinated by the Tunnel Officer, who will enlist the expertise of Inspectors and experts while justifying the choices made in relation to specific identified issues.

3 ANNEXES TO GUIDELINES 2022

3.1 *Annex A*

The Annex A contains a "Level 0 Census and Knowledge Sheet" to be compiled for each structure, serving as the initial phase in organizing documentation related to the tunnel. This sheet, signed by the tunnel's manager, provides an assessment of the existing knowledge level and identifies initial indicators of potential hazards, especially those relevant to classifying attention levels. Additionally, the sheet suggests specific areas for in-depth examination during the tunnel's ongoing development. While this document serves as a starting point for determining the initial Attention Class, it will be continuously updated over time to maximize understanding of the structure. To efficiently manage this information, employing a computerized data management system is recommended.

3.2 *Annex B*

The defect catalogue serves as a reference throughout various inspection phases for identifying consistent, comparable, and repeatable elements in tunnels, monitoring their evolution over time, and ensuring the objectivity of defect assessments.

The defect list is categorized into sections, including defects due to water presence, surrounding soil-related defects, deterioration in unreinforced sections, defects in lining materials (stone or masonry, concrete), defects in waterproofing, drainage, and surface water collection systems, defects related to structural elements and tunnel geometry, fire-related defects, defects due to inadequate maintenance, defects related to the road platform, defects in non-structural elements and installations.

The defect level should be evaluated by critically analysing inspection results alongside other available information, either documented or obtained through specialized investigations, using expert judgment. It's crucial for the appointed inspector to gather the necessary elements, through data sheets, to assess the current state of the structure as accurately as possible.

Inspectors should refrain from assessing the causes of defects during inspections, as tunnel contexts often lack straightforward cause-and-effect relationships. Instead, a comprehensive evaluation considering inspection findings and the overall knowledge base, with the inspector collaborating with specialists, should guide the assessment, especially when a single cause can lead to multiple correlated defects or a single defect can have multiple potential causes.

During inspections, inspectors must geographically reference each defect along the tunnel's alignment. Geometrically referencing each defect is essential to clearly identify evolutions of the defects in time.

The assignment of defect severity (G), with possible values from 1 (not severe) to 4 (high-severity) is the responsibility of the Tunnel Officer, based on all inspection findings. Additionally, for each defect type, two parameters should be defined: extension (k1) and intensity (k2), which reflect the defect's spatial spread and magnitude, respectively.

With this information, defect levels can be classified from High, for tunnels with defects that they may lead to the incipient failure or loss of functionality of the structure, to Low for defects that does not pose a significant risk to the structure's overall stability.

3.3 *Annex C*

In Annex C inspection sheets are given. In the header of each inspection sheet, for each element, it is necessary to indicate:

- The tunnel's location by providing toponymic information or the road's name it serves, along with the kilometric progression.
- The identifier of the reference section subject to inspection.
- The date of inspection site visits and the technician who conducted them.

In case the defect is identified on the structure, it is essential to indicate its extent, following the quantitative indicators provided on the specific defect sheet given in Annex B. During the evaluation of the inspection results, these data will be examined to determine the values to be attributed to the defect's extent using the variable coefficient k1 and the defect's intensity using coefficient k2. The potential values for these two coefficients, based on the elements identified during the inspection, are outlined in the defect recording and evaluation sheets (Annex C).

Each defect is associated with a severity (G). The presence of high-severity defects, requiring thorough assessment, may indicate significant and/or immediate structural issues potentially endangering user and employee safety. Therefore, they have a considerable impact on determining the defect class level.

Furthermore, for defects of greater severity, there is the option to indicate whether the presence of such defects could jeopardize the structure's stability and pose a significant risk ("PSg" for a defect affecting the "global" structural response of the structure, and "PSl" for a defect that, although widespread, may lead to local structural crises).

It should be noted that the field inspector should limit themselves to collecting relevant information for the subsequent defect severity assessment, which will be performed by expert judgment in coordination with the Tunnel Officer.

If a defect listed on the sheet is not identified on the structure, to further characterise the reason why, it should be indicated as follows:

- Use the "NA" box if the defect does not apply to the type of structure and element under examination.
- Use the "NR" box if the defect cannot be detected through visual inspection (e.g., part of the structure is not accessible, etc.).
- Use the "NP" box if the defect is not actually present.

The photo of each defect should be attached to the inspection sheet and appropriately catalogued, numbered, and provided with captions indicating the type of defect, its location, and geometric references within the structural complex.

Finally, each sheet includes a dedicated space for any notes and observations. Emphasis is placed on acquiring as much data as possible during the inspection, so it's important to note any additional relevant information, even if not explicitly indicated in the sheets. This aligns with the primary function of the inspection, which is to record anything potentially useful and meaningful for subsequent evaluations.

In addition to the defect recording sheets, for each tunnel, it is necessary to verify the data from the tunnel census sheet (Annex A) with the main characteristics of the structure identified during the visual inspection, such as structural type, type and material of structural elements, hydro-geomorphological characteristics of the area, rough geometric layouts, and so on. The information collected in this sheet is useful for verifying and confirming the reliability of the data gathered during the initial census and for enhancing the knowledge of the examined structure.

3.4 *Annex D*

Within this Safety Management System, various types of inspections are specified:

1. Initial Inspections
2. Detailed Inspections
3. Regular Periodic Inspections
4. Post-Incident Inspections

The frequency of these inspections is determined based on the infrastructure's Attention Class and environmental conditions.

Authorities overseeing network Operators have the option to conduct their inspections, in addition to those performed by the Operators or other involved bodies.

All inspection findings and observations must be documented, including the use of predefined forms. Detailed inspection reports are required for comprehensive assessments.

Initial inspections are performed when the guidelines are first implemented, upon opening new tunnels, or after major renovations. For existing tunnels, they may also be carried out following significant upgrades or structural changes. These inspections use information gathered from previous activities to establish a baseline knowledge level.

Initial inspections aim to validate the accuracy of available documentation, assess the tunnel's physical and structural characteristics, and evaluate its overall condition. The outcomes determine the tunnel's initial Attention Class, which may lead to further assessments for tunnels with limited data or concerning findings.

Detailed inspections are conducted when specific issues or concerns arise during initial or regular periodic inspections, classifying the tunnel as high or medium-high attention, or as required for in-depth investigations. These inspections may involve the removal of non-structural tunnel linings for comprehensive examinations.

Comprehensive assessments encompass various specialized non-destructive and direct testing methods, including laboratory analysis, to investigate structural components. Advanced technologies like laser scanning, thermography, or ground-penetrating radar may be employed to detect hidden defects or anomalies.

Regular periodic inspections are routine assessments based on predefined schedules, adapted to the tunnel's Attention Class. These inspections are vital to monitor the tunnel's ongoing condition and ensure safety.

Post-incident inspections are initiated following significant events, such as accidents, fires, structural failures, or seismic activity, which could compromise the tunnel's stability. These inspections help assess damage and plan necessary repairs or maintenance.

In summary, various inspection types are integral to maintaining the safety and integrity of road and highway tunnels. They involve a combination of visual assessments, non-destructive testing, and, if necessary, in-depth investigations. The data collected during these inspections inform safety evaluations, maintenance programs, and any required interventions, ensuring the ongoing reliability of tunnel infrastructure.

4 CONCLUSIONS

In conclusion, the introduction of Italy's Guideline for the Risk Classification, Safety Evaluation, and Monitoring of Existing Tunnels (GL2022) represents a significant milestone in the nation's commitment to the preservation and security of its large number of subterranean infrastructures. As we have summarised in this paper, GL2022 is a multifaceted framework, structured across six steps (levels), each with its specific role and purpose.

Level 0 serves as the information repository. Moving up to Level 1, we encounter the initial inspection phase, where the condition and basic characteristics of each tunnel are assessed. Level 2 takes a more nuanced approach, defining the class of attention for each tunnel, considering various parameters and ultimately providing a comprehensive overview of tunnel's status distinguishing across different possible risk sources. At Level 3, the focus shifts towards regular safety assessments, ensuring that these tunnels continue to meet the required safety standards. At the highest operational level, Level 4, in-depth safety evaluations are developed. Level 5 developed for to strategically significant tunnels.

In adopting GL2022, Italy has established a unified and systematic approach to tunnel management, ensuring that the challenges posed by aging infrastructure are met with a comprehensive and forward-thinking strategy.

Through the institution of an observatory for the application of GL2022, it is ensured an increasing level of knowledge also on the compliance practicality and a periodic review of this technical document making this regulation a dynamic and evolving tool, able to adapt to the changing landscape of tunnel maintenance and safety.

REFERENCES

D. Lgs. 264/2006 (2006). Attuazione della direttiva 2004/54/CE in materia di sicurezza per le gallerie della rete stradale transeuropea. (GU Serie Generale n.235 del 09-10-2006 - Suppl. Ordinario n. 195).

D. Lgs. 35/2011 (2011). Attuazione della direttiva 2008/96/CE sulla gestione della sicurezza delle infrastrutture. (GU n. 81 del 8-4–2011).

D.M. Infrastrutture e Trasporti 42/2018 (2018). Norme tecniche per le costruzioni (NTC2018) (G.U. 20 febbraio 2018, n.42)

D.M. Infrastrutture e Mobilità Sostenibili 247/2022 (2022). Approvazione delle Linee Guida per la classificazione e gestione del rischio, la valutazione della sicurezza e il monitoraggio delle gallerie esistenti lungo le strade statali o autostrade gestite da ANAS S.p.a. o da concessionari autostradali (G.U. 23-8-2022, n.196)

Pireddu, A., Bruzzone, S., 2021. "An analysis of the influence of tunnel length and road type on road accident variables" Riv. Stat. Uff., 2, 71–102.