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School of Civil, Environmental and Land Engineering

Master of science in Geoinformatics Engineering

Assessment of a tunnel safety

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ABSTRACT

Evaluating the impact of tunnelling on above-ground structures in urban areas highly relies on predictions of the settlement through at surface level. It is important to monitor tunnels integrity and health. There exists many techniques to do that. The thesis presents a case history performed during an internship in a geophysical company (Geosurveys Srl), where I have been an active member of the technical team. It dispenses a review of testing methods and a classification of strategies and tools, in terms of technologies and techniques, to the monitoring of tunnels. Myself along with my colleagues, have done multiple surveys. We have applied a set of non-destructive techniques, in order to find stability and strength of the tunnel. We performed videoendoscopic examinations to find holes inside the tunnel walls. The samples of concrete which we gathered from the tunnel were dispatched to the laboratory. This document describes all the techniques, the acquisition campaign, and the results. The applied work flow can be generalized to a "best practice manual" for monitoring tunnel integrity. Based on the geophysical analysis, we obtained the state of the concrete and the position of holes and cracks inside the tunnel.

SOMMARIO

La valutazione dell'impatto della costruzione delle gallerie sulle strutture sopra il livello del suolo, nelle aree urbane, si basa fortemente sulle previsioni dell'assestamento a livello della superficie. È importante monitorare l'integrità e la salute delle gallerie e per farlo esistono molte tecniche. La tesi presenta un’analisi svolta durante uno stage in un'azienda di geofisica (Geosurveys srl), dove sono stato membro attivo del team tecnico. Questa mostra una rassegna dei metodi di prova e una classificazione delle strategie e degli strumenti in termini di tecnologie e tecniche applicate al monitoraggio delle gallerie. Insieme ai miei colleghi abbiamo svolto più rilievi: abbiamo applicato una serie di tecniche non distruttive al fine di trovare stabilità e integrita’ del tunnel; per trovare buchi all'interno del tunnel abbiamo eseguito esami videoendoscopici. I campioni di calcestruzzo raccolti sono stati inviati al laboratorio di prova. Questo documento descrive tutte le tecniche, la procedura di acquisizione e i risultati. Il flusso di lavoro può essere generalizzato a un "manuale di buone pratiche" per il monitoraggio dell'integrità del tunnel. Sulla base dell'analisi geofisica si sono riscontrate delle crepe nelle gallerie e lo studio si conclude con lo stato del calcestruzzo e le crepe e i buchi trovati nella galleria.

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1.INTRODUCTION

In conventional tunnelling, “geotechnical monitoring” is of fundamental importance as an instrument for verifying the appropriateness of the operations specified in the design and for calibrating the intensity and sequence of those operations. It is also important for recording tunnel behavior when it is in service, in order to check the condition of the tunnel over time, especially in relation to the rheological behavior of the rock mass and possible changes in the hydrogeological conditions.

"Guidelines for the assessment of the degree of safety of tunnels", following the examination of the massive investigations, the detailed inspection, the elaboration of the selective investigation plan and the conduct of the same, the results of the investigations carried out in the field and in the laboratory were collected and analyzed. The results of this activity are the subject of this Final Report on the Ratella tunnel, Via Francia.

The state of knowledge acquired in the initial activities of (1) analysis and study of the previous documentation available on the tunnel, (2) interpretation of the results of massive georadar surveys, and (3) detailed inspection is summarized in the Detailed Inspection Report and in the documentation attached to it. This document supplements the level of knowledge acquired from the data and evidence acquired and the results of the selective surveys and the supplementary inspections accompanying them and summarizes in the final assessment the assessment of the state of the tunnel. The final assessment shall, where appropriate, amend the preliminary IQOA classification obtained after the detailed inspections. The following figure schematically illustrates the place of the elaboration activity of this document within the methodological approach illustrated in the aforementioned Guidelines.

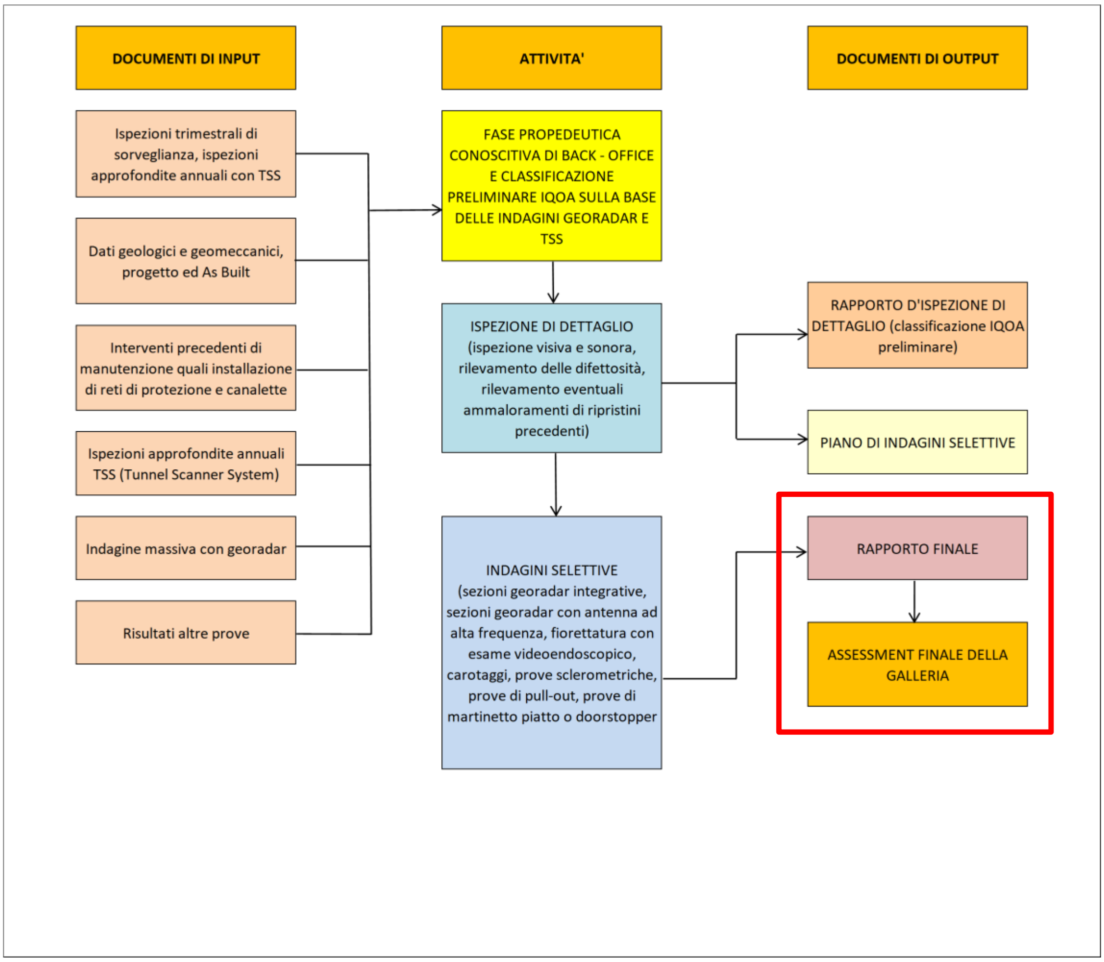


Figure 1: *Flow – summary chart of activities*

The Final Report is accompanied and supplemented by further documents prepared in advance (G) and in completion (M1, D1, D2) of the detailed inspection and in consequence (M2) of the selective investigation.

With regard to the results of massive georadar surveys (hence the letter "G") and historical documentation, this report refers to the extended discussion contained in the document:

[1] FG72 0-G1 – Georadar survey screening (massive survey)

As regards the evidence found in the field during the detailed inspection, the description of the inspection methods, please refer to the "M" campaign forms:

[2] FG72 0-M1 – Campaign module

For the description of the selective investigation plan defined following the detailed inspection phase (hence the acronym "D1") and the definition of the critical areas, please refer to the document:

[3] FG72 0-D1 – Detailed inspections: Prescription Selective Investigations

For the analysis of the reference documentation relating to the tunnel in question, and the preliminary assessment of the tunnel following the analysis of the results of the detailed inspection (hence the acronym "D2"), please refer to the document:

[4] FG72 0-D2 – Detailed inspection report

As regards the evidence found during the selective investigation, the description of the investigation methods, any changes made to the investigation plan (removal and / or repositioning of the investigations), and the critical issues observed and the request for safety measures, the document is finally recalled:

[5] FG7 2 0-M2 – Campaign module

Finally, reference is made to the drawings and the technical and calculation report relating to the typological interventions of provisional safety, entitled "Tunnel assessment, safety of tunnels, safety. Typological safety interventions", to which reference should be made for technical requirements and construction details:

[6] Technical and calculation report

[7] Typological safety interventions - Provisional intervention Type "A" - Code M 100 OM TP 01;

[8] Typological safety interventions - Provisional intervention Type "Abis" - Code M 100 OM TP 02;

[9] Typological safety interventions - Provisional intervention Type "Ater" - Code M 100 OM TP 03;

[10] Typological safety interventions - Provisional intervention Type "B" - Code M 100 OM TP 04;

[11] Typological safety interventions - Provisional intervention Type "C1" - Code M 100 OM TP 05;

[12] Typological safety interventions - Provisional intervention Type "C2" - Code M 100 OM TP 06;

[13] Typological interventions ;id safety measures - Provisional intervention Type "D" - Code M 100 OM TP 07

[14] Typological safety interventions - Provisional intervention Type "E" - Code M 100 OM TP 08;

[15] Typological safety interventions - Provisional intervention Type "A1" - Code M 100 OM TP 09;

[16] Typological safety interventions - Provisional intervention Type "C3" - Code M 100 OM TP 10;

[17] Typological safety interventions - Provisional intervention Type "C4" - Code M 100 OM TP 11.

2.COGNITIVE FRAMEWORK OF THE GALLERY

This chapter summarizes the results of the in-depth analysis process conducted and documented in the Detailed Inspection Report [4][4] the chapters and the issues addressed are recalled.

Chapter 1 - General characteristics

- Main features of the tunnel: the total length of 332 m, which is presumed to be distinguished by a central section of natural tunnel and two extreme sections of entrance;
- Geometry: no historical documents are available (design drawings and / or as built) that define the geometry of the final coatings and any pre-coatings;
- Structure of the gallery: no documents are available (project drawings and / or as built) on the subject. From the investigations carried out it was deduced that the coatings were entirely made of reinforced concrete;
- Characteristics of the entrances: s i are portal structures in reinforced concrete;
- Drainage and waterproofing: no documents are available. However, considering the age of the gallery, it is supposed to be equipped with waterproofing;
- Platform and sidewalk: no historical documents are available (elaborated design and / or as built) on the subject;
- Related structures: there is an SOS niche at progr 163. In addition, the furnace is characterized by a change of section to the progr. 287, at the western entrance (France side). This widening of the section is due to the presence of the deceleration lane that allows the exit from the SS1-BIS towards SANREMO Centro;
- Repairs or improvements: The reference documentation does not report the implementation of repairs and/or improvements.

Chapter 2 - Geological and geotechnical context

- Context analysis: the entrances are inserted in two natural slopes, covered with forest vegetation and devoid of incisions or streams;
- Geological and hydrogeological conditions: no historical documents are available (design drawings and/or as built) that define the geological and hydrogeological characteristics of the cluster surrounding the fornix.

- Longitudinal profile with indication of the roofs: the reference documentation does not include a longitudinal profile in axis of the furnace, however it is clear that the maximum coverage of the tunnel is about 50-60 m;
- Analysis of any problems encountered during the construction of the work: there are no documents that report problems encountered during the excavation and more generally the construction of the tunnel.

Chapter 3 - State of consistency of the work

- Principals and installations: The furnace is not present on the final coatings principals or installations, such as plastic or metal indulines and / or tessellated nets;
- Restoration interventions, repairs, structural changes and installations carried out over time: From the documentation in possession there is no evidence in this regard;
- Specific investigations or monitoring implemented: From the documentation in possession there is no evidence in this regard;
- From the reference documentation no information can be deduced regarding any structural and / or geotechnical safety measures adopted along the furnace.

Chapter 4 - Characteristics of the inspection

The detailed inspection of the tunnel object was carried out on 02/12/20 with lane closure to traffic.

Chapter 5 - Description of the main defects detected

In this part of the Detailed Inspection Report are presented for each inspection segment:

1. the analysis of the defects treated in the back-office with the analysis of the results of the TSS survey, the massive georadar and the video endoscopies, during the preparation of the detailed inspection (Table 1),
2. a summary of the defects found in the tunnel during the detailed inspection to supplement the anomalies (Table 2),
3. the assessment of the general state of the coating and the characteristics of cracking systems.

The prevalent degradations found are: lesions (more or less calcified), swelling, detachments, exposed irons and traces of superficial huminess.

Chapter 6 - Assessment of the tunnel based on the IQOA classification system

Taking as a reference the representative indices of the static conditions of the coating and the presence of water attributed according to the IQOA classification to the various inspection segments, a summary of the evidence collected in the field and back-office was provided, identifying the most critical areas, and obtaining an overall assessment of the state of the tunnel. Below is a table that summarizes the IQOA indices of Civil Engineering and Water attributed to the inspection segments.

Table 1: *Detailed inspection. IQOA index incidence*

IQOA - Civil Engineering					**IQOA - Water**		
1	**2**	**2E**	**3**	**3U**	**1**	**2**	**3**
0.0%	65. 7%	34.1%	0.2%	0. 0%	100. 0%	0. 0%	0.0%

As far as static IQOA is concerned, 1 zon has been identified and classified as 3 for an extension equal to 0. 2% and no zons rated a as 3U. The remaining areas were given a 2E rating or lower.

As far as water IQOA is concerned, there are no areas classified as 3. All areas have been given a classification of 1.

METHODS OF EXECUTION OF THE SELECTIVE INVESTIGATION

The selective survey of the tunnel covered by this report was carried out on 14/09/21 with the carriageway closed to traffic.

The selective survey was carried out with the help of MEWP, and saw the involvement of an "inspection train" consisting of:

- a team of inspectors;
- by a support team, in charge of dismantling/reassembling the channels and installing safety measures;
- by the companies and laboratories responsible for carrying out field investigations.

The field activities carried out by the inspectors during the selective investigations included:

- the tracking on the ground of the planned selective investigations;
- supervising the conduct of selective investigations, to verify their correct location and setting up with reference to the investigation plan;
- where necessary and appropriate, the amendment of the investigation plan for
    1. take into account any interference, for example due to the presence of plants and/or installations and/or facilities, such as to prevent the planned investigations from being carried out;
    2. delete investigations that have proved ineffective;
    3. integrate the content, in order to verify and / or investigate any defects and / or anomalies and / or critical issues that emerged during the course of the selective investigations;
- direct comparison with the teams in charge of carrying out the extensive hammering survey to assess any critical issues encountered in the field and the need for any provisional safety measures;
- the possible updating of the IQOA classification of the inspection segments;
- the prescription of provisional safety measures;
- the reporting of any further critical issues.

The activities carried out were described first, in summary form, in e-mail communications to the Customer and subsequently, in more detail, in the field modules.

It should be noted that the present campaign of selective investigations has seen the execution of most of the investigations provided for in the selective investigation plan[3] (see next chapter for definition).

For further details

- the operational procedures for carrying out selective surveys with respect to the technical specifications referred to in Chapter §5 of this document;
- any preliminary results obtained during the investigation;
- the timing of the execution of investigations;
- the possible relocation or deletion respectively of investigations prevented by the presence of interference or investigations rendered ineffective by the operating methods,

Please refer to the campaign form[5] prepared following the field activities.

Attached to this document is the update of the survey of anomalies and planned safeguards (see Annex 1-Inspection forms) and the related photographic documentation shown in Annex 4.

TECHNICAL SPECIFICATIONS OF SELECTIVE SURVEYS

With reference to the phenomena of degradation, superficial and / or deep, found in the furnace, a plan of selective investigations has been identified [3] with the aim of:

- characterize the strength of the structural materials used (concrete and steel);
- classify and analyze cortical degradation phenomena;
- verify deep degradation (under thicknesses, cavities and/or excavations, areas of degraded or deteriorated concrete, deep lesions, percolation);
- comprehensively inform the design activities of any repair, reinforcement and / or safety interventions.

The selective survey plan shall contain, for the critical areas identified in the area, the planned selective investigations, their location, any explanatory notes relating to the methods of execution and further technical specifications. In addition, a priority for the execution of investigations is defined, established on the basis of the greatest criticality found in the investigated areas. Therefore, the survey campaign provides for the execution of the "priority" surveys, considered most relevant for the purpose of assessing the state of the tunnel and, alternatively, the completion of the remaining investigations, called "optional", to be completed as part of the subsequent periodic inspections.

Geotechnical investigations for the geotechnical and/or geomechanically and/or hydrogeological and/or geophysical characterization of the cluster in which the tunnel was carried out are outside the scope of selective investigations. The definition and planning of these investigations may take place as part of the design activities of rehabilitation and / or structural reinforcement and / or adaptation of the tunnel.

The selective surveys carried out in the gallery covered by this report included:

- detailed georadar surveys (I-GEO);
- nucleus-destroying perforations with videoendoscopic examination (I-PERF);
- relief of reinforcements with pacometer (I-PACO);
- sampling and compression test of concrete samples (I-CLS);
- laboratory analysis of samples (A-CAR and A-CLO);
- pull out tests (I-PUL);
- sclerometric tests (I-BS), combined with the SonReb (I-SON) method;
- light extensive hammering (I-TM);
- tests with flat jack (I-MAR).

A summary description of the abovementioned investigations and any relevant technical reference standards is provided in the following paragraphs.

Detailed georadar investigations: these investigations were carried out in the portions of the final coating in which there is evidence, as a result of the massive georadar investigation and / or other previous structural diagnostic investigations, of the possible presence of deep anomalies (underthicknesses, deep crawl spaces, volumes of degraded and / or defective concrete, cavities in the final coating, lesions and / or dislocations, Excavations between final coating and preliminary coating and/or between coatings and back storage.

The use of antenna with nominal frequency of emission is prescribed:

- to investigate areas with a thickness greater than 40cm: medium frequency, i.e. 900 MHz.

Depending on the need, it is planned to carry out detailed georadar surveys transverse and / or longitudinal with respect to the axis of the tunnel.

Nucleus destruction perforations with videoendoscopic examination: nucleus destruction perforations, with an approximate diameter of 17mm, orthogonal to the surface of the final coating, were performed with videoendoscopic examination throughout the development of the perforation in order to

- define the thickness of the coatings (final and "first phase"),
- identify possible material changes,
- identify any deep anomalies (under thicknesses, deep crawl spaces, cavities in the final coating, lesions and/or dislocations, excavations between the final coating and the preliminary coating and/or between the coatings and the cluster on the back).

After cleaning the hole from fragments and/or dust using a special metal brush ("brush"), the stratigraphy of the materials (final coating; pre-coating; filling materials, e.g. timber; clogging injections) was surveyed with recognition of any anomalies (e.g. cavities and crawl spaces).

During visual inspection, high-resolution AVI video images were captured at significant points, often reported in the test report.

Pacometric investigations: in the tunnel sections marked by definitive coatings and/or reinforced cortical reinforcements, magneto metric / pacometric investigations were carried out according to BS 1881-204, in order to determine the diameter, inter-iron and iron cover of the reinforcing bars. The location of the final reinforced coating sections was identified thanks to the analysis of the reference documentation and, specifically, of the design and/or as built drawings and the results of previous georadar and TSS investigations.

Sampling and compression test of concrete samples: they were taken (ref. UNI 12504-1) undisturbed concrete samples (core drill diameter 100mm, sample length L=400mm) then subjected to destructive compression laboratory tests according to UNI 6131 and UNI 6132, UNI EN 12390-1, UNI EN 12390-3, UNI EN 12504-1, and D.M. 17/01/2018. The sampling was either carried out in such a way as to sample the coating defined or having a load-bearing structural function: it follows that the depth of sampling has been defined in such a way as to pass through any cortical restorations (e.g. reinforced concrete) and/or surface remediation interventions (e.g. rinzaffature). The restoration of the final coating at the point of execution of each core takes place with the laying of compensated shrinkage mortar.

Laboratory tests carried out on water and concrete samples: the following laboratory tests were carried out for the samples taken on site:

- Carbonation tests on concrete samples according to UNI EN 14630 and UNI 9944, in order to identify the potential risk of corrosion of reinforcing bars, in tunnel sections made of reinforced concrete, and / or metal elements in contact with the surface of the final coatings;
- Tests for the determination of resistance to chlorides according to UNI EN 12390-11, to verify the resistance of the final coatings with respect to de-icing salts and / or precipitation (in the entrance areas).

Pull out tests: in order to evaluate the compressive strength of the final coatings and therefore the compliance with the performance requirements (e.g. installation points of plant systems) according to UNI EN 12504-3, extraction / pull out tests were carried out. For each test, the following are prescribed: 1) the preparation of the test surface with removal of any surface coatings (painting; rinzaffi; projected concrete coating, unless otherwise indicated); 2) the definition of the correlation curve, to be achieved in specific furnace sections, in which the pull-out tests are placed adjacent to the sclerometric measurements and to the sampling points of the concrete for the subsequent compression test. The correlation curve is calibrated by the laboratory or company appointed to carry out the investigation.

Ultrasonic and/or Sonreb tests: ultrasonic tests (generally "direct") are provided for the verification of the state of aggregation of the coating according to UNI EN 12504-4. These are performed by transparency (preferable) or by surface. Ultrasonic tests are generally provided coupled with sclerometric investigations in order to allow the mechanical characterization of the coating according to the "Sonreb" method in accordance with the UNI EN 12504-2: 2001, UNI EN 583-1/2004, and UNI EN 12504-4: 2005 standards.

Sclerometric tests: sclerometric measurements were carried out according to UNI EN 1250 4-2. For each test, the following are prescribed: 1) the preparation of the test surface with removal of any surface coatings (painting; rinzaffi; projected concrete coating, unless otherwise indicated); 2) the definition of the correlation curve, to be carried out by the undertaking or by the laboratory responsible for carrying out the survey, to be carried out in specific furnace sections, where the sclerometric tests are placed adjacent to the pull-out tests and to the sampling points of the concrete for the subsequent compression test.

The light extensive hammering of the final coatings integrates the sample hammering performed during the detailed inspection and allows the identification of:

- cortical deterioration (detachments to the joints, detachments of superficial restoration – rinzaffature; crawl spaces; superficial detachments; injuries);
- water percolation;
- resonant portions of the final coating, potentially affected by deep anomalies (under thicknesses, deep crawl spaces, cavities in the final coating, lesions and/or dislocations, excavations between the final coating and the preliminary coating and/or between the coatings and the cluster on the back);
- the state of deterioration of existing garrisons (gutters, protective nets).

The survey estimates the extent of the deterioration (classified with an index ranging from 1 to 3 attributed as follows: 1 – mild deterioration, 2 – medium deterioration; 3 – strong deterioration) and returns the location. The results are reported:

- in summary form, in the report of "reports", which lists the defects and / or the main degradations to be examined, in general classified as "resonances" and / or with index 3;
- in extended and tabular form, in the "hammering card".

Flat jack tests: Single flat jack measurements were performed according to ASTM C 1196-09 and 1197-09 and RILEM LUM D3 (1994). The test consists of the installation of the measuring bases, formed by pairs of cornerstones, and then the execution of a cut in the final coating of the pedestal and the subsequent application on the cutting surfaces of a pressure to restore the initial stress conditions, i.e. bring the edges of the slit back to the initial conditions. From the force exerted by the jack to restore the initial situation it was possible to identify the stress state originally present in the investigated element.

Control / detection of cracks: Systematic and automatic detection will be carried out with TSS technology of the width of all cracks, open and / or calcified, to integrate the sample survey performed during the possible integration of detailed inspections.

Visual and photographic inspection: detailed visual inspection with possible collection of photographic documentation, to integrate, where necessary, what was done on the occasion of the detailed investigations.

The results of the selective surveys, detailed in the documentation listed below (Annex 6), are briefly discussed in the following chapter.

Annex 6.1 – Technical report selective georadar survey

Annex 6.2 – Technical report perforations with videoendoscopic examination

Annex 6.3 – Detection of the presence of reinforcements with pacometer

Annex 6. 4 – Sampling and compression test of concrete samples

Annex 6. 5 – Carbonation depth tests

Annex 6. 6 – Determination of the penetration depth of chloride ions

Annex 6. 7 – Pull-out tests

Annex 6. 8 – Sonreb investigation (ultrasonic and sclerometric)

Annex 6. 9 – Determination of the sclerometric index

Annex 6. 10 – Direct reliefs of the intrados of the coating by hammering

Annex 6.11 – Flat jack tests

RESULTS OF SELECTIVE SURVEYS AND THEIR INTERPRETATION

This chapter analyzes with engineering criteria the results of the selective investigations conducted along the furnace and characterizing the state of the coating in the critical areas, identified in the selective investigation plan D1 [3]defined as portions of the furnace and characterized by defects and / or anomalies relatively homogeneous, in terms of type, extension and intensity.

Therefore, they analyze

- the resistance of the structural materials that were used to build the tunnel;
- the extent and severity of surface degradation detected during the detailed inspection;
- the extent and severity of any deep anomalies (under thicknesses, deep crawl spaces, volumes of degraded and/or defective concrete, cavities, lesions and/or dislocations, excavations).

The following figure refers to the convention already adopted in the inspection sheets to locate the defects found, used in this document in order to define the position of the tests carried out and/or the planned devices. The cross-section is then divided into pedestals, kidneys/vestments and cap/vault.

The directions referred to in the rest of the chapter follow the direction of travel of the tunnel, so the right corresponds to the side of the lane and the left to the side of the fast lane.

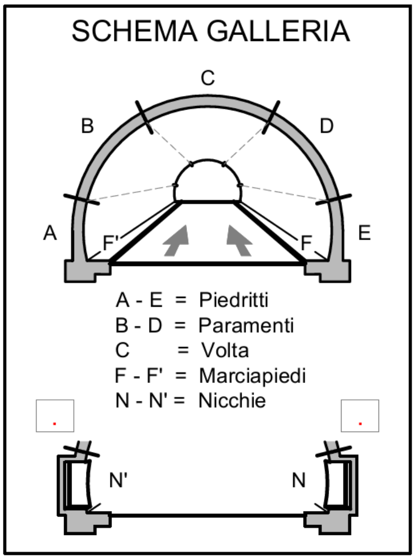


Figure 2: *Tunnel reference diagram*

The progression adopted is the same at the base of the TSS survey of the fornix, also reported in the inspection sheets attached to the TSS in-depth inspection technical report, where the initial progressive ("zero") located at the base of the flute spout of the entrance portal is assumed. This choice determines a lag with respect to the progression adopted in part of the reference documentation, and in particular:

- in the historical documentation (elaborated as built),
- in some cases in the results of massive, historical and more recent georadar surveys,

all referred to an initial progressive identified by the "first cover of the sky" (beginning of the cap. This same convention was adopted in the marking of the fornix affixed by the Dealership.
This lag was taken into account in the cross-analysis of the baseline data and evidence found in the field. For the tunnel in question, considering the geometry of the entrance portal, the phase shift is equal to about 4m.

In the analysis tables of the results of the investigations reported in the following paragraphs, in order to facilitate reading, different character styles are adopted to highlight the defects or anomalies found according to the growing criticality. Therefore, *italics* will be used, for *moderate criticality* and **bold** for **critical issuesand** as reported in the following legend.

Table 2: *Legend*

normal	No Critical or Minor Criticality
italics	*Moderate criticality*
boldface	**Severe criticality**

5.1 Detailed georadar surveys

The detailed georadar surveys were located in the critical areas where anomalies were found during detailed inspections and / or analysis of reference documentation (eg results of verification drilling carried out at the end of the work, results of georadar investigations and / or video endoscopies in previous holes, outcome of massive georadar surveys conducted in 2020).

The use of antennas with different frequencies allowed to investigate the coating with different resolutions. In order to detect the presence of anomalous thicknesses, excavations or cavities located at a depth of more than 40cm from the intrados or to investigate portions of the coating with a thickness greater than 40cm (eg piers, and reverse arch) or analyze sections affected by diffuse surface humidity and / or percolation, antennas with a nominal frequency of 900 MHz were used.

The evaluation of the thickness of the final coating is of fundamental importance to verify any construction defects, found above all in the joints and / or in the vault, which may have generated under thicknesses compared to the theoretical thicknesses hypothesized in the design or as built documents. The presence of under thicknesses is in fact one of the main causes that determine the formation of cracks in the coatings, kinematics and collapses, extended or localized.

The georadar is also able to

- highlight any discontinuities within the thickness of the final and first phase coatings,
- identify the interface with the terrain/rock behind,
- identify the possible presence of ribs in the first phase coating and the presence of reinforcements in the sections where the final coating is armed.

Table 3 performed, where they are indicated with: T, the transversal detailed georadar surveys; L, surveys of longitudinal detailed georadar. and AR, georadar surveys on pavement. The results of the I-GEO surveys foreseen at the progressives: 58, 59, 69, 70, 79 and 70-79 (longitudinal) are not available.

The main critical issues found can be summarized as follows:

- presence of voids on the back and / or cavities and / or crawl spaces and / or deteriorated concrete in the shell, paramenti and piers, with reduction of the structural thickness of the final coating;
- possible cortical detachments;
- deep lesions in the key of cap and vestments;
- significant irregularities in the reinforcement cover (Figure Figure 3Figure 4

Table 3: *Final detailed georadar surveys*

Progr. [m]	Position	Direction of paving	Minimum theoretical thickness of the final coating	Description
7-9	C	L	n.a.	The acquired trait is armed.
8	*A-B-C-D-E*	*T*	*n.a.*	*The acquired trait is armed. The investigation identified the presence of some features attributable to cortical discontinuities that are located at the level of the intrados reinforcement bars (from 5cm to 11cm) of metric extension.*
29	**A-B-C-D-E**	**T**	**n.a.**	**The acquired stroke is armed with considerable irregularity of the iron cover whose thickness varies from about 10 cm in C to about 30 cm on kidneys and piers. There is a discontinuity in C (from 17cm to 40cm) of metric extension and a portion of coating with possible anomalies or inhomogeneities (possible crawl space**

Progr. [m]	Position	Direction of paving	Minimum theoretical thickness of the final coating	Description
				and / or deteriorated) in C (from 22cm to 62cm) of metric extension.
181.5	**A-B-C-D-E**	**T**	**n.a.**	**The acquired section is armed with considerable irregularity of the iron cover whose thickness varies from about 10 cm on the piers to about 30 cm on the kidneys and key, ie with the opposite trend compared to that detected at the progressive 28. The survey identified the presence of some features (from 4cm to 29cm) attributable to discontinuities. In addition, there is a possible void on the back in A (from 64cm to 77cm) of decimetric extension.**
200.5	*A-B-C-D-E*	*T*	*n.a.*	*The acquired section is armed with considerable irregularity of the iron cover whose thickness varies from about 10 cm on the pedestals to about 30 cm on the kidneys and key (as at the progressive 181.5). The investigation identified the presence of a feature attributable to a discontinuity (from 12cm to 18cm) and a portion of coating with possible anomalies or inhomogeneities in C (possible vespanous and / or deteriorated area) (from 2cm to 15cm) of metric extension.*
200-205	**C**	**L**	**n.a.**	**The acquired section is armed and the georadar signal is partly shielded. The presence of a possible cavity in C (from 8cm to 27cm) of metric extension is detected.**
269	A-B-C-D-E	T	n.a.	The acquired stroke is armed with considerable irregularity of the iron cover whose thickness varies from about 10 cm on the piers to about 30 cm on the kidneys and key.
297	*A-B-C-D-E*	*T*	*n.a.*	*The acquired trait is armed. The iron cover of the reinforcements has a more limited variability than the other sections analyzed (minimum 10cm, maximum 30cm). The survey revealed the presence of a possible void on the back in B (from 76cm to 104cm)*

Progr. [m]	Position	Direction of paving	Minimum theoretical thickness of the final coating	Description
				of metric extension and some features attributable to discontinuities (from 22cm to 46cm). There is also a portion of coating with possible anomalies or deep inhomogeneities in D (possible crawl space and / or deteriorated area, from 65cm to 98cm) of metric extension.
316	*A-B-C-D-E*	*T*	*n.a.*	*The acquired section is armed and the georadar signal is partly shielded. The iron cover of the reinforcements has a modest variability (minimum 5cm, maximum 10cm). The presence of features attributable to discontinuities is detected at the level of the intrados reinforcement bars (from 5cm to 14cm).*
324-326	C	L	n.a.	The acquired section is armed and the radar signal is partly shielded.
325	*A-B-C-D-E*	*T*	*n.a.*	*The acquired trait is armed. The presence of some features attributable to cortical discontinuities is detected at the level of the intrados reinforcement bars (from 6cm to 35cm). The iron cover of the reinforcements has a modest variability (minimum 5cm, maximum 10cm).*

FG720-Galleria Ratella	NOTA INTERPRETATIVA	14/09/2021
Sistema di acquisizione	Georadar K2 FastWave - Antenna monostatica 900MHz	
Progressiva (m)	29	

Radargramma

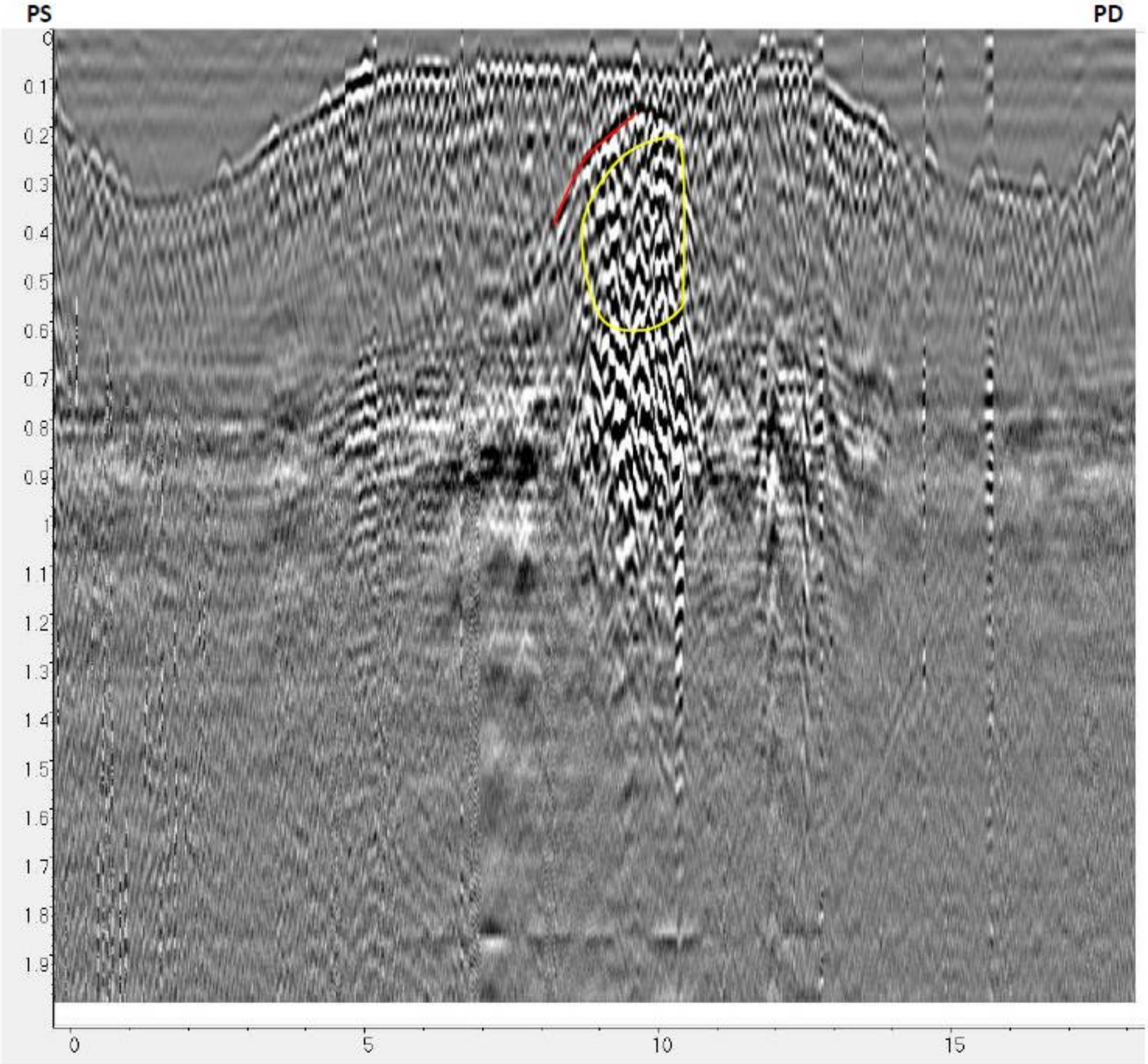


Figure 3: *Transverse detail georadar at pm 29. Variability of the iron cover (construction defect).*

FG720-Galleria Ratella	NOTA INTERPRETATIVA	14/09/2021
Sistema di acquisizione	Georadar K2 FastWave - Antenna monostatica 900MHz	
Progressiva (m)	181.5	

Radargramma

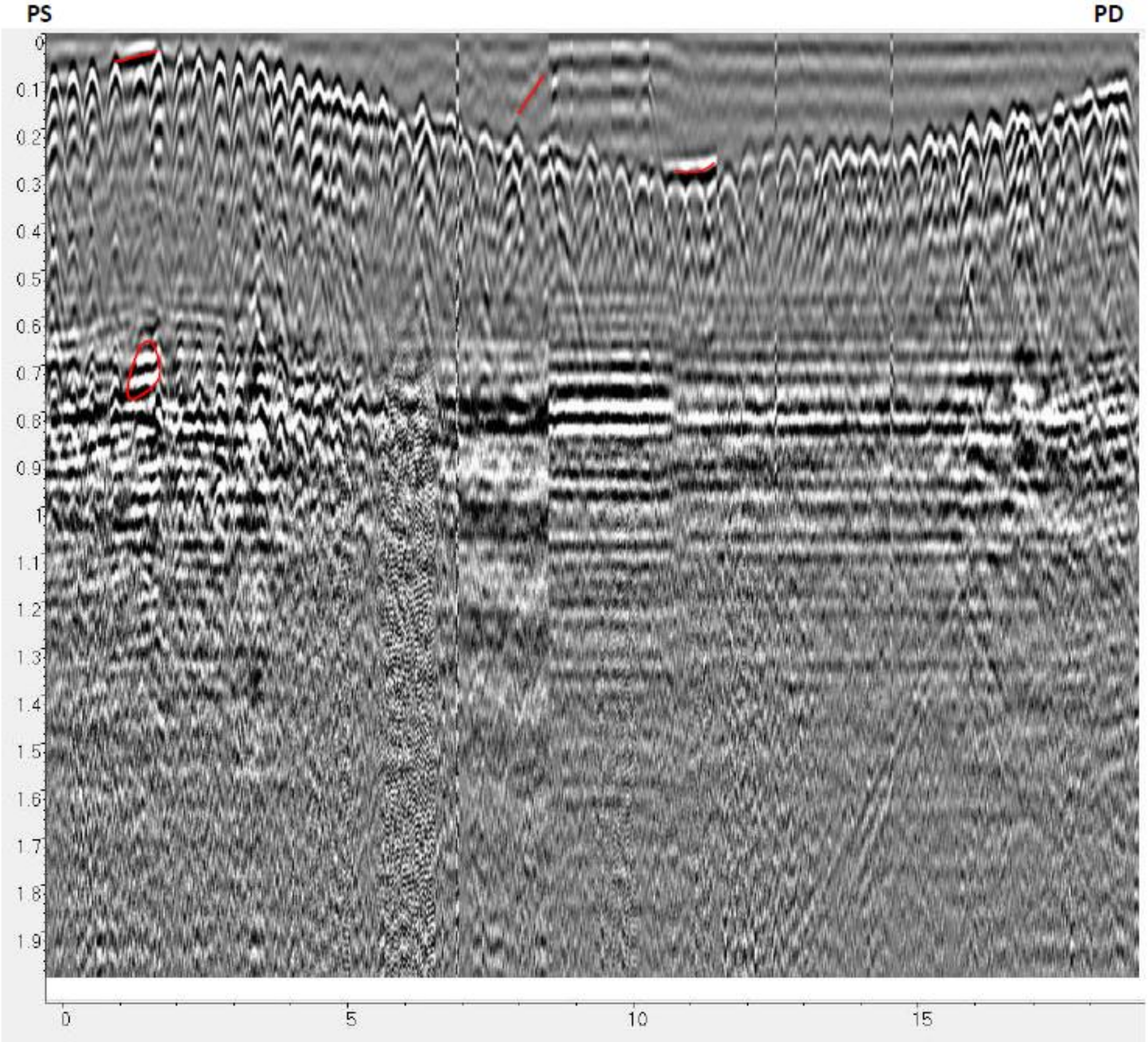


Figure 4: *Transverse detail georadar at pm 181.5. Variability of the iron cover (construction defect).*

5.2 Perforations with videoendoscopic examination

The videoendoscopic examination of the core destruction perforations, located in the areas characterized by anomalies and / or deep defects, allowed to investigate and determine in a certain but timely manner the thickness of the final coating, the types and changes of material, the state of conservation of the concrete as well as the presence of deep anomalies.

Table Table 4 summarizes the data collected with video endoscopies: to indicate the growing criticality, the cells have been highlighted in accordance with the legend.

The video endoscopies (I-PERF) falling on the same position as the selective georadar investigations (I-GEO) confirm the defects (represented above all by discontinuities / cracks, portions of wasp and / or deteriorated concrete and cavities) found by the latter. The I-PERF surveys provided for at the progressive: 58.5, 69 and 77 are not available.

Table 4: *Final perforations with videoendoscopic examination*

Hole	Prog. [m]	Position	Thickness [cm] - DA	Thickness [cm] - A	Videoendoscopic result	Notes
V1	9	C	0	33	Ordinary concrete in the absence of water	2.2 m from the key
V2	29	C	0	19	Ordinary concrete in the absence of water	
V2	**29**	**C**	**19**	**20**	**Fractured concrete in the absence of water**	
V2	**29**	**C**	**20**	**23**	**Discontinuity (open slot)**	
V2	29	C	23	23	Waterproofing sheath	
V3	39	C-B	0	31	Ordinary concrete in the absence of water	2.2 m from the key
V3	**39**	**C-B**	**31**	**33**	**Deteriorated concrete with the presence of an open crack.**	**2.2 m from the key**
V3	39	C-B	33	33	Waterproofing sheath	2.2 m from the key
V3	*39*	*C-B*	*33*	*38*	*Weakly deteriorated concrete in the absence of water, uneven by coloring.*	*2.2 m from the key*
V4	*181.5*	*D*	*0*	*24*	*Ordinary concrete in the absence of water, sometimes weakly deteriorated.*	*4.4 m from C*
V4	181.5	D	24	24	Steel: Reinforcing Bar	4.4 m from C
V5	191	C	0	29	Ordinary concrete in the absence of water	
V5	**191**	**C**	**29**	**33**	**Discontinuity (open slot)**	
V5	191	C	33	37	Ordinary concrete in the absence of water	
V6	200.5	C	0	34	Ordinary concrete in the absence of water	

Hole	Prog. [m]	Position	Thickness [cm] - DA	Thickness [cm] - A	Videoendoscopic result	Notes
V7	269	C	0	34	Ordinary concrete in the absence of water	
V8	297	C	0	31	Ordinary concrete in the absence of water	
V9	316	C-D	0	34	Ordinary concrete in the absence of water	2.2 m from C
V10	321.5	D	0	30	Ordinary concrete in the absence of water	
V10	**321.5**	**D**	**30**	**30**	**Discontinuity: lesion with adherent flaps**	
V10	*321.5*	*D*	*30*	*35*	*Weakly damaged concrete in the absence of water*	

As part of the massive georadar surveys of 2020, videoendoscopic investigations were carried out in control and calibration holes, the results of which are shown in the table below. The following data have been taken into account in the assessment process.

Table 5: *Massive georadar surveys. Control and calibration holes: results.*

Perforation: Prog. [m]	Individual stratigraphy [cm]
30 High Right Kidney (2020)	0-78 cls light grey, millimeter local porosity
165 right high kidney (2020)	0-85 cls light grey, millimeter local porosity
265 High Right Kidney (2020)	0-78 cls light grey, millimeter local porosity
315 High Right Kidney (2020)	0-57 cls light grey, millimeter local porosity

The boroscopy performed at progressive 30 shows a thickness of the coatings attributable to that determined with massive georadar investigations and highlights how the anomaly found with V2 videoendoscopy (progressive 29 in C) may have a confined character.

5.3 Status of reinforcing bars

This chapter analyzes the results of specific tests conducted in order to determine the distribution, characteristics, condition and strength of the reinforcing bars of the final coating.

5.3.1 Detection of the presence of reinforcements with pacometer

The detection of the distribution of the reinforcing bars in the tunnel sections with definitive reinforced concrete coatings was carried out through pacometric investigations.

The table specifies the longitudinal (PL) and transverse (PT) pitch of the reinforcements and the iron cover (C) of the different portions of the furnace investigated. These investigations did not make it possible to assess the diameter of the reinforcements. For important details (interferro, copriferro) please refer to the attachments.

From the results obtained, valid for the purposes of structural verification of the strength of the sections of the fornix made of reinforced concrete, it can be deduced that:

- The entire portion of the fornix is made of reinforced concrete;
- At the eastern entrance there is an average pitch of the reinforcements higher than the theoretical one, and therefore to the detriment of safety. For the remaining portions investigated, however, the average pitch of the reinforcements is lower than the theoretical one;
- The portions of the furnace investigated have a thickness of the iron cover lower than the maximum depth of the carbonation phenomena (see chapter §6.4.1), thus favoring corrosion phenomena of the reinforcements, the reduction (in the long term) of the structural strength and degradation phenomena such as injuries, expulsion of the iron cover and detachments. An exception is the survey carried out on the right foot at the east entrance where the thickness of the cover is higher than Pcar.

Table 6: *Reinforcement surveys (dimensions in centimeters; n.r.=reinforcement not detectable)*

Progressive [m]	**Position**	**Medium wheelbase transv. [cm]**	**Medium long wheelbase. [cm]**	**Medium pitch [cm]**	**Medium iron cover transv. (cm)**	**Medium long iron cover. (cm)**	**Medium iron cover [cm]**
8	A	-	-	29	-	-	2
8	**B**	**-**	**-**	**32**	**-**	**-**	**2**
8	**C**	**26**	**39**	**-**	**-**	**-**	**0**
8	**D**	**-**	**-**	**35**	**-**	**-**	**3**
8	**And**	**-**	**-**	**31**	**-**	**-**	**7**
94	A	30	19	-	-	-	1
94	C	-	-	18	-	-	0.5
94	And	19	29	-	-	-	6
324	A	-	-	19	-	-	0.5
324	B	15	28	-	-	-	2
324	C	-	-	15	-	-	0.5
324	D	-	-	18	-	-	3
324	And	29	15	-	-	-	2

5.3.2 Determination of chloride ion concentration in concrete

The determination of the concentration of chloride ions in concrete is useful for assessing the risk of triggering corrosion of reinforcements due to alteration of the protective oxide film present on the surface of the reinforcements. This alteration occurs when critical chloride concentrations are exceeded near the bars.

The critical concentration of Cl^- ions is related to the type of structure: for aerial structures the value will be lower than that necessary to trigger the corrosion process in a submerged structure, since the diffusion of oxygen is strongly slowed down.

In practice, for aerial structures a concentration of chlorides approximately between 0.05 and 0.15% compared to the mass of concrete can be considered critical (stated by Prof. Luigi Coppola in the book: Concretum).

Along the entire furnace the measurements were performed by investigating the percentage concentration of chloride ions up to a depth of 50 mm and no critical conditions are reported.

Table 7: *Results ofchloride concentration*

Sample	Progressive [m]	Position	Concentration [%]
6551_1A	8	And	0.029
6551_1B	8	And	0.021
6551_1C	8	And	0.03
6551_2A	8	A	0.008
6551_2B	8	A	0.012
6551_2C	8	A	0.01
6551_3A	8	C	0.018
6551_3B	8	C	0.015
6551_3C	8	C	0.014
6551_4A	156	And	0.022
6551_4B	156	And	0.032
6551_4C	156	And	0.027
6551_4A	156	A	0.042
6551_5B	156	A	0.01
6551_5C	156	A	0.039
6551_6A	156	C	0.032
6551_6B	156	C	0.033
6551_6C	156	C	0.027
6551_7A	325	And	0.014
6551_7B	325	And	0.015
6551_7C	325	And	0.015

Sample	Progressive [m]	Position	Concentration [%]
6551_8A	325	A	0.01
6551_8B	325	A	0.01
6551_8C	325	A	0.008
6551_9A	325	C	0.005
6551_9B	325	C	0.014
6551_9C	325	C	0.005

5.4 Concrete condition

This section analyses the results of specific tests carried out in order to determine the state and strength of the concrete of the final coating using destructive and non-destructive methods.

5.4.1 Compression tests on concrete cores pursuant to Ministerial Decree 17/01/2018 and determination of carbonation depth

Along the entire furnace, on the coating definedIV, a total of 9 samples were taken of cylindrical cores of variable length between 23 0-40 0 mm, in the key of the cap (axis) and in correspondence of the right and left pedestals.

On each core was performed the determination of the carbonation depth according to the reference standard UNI 9944. The test allows to detect the state of conservation of structural elements in concrete through the chemical process of carbonation, which provides that by the action of carbon dioxide that is present in the air the lime present in the concrete is neutralized.

The measurement of the carbonation depth was obtained with a specific colorimetric test. The measure also takes into account scraps removed from the sample at the time of cutting for the preparation of specimens.

Subsequently, from the aforementioned cores taken, and compatibly with their length, it was possible to obtain on average 2 provini on which the uniaxial compression tests were performed, with reference to the indications of the UNI EN 12504-1 standard and using a 3000 kN compression testing machine.

The following table shows the results of the carbonation depths and the average compressive strength of the various specimens obtained for each sampled core. The critics are not worthit.

Table 8: *Results of compression tests of cylindrical samples*

Sample	Progressive [m]	Position	Number of samples	Carrot length [mm]	Average density [kg/m3]	Mean compressive strength Fc [N/mm2]
8PDX	8	And	2	380	2428	48.3

Sample	Progressive [m]	Position	Number of samples	Carrot length [mm]	Average density [kg/m3]	Mean compressive strength Fc [N/mm2]
8PDX	8	And	2	380	2403	41.2
8PSX	8	A	2	370	2399	37.6
8PSX	8	A	2	370	2359	28.2
8CAL	8	C	1	230	2429	36.7
156 PDX	156	And	2	400	2447	50.6
156 PDX	156	And	2	400	2463	45.8
156 PSX	156	A	2	380	2475	43.2
156 PSX	156	A	2	380	2404	46.8
156 CAL	156	C	1	240	2336	42.4
325 PDX	325	And	2	260	2319	31.5
325 PDX	325	And	2	260	2327	33.4
325 PSX	325	A	2	380	2360	50.5
325 PSX	325	A	2	380	2373	46.5
325 CAL	325	C	1	230	2307	39.2

Table 9: *Results of carbonation depth of cylindrical samples*

Sample	Prog. [m]	Position	Number of samples	Carrot length [mm]	Carbonation depth [mm]
8C	8	C	1	230	21
8_PSX	8	A	1	370	30
8_PDX	8	And	1	380	25
156C	156	C	1	240	21
156_PSX	156	A	1	380	20
156_PDX	156	And	1	400	30
325_PSX	325	A	1	380	20
325C	325	C	1	230	20
325_PDX	325	And	1	260	30

Table 10: *Results of carbonation depth tests of cylindrical samples and pachytric iron cover (n.a.=not available)*

I-CAR I-PACO COMPARISON				
Prog. [m]	**Position**	**Carbonation depth Pcar[mm]**	**Iron cover c (mm)**	**c> Pcar?**
8	A	30	20	No
8	B	n.a.	20	n.a.
8	C	21	0	No
8	D	n.a.	30	n.a.
8	And	25	70	Yes
94	A	n.a.	10	n.a.

I-CAR I-PACO COMPARISON				
Prog. [m]	**Position**	**Carbonation depth Pcar[mm]**	**Iron cover c (mm)**	**c> Pcar?**
94	C	n.a.	5	n.a.
94	And	n.a.	60	n.a.
156	C	21	n.a.	n.a.
156	A	20	n.a.	n.a.
156	And	30	n.a.	n.a.
324	A	20	5	No
324	B	n.a.	20	n.a.
324	C	20	5	No
324	D	n.a.	30	n.a.
324	And	30	20	No

Plausible reasons for the variability in the length of samples ("cores") of extracted material are the presence of defects, namely:

- lesions, visible on the intrados surface of the shell which, as evidenced by the georadar investigations carried out, propagate deep into the final coating;
- discontinuities in the casting;
- cavities and/or areas of crawl spaced concrete;
- irregularities of the interface between the final coating and the first stage.

As can be seen, the carbonation depths vary from a minimum of 2 cm to a maximum of 3 cm and the cylindrical compressive strengths (Fc=Rc due to the lack of the 2:1 ratio in the specimen) measured showvariable values around 28.2-50.6 N/mm 2. There are noportions of fornicand with critical values.

5.4.2 Non-destructive testing

Non-destructive tests have the advantage of being minimally invasive, easy and quick to perform and do not alternate the stator tensionaland thestructure. On the other hand, they may be less reliable than destructive tests as they are influenced more significantly by the methodology of execution, by the adequate preparation of the test surface, as well as by the state of cortical alteration of the element to be investigated.

The following chapters summarize the estimates of cubic compressive strengths resulting from the specific tests performed on the final coating.

5.4.2.1 Pull-out test

The following table summarizes the results of the pull-out surveys carried out by extracting a post-inserted "Thoro" test piece. There is no I-PUL investigations provided for progressive: 12 (in key and on the pedestals), 58 (on the right kidney) and 251 (on the right foot).

Table 11: *Pull-out test results*

Prog. [m]	Position	Breakout force [N]	Rated compressive strength Rc [N/mm2]
8	And	39168.4	n.a.
8	A	33149	n.a.
8	C	33446.5	n.a.
38	C	30944.1	n.a.
102	D	35598.8	n.a.
102	B	42493	n.a.
156	And	35931.2	n.a.
156	C	29859.2	n.a.
156	C	33184	n.a.
167	C	41163.1	n.a.
182	D	44802.6	n.a.
229	And	30104.2	n.a.
232	And	31329.1	n.a.
232	A	35703.8	n.a.
232	C	33254	n.a.
296	D	22054.4	n.a.
296	B	21879.4	n.a.
315	D	30629.2	n.a.
315	B	31329.1	n.a.
316	And	18379.3	n.a.
316	A	20479.4	n.a.
316	C	27829.3	n.a.
325	And	26429.3	n.a.
325	A	23979.4	n.a.
325	C	39728.3	n.a.

The estimate of compressive strength derived from the breakout force has not been determined by the laboratory in charge.

5.4.2.2 Sclerometric and ultrasonic tests (SonReb method)

The following tables summarize the estimated compressive strength results with reference to the results of the sclerometric measurements and the application of the Sonreb method, which also takes into account the ultrasonic measurements performed on the final coatings. There are no I-BS surveys at the progressive: 12 (in B-C and C-D) and 58 (on right foot).

Table 12: *Sonreb test results*

Prog. [m]	Position	Ultrasonic pulse rate [m/s]	Calibrated compressive strength Rc [N/mm2]	Rated compressive strength Fc [N/mm2]
1	And	3370	41.2	34.2
1	A	2457	40.2	33.4
1	C	2403	37.6	31.2
325	And	1775	33.1	27.5
325	A	2888	45.5	37.8
325	C	3762	45.6	37.8

The compressive strength estimated at the end of the Sonreb tests was evaluated using different curvingsand correlation of literature (see attached documentation for saidgli). The values thus obtained are lower than those obtained from the destructive tests on concrete cores. A certain degree of uncertainty about these results must also be taken into account because of the randomness of the indirect investigation method. However, being in favor of safety, such evidence is considered relevant to the purpose of this document.

Table 13: *Results of sclerometric measurements*

Progressive [m]	**Position**	**Bounce index**	**Rated compressive strength Rc [N/mm2]**	**Rated compressive strength fc [N/mm2]**
8	C	49	48.24	40.04
8	And	46	49.5	41.09
8	A	42	41.31	34.29
38	D	41	32.85	27.27
94	D	39	29.25	24.28
94	B	41	32.85	27.27
156	C	50	51.12	42.43
156	And	49	54	44.82
156	A	43	43.29	35.93
167	D	51	51.75	42.95
167	B	53	51.75	42.95
182	And	44	45.36	37.65
229	D	53	51.75	42.95
232	D	51	51.75	42.95
232	B	53	51.75	42.95
267	A	47	51.75	42.95
315	And	52	41.31	34.29
315	A	52	41.31	34.29
316	D	51	51.75	42.95
316	B	53	51.75	42.95
325	C	50	51.15	42.45
325	And	40	37.44	31.08
325	A	42	41.31	34.29

The comparison between the compressive strength estimates obtained from sclerometric readings and the compressive strength tests highlights the following aspects:

- The sclerometric measurements lead to values estimated by correlation curve of compressive strength similar to those derived from compression strength tests. The estimated maximum value is 44. 82 MPa, minimum 24. 28 MPa and the middle 38. 05 MPa;
- The average value (38. 05 MPa) is higher than the results of the Sonreb tests (3 3.6 MPa) andd lower than the average of the compression tests (41. 46 MPa);
- Also in this case the deviations recorded with respect to the compressive strength tests may have been determined by degradation (carbonation) and cortical surface construction defects;

- These tests constitute a validation of the compression tests performed and return an estimate of the resistance of the surface "rind" of the final coating, neglecting the defects present on the back of the coating (crawl spaces / cavities).

5.4.3 Comparison of concrete characterization results

To confirm the above considerations, the following figure shows the comparison between the compressive strength values determined as a result of the compressive strength tests (I-CLS), the Sonreb tests (I-SON) and the sclerometric tests (I-BS) along the development of the tunnel. The values of the I-SON_fc have been converted from cubic to cylindrical resistance to be able to compare them with other cylindrical resistances.

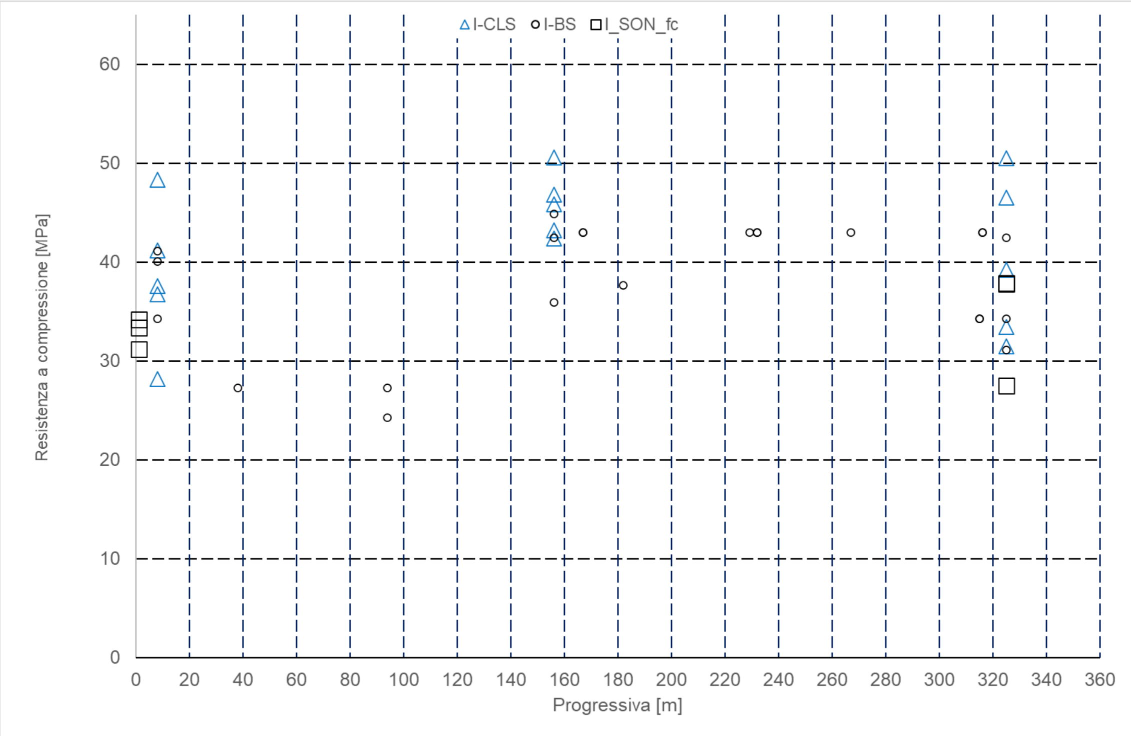


Figure 5: *Comparison of compressive strength values estimated with destructive and non-destructive tests*

5.5 Execution of direct surveys of the intrados of the coating by hammering

The survey of the coating soffit by means of extensive light hammering was carried out on 14 September 2021, inspecting the vault area and the vestments with the aid of a lifting vehicle.

The gallery has been ideally divided – in a transversal sense – into five sections A,B,C,D,E which represent (see Figure 2):

- A: left foot;
- B: left facing;
- C: vault;
- D: right vestment;
- E: right pederect.

The aim of the investigation was to identify any cortical deterioration of the intrados coating, with particular attention to degradation situations susceptible to possible detachments, and the "resonant" portions of the coating.

Below is the list of types of superficial deterioration treated:

- Joint detachment: it is found in correspondence of the casting joints between successive construction segments, in some cases restored with cement mortar to restore both continuity and any surface construction defects;
- Detachment rinzaffatura: it is found in correspondence of rinzaffature in cement mortar or other restoration materials performed on to restore the definitive coatings with respect to construction defects or degradation phenomena;
- Crawl space: part of the concrete characterized by lack of binder between the aggregates, high percentage of voids and coarse aggregates in sight;
- Surface detachment: cortical detachments of concrete slabs in correspondence with construction defects and / or surface degradation. By performing the light hammering of the final coating in correspondence with this deterioration, a "muffled" sound is found.
- Lesions: presence of linear cracks in the concrete.
- Water percolation: leakage of water from the concrete mass.

For each of these deteriorations, a severity index has been assigned, to which the following values are attributed:

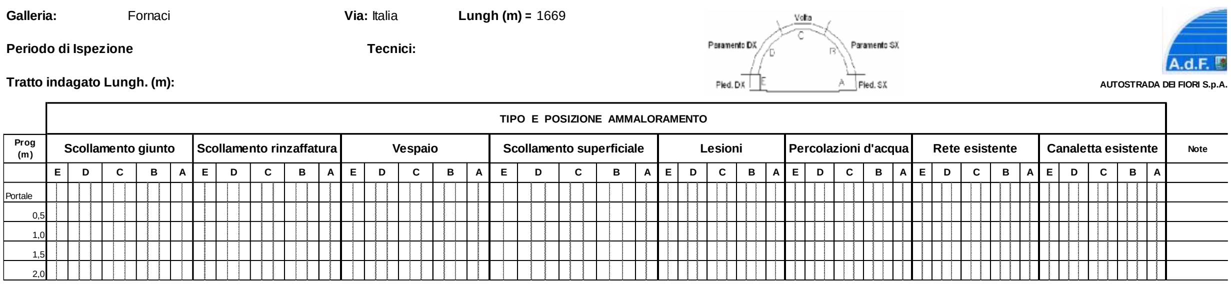
1. Mild deterioration;
2. Medium deterioration;
3. Strong deterioration.

The severity index of the deterioration has been reported on the hammering cards attached to this document.

For water lesions and percolation, the symbol "x" has been inserted to indicate the presence of deterioration; The same symbol is also used to indicate the presence of existing protective nets - installed prior to the survey by hammering - and the existing channels, placed for the collection of percolations and / or dripping in the vault.

The inspection identified the following deteriorations (see Table Table 14).

Table 14 involved)" where the severity index of the deterioration is indicated (1,2,3, increasing as a function of severity) indicated by the hammer throwers and the column indicating the extent of the surface involved indicated as a percentage (33%,50%66%100% depending on how much an area is affected by the defect). Figure Figure 6 an excerpt of the hammering card where the subdivisions of the various areas of the cross-section of the tunnel (A, B, C, D, E) are visible.


Galleria: Fornaci Via: Italia Lungh (m) = 1669
Periodo di Ispezione Tecnici:
Tratto indagato Lungh. (m):

Prog (m)	TIPO E POSIZIONE AMMALORAMENTO								Note
	Scollamento giunto	Scollamento rinzaffatura	Vespaio	Scollamento superficiale	Lesioni	Percolazioni d'acqua	Rete esistente	Canaletta esistente	
	E D C B A	E D C B A	E D C B A	E D C B A	E D C B A	E D C B A	E D C B A	E D C B A	
Portale									
0,5									
1,0									
1,5									
2,0									

Figure 6: *Hammer card excerpt*

Table 14: *Results of direct surveys of the soffit by hammering*

Prog. [m]	Position	Gravity	% of area involved	Deterioration	Notes
4	*B*	*2*	*33*	*Crawl space*	
4.5	*B*	*2*	*33*	*Crawl space*	
5	*B*	*2*	*33*	*Crawl space*	
5.5	*B*	*2*	*33*	*Crawl space*	
6	*B*	*2*	*33*	*Crawl space*	
6.5	*B*	*2*	*33*	*Crawl space*	
7	*C*	*2*	*33*	*Crawl space*	
7	*B*	*2*	*66*	*Crawl space*	
8	*B*	*2*	*33*	*Crawl space*	
10	**B**	**2**	**33**	**Crawl space**	**Armor exposed.**
26	*C*	*2*	*33*	*Surface detachment*	
30	*D*	*2*	*66*	*Detachment rinzaffatura*	
39	*C*	*2*	*33*	*Joint detachment*	
41	*D*	*X*	*66*	*Lesions*	
41.5	*D*	*X*	*66*	*Lesions*	
42	*D*	*X*	*66*	*Lesions*	
42.5	*D*	*X*	*66*	*Lesions*	

Prog. [m]	**Position**	**Gravity**	**% of area involved**	**Deterioration**	**Notes**
43	*D*	*X*	*66*	*Lesions*	
43.5	*D*	*X*	*66*	*Lesions*	
44	*D*	*X*	*66*	*Lesions*	
44.5	*D*	*X*	*66*	*Lesions*	
45	*D*	*X*	*66*	*Lesions*	
45.5	*D*	*X*	*66*	*Lesions*	
46	*D*	*X*	*66*	*Lesions*	
46.5	*D*	*X*	*66*	*Lesions*	
47	*D*	*X*	*66*	*Lesions*	
66	*D*	*2*	*66*	*Joint detachment*	
76	*D*	*X*	*66*	*Lesions*	
76.5	*D*	*X*	*66*	*Lesions*	
77	*D*	*X*	*66*	*Lesions*	
77.5	*D*	*X*	*66*	*Lesions*	
78	*D*	*X*	*66*	*Lesions*	
85	*D*	*2*	*66*	*Crawl space*	
85	*C*	*2*	*33*	*Crawl space*	
88	*And*	*X*	*100*	*Lesions*	
88	*D*	*X*	*100*	*Lesions*	
88	*C*	*X*	*33*	*Lesions*	
88.5	*And*	*X*	*100*	*Lesions*	
88.5	*D*	*X*	*100*	*Lesions*	
88.5	*C*	*X*	*33*	*Lesions*	
89	*And*	*X*	*100*	*Lesions*	
89	*D*	*X*	*100*	*Lesions*	
89	*C*	*X*	*33*	*Lesions*	
91	*C*	*2*	*33*	*Surface detachment*	
93	**D**	**2**	**33**	**Detachment rinzaffatura**	**Armor exposed.**
93	**D**	**2**	**33**	**Crawl space**	**Armor exposed.**
106	*And*	*X*	*100*	*Lesions*	
106	*D*	*X*	*100*	*Lesions*	
106.5	*And*	*X*	*100*	*Lesions*	
106.5	*D*	*X*	*100*	*Lesions*	
107	*And*	*X*	*100*	*Lesions*	
107	*D*	*X*	*100*	*Lesions*	
107.5	*And*	*X*	*100*	*Lesions*	
107.5	*D*	*X*	*100*	*Lesions*	
108	*And*	*X*	*100*	*Lesions*	
108	*D*	*X*	*100*	*Lesions*	
112	*B*	*2*	*66*	*Joint detachment*	
112	*D*	*2*	*33*	*Crawl space*	
112.5	*D*	*2*	*33*	*Crawl space*	

Prog. [m]	**Position**	**Gravity**	**% of area involved**	**Deterioration**	**Notes**
113	*D*	*2*	*33*	*Crawl space*	
113.5	*D*	*2*	*33*	*Crawl space*	
114	*D*	*2*	*33*	*Crawl space*	
114.5	*D*	*2*	*33*	*Crawl space*	
115	*D*	*2*	*33*	*Crawl space*	
115	*C*	*2*	*33*	*Crawl space*	
115.5	*D*	*2*	*33*	*Crawl space*	
116	*D*	*2*	*33*	*Crawl space*	
121	*C*	*2*	*33*	*Joint detachment*	
121	*B*	*2*	*66*	*Joint detachment*	
167	*D*	*2*	*66*	*Joint detachment*	
172	*D*	*2*	*100*	*Joint detachment*	
180	*B*	*2*	*33*	*Crawl space*	
180.5	*B*	*2*	*33*	*Crawl space*	
181	*B*	*2*	*33*	*Crawl space*	
181.5	*B*	*2*	*33*	*Crawl space*	
182	*B*	*2*	*33*	*Crawl space*	
182.5	*B*	*2*	*33*	*Crawl space*	
183	*B*	*2*	*33*	*Crawl space*	
183.5	*B*	*2*	*33*	*Crawl space*	
184	*B*	*2*	*33*	*Crawl space*	
184.5	*B*	*2*	*33*	*Crawl space*	
185	*B*	*2*	*33*	*Crawl space*	
200	*B*	*2*	*33*	*Crawl space*	
203	**C**	**#**	**66**	**Joint detachment**	**Presence of areas to watch out for and Resonance.**
203	*B*	*2*	*33*	*Joint detachment*	
203.5	**C**	**#**	**66**	**Joint detachment**	**Presence of areas to watch out for and Resonance.**
204	**C**	**#**	**66**	**Joint detachment**	**Presence of areas to watch out for and Resonance.**
204.5	**C**	**#**	**66**	**Joint detachment**	**Presence of areas to watch out for and Resonance.**
205	**C**	**#**	**66**	**Joint detachment**	**Presence of areas to watch out for and Resonance.**
211	*B*	*2*	*33*	*Crawl space*	
248	*B*	*2*	*33*	*Joint detachment*	
252	*B*	*2*	*100*	*Detachment rinzaffatura*	
278	*C*	*2*	*33*	*Joint detachment*	
278	*B*	*2*	*100*	*Joint detachment*	
278	*B*	*2*	*66*	*Crawl space*	
287	*C*	*2*	*100*	*Joint detachment*	

Prog. [m]	Position	Gravity	% of area involved	Deterioration	Notes
287	*B*	*2*	*100*	*Joint detachment*	
315	**B**	**2**	**66**	**Joint detachment**	**Armor exposed.**
315	**B**	**2**	**66**	**Crawl space**	**Armor exposed.**
319	*D*	*2*	*66*	*Joint detachment*	
319	**D**	**3**	**33**	**Joint detachment**	**Resonance.**
319	**C**	**3**	**66**	**Joint detachment**	**Resonance.**
320	*C*	*2*	*33*	*Crawl space*	

It is noted that the "resonance" reported by the I-TM survey among the prog. 203-205 in the cap corresponds to a portion affected by the presence of a significant profound defect; vice versa, the one reported to the prog. 319 in the cap and right facing does not correspond to a portion affected by the presence of deep defects and are therefore attributable only to concomitant surface defects. It is also noted that none of the lesions identified is reported as "resonant", i.e. deep and / or such as to favor the triggering of releases of material into the roadway.

Attached, in addition to the detailed results of the survey, are some of the most significant images acquired during the inspection phases of the structure in question.

5.6 Stress state: tests with single flat jack

All and progressiv and indicated and in Table Table 15 tests and flat jacks were carried out. The single flat jack test is an on-site test for the determination of the stresses present inside a masonry or concrete structure, conducted according to ASTM C1196.

The test carried out is ineffective when there is no reset tension but a non-closure of the cut made, to highlight a presumed absence of stresses ("discharge" coating), The stresses detected are however significantly lower than the mechanical strength of the concrete.

Table 15: Test *results with flat jacks (n.a. = not available)*

Prog. [m]	Position	Reset voltage [N/mm2]	A mart. (cm2)
166	A	0.18	778.6
166	And	0.55	778.6
297	A	0.2	778.6
297	And	0.19	778.6

5.7 Crack control / detection

The results of the investigation, which allow to integrate the results of the sample measurement of the extent of the lesions reported in the Detailed Inspection Report D2 [4] (see Table 2 and inspection sheets), [4]inthe Technical Reports of In-depth Inspection soon to be issued. .

6. SAFETY MEASURES

With reference to the findings

- Dextensive light hammering;
- Back-office evaluations.

The safety measures summarized in the following table were considered necessary, in which the interventions prescribed during the detailed inspections are highlighted in gray. These interventions are mainly required due to the widespread restoration of all joints that risks causing detachments in the roadway. All planned interventions (nets and/or corrugated sheets) are evaluated with the data available at the date of the selective survey.

The term priority indicates the urgency of the intervention, taking into account:

- firstly, avoiding the detachment of material in the lanes of travel and overtaking,
- secondly, to take into account the time available to carry them out.

There was no priority plan in this tunnel and all tests were indicated as of equal importance. During the selective inspections, only some interventions were carried out, the others were planned as soon as possible.

Table 16: *Safety measures*

Progressive [m]	Position	Defect description	Intervention	Prescription of the intervention	N.°	Priority
11	B	Exposed crawl space and bars	Typological Aquarter	Selective survey, I-TM survey result	1	Requests
202.5-205	C	Resonance joint detachment	Typological Abis	Selective survey, I-TM survey result	2x3	Requests
314-316	B-C	Joint detachment, crawl space and exposed bars	Typological A	Selective survey, I-TM survey result	1x2	Requests
320.5	C-D	Resonant joint detachment	Typological A	Selective survey, I-TM survey result	2	Installed
320.5	D	Resonant joint detachment	Typological A	Selective survey, I-TM survey result	2	Requests
325	B-C-D	Joint detachment and exposed bars	Typological A	Selective survey, I-TM survey result	6	Requests

The safety measures highlighted above in red are suggested by the back-office in relation to the results of the I-TM survey in order to avoid releasing portions, albeit modest, of material on the roadway. The table shows the progressive reporting of the defect that highlights the need to install a safety intervention.

The measures adopted are

- Corresponding to typological type A and type Abis, illustrated in the drawings [7] (type A) [7][8] ([8]).

The highlighted interventions that fall within portions of coating ordefinitive affected by degradation phenomena (corrosion of the reinforcements, degradation and / or swelling of the iron cover, incipient detachment of the iron cover) that require the application of the Aquater typological intervention.

The interventions are represented graphically in the inspection sheets attached to this report. Urgent implementation is recommended for priority interventions. For the typological Abis must be carried out tensile tests on at least 3 pieces of the intervention, providing an adequate maturation time of the resins, in the case of chemical anchors. The test load, N, will be equal to 1.5 times the working load and will be achieved through the following steps: 1/3 N - 2/3 N - N. Each intermediate load step must be maintained for at least 1 minute, the final load N for at least 5 minutes. In case of failure of the load tests, the application of another type of intervention (e.g. C3) must be evaluated.

The size, quantity and location of the devices are to be verified during installation.

Below is the final balance of the total safeguards provided for the safety of the diseases:

Table 17: *Expected financial statements*

	Tip. A/Abis Nets 2x1m	**Tip. Aquater**	**Tip.A ter Networks 1x1m**	**Tip. B Onduline**	**Cleanliness**
N°	18+variable quantity chosen on site	1			

7. FINAL ASSESSMENT

As reported in the document "Guidelines for the assessment of the safety level of tunnels of the motorway network", and in accordance with the MIT Tunnel Inspection Manual, dated 25/05/2020, the IQOA classification system is adopted for the assessment of tunnel conditions.

This classification is divided into two parts, the first allows the classification of static defects of civil elements, the second classifies water inflows. The following tables summarize the criteria for the IQOA classification.

Table 18: *Classes for static conditions of tunnel lining*

CLASSE 1
Area in buone condizioni.
Le aree di classe 1 richiedono solo manutenzione ordinaria e manutenzione preventiva programmata.
CLASSE 2
Area con lievi deterioramenti sulla struttura o sulle finiture ed impiantistica della galleria, che non mettono in pericolo la stabilità della struttura
Le aree di classe 2 possono richiedere una manutenzione correttiva specializzata non urgente, oltre alla manutenzione necessaria per le aree di classe 1.
CLASSE 2E
Area che include i deterioramenti di classe 2 (sulla struttura e nella sua area d'influenza), che potrebbero degradarsi e aumentare di estensione, mettendo in pericolo la stabilità della struttura
oppure
Aree che includono impianti civili che sono stati seriamente danneggiati o di cui la stabilità può essere compromessa.
Le aree di classe 2E richiedono un monitoraggio specifico e un'urgente manutenzione correttiva per prevenire il rapido sviluppo di un deterioramento più sostanziale della struttura, oltre alla manutenzione necessaria per le aree di classe 1.
L'indice "E" riflette una possibile evoluzione a breve termine del difetto.
CLASSE 3
Area con degrado profondo in cui i difetti rilevati indicano che la struttura (rivestimento) è stata alterata o che la stabilità dell'area in questione è probabilmente compromessa.
Le aree di classe 3 richiedono lavori di protezione, riparazione o rinforzo non urgenti. Tuttavia, è necessaria un'analisi e diagnosi rapida.
CLASSE 3U
Area nella quale il deterioramento osservato mostra un degrado profondo e che la stabilità complessiva dell'area è stata compromessa a breve o medio termine.
Le aree di classe 3U richiedono riparazioni urgenti per garantire la conservazione a lungo termine della struttura o impedire qualsiasi rapido sviluppo di difetti più gravi. I lavori di riparazione devono essere generalmente preceduti da indagini che rendano possibile stabilire anche le condizioni del terreno circostante, che spesso sono poco conosciute.
L'indice "U" riflette la natura urgente delle azioni da intraprendere.
INDICE "S"
Questa sigla aggiuntiva **"S"** è assegnata ad una delle 5 classi, di cui sopra, quando specifici difetti rilevati, indipendentemente dall'area in questione, possono mettere in pericolo la sicurezza degli utenti e quindi richiedere un'azione correttiva estremamente urgente.
La sigla aggiuntiva "S" riflette l'esistenza di un difetto in una sezione della struttura che influenza la sicurezza degli utenti e una non conformità con le norme di sicurezza o un non adeguato livello di sicurezza.

Table 19: *Classes with reference to the presence of water*

CLASSE 1
Area senza flusso d'acqua visibile;
o
Area nella quale vengono rilevate macchie di umidità sul rivestimento o in corrispondenza dei marciapiedi.
Le aree di classe 1 richiedono solo manutenzione ordinaria e manutenzione preventiva specializzata con adeguate soluzioni di drenaggio e controllo dell'inquinamento.
CLASSE 2
Area con presenza di un flusso d'acqua importante: (a) gocciolamento (di qualsiasi portata); (b) pozzanghera locale con una profondità non superiore a cinque millimetri; (c) macchia di umidità sull'asfalto; (d) flusso continuo tale da creare un film d'acqua lungo il rivestimento, con una profondità inferiore di un millimetro; (d) entità d'acqua come in (a) o (d) con raccolta da una canaletta .
Le aree di classe 2 sono caratterizzate da una possibile evoluzione dei degradi a lungo termine e devono essere soggette a sorveglianza regolare da parte del gestore in aggiunta alle azioni necessarie per le aree di classe 1.
CLASSE 3
Area con presenza di un flusso d'acqua importante: (a) flusso continuo tale da creare un film d'acqua lungo il rivestimento, con una profondità maggiore di un millimetro; (b) ingresso di acqua in pressione; (c) flusso continuo sull'asfalto (di qualsiasi portata): (d) pozzanghera con una superficie di oltre 10 metri quadrati o una profondità superiore a cinque millimetri; (e) come in (a) o (b) con raccolta da una canaletta.
La classe 3 viene utilizzata quando la portata d'acqua in ingresso, o la presenza di grandi volumi d'acqua (pozzanghera) è significativa. In questi casi sono richiesti urgenti interventi correttivi.
INDICE "S"
Questa sigla aggiuntiva **"S"** è assegnata a una delle 3 classi, di cui sopra, quando la presenza di acqua è tale da mettere in pericolo la sicurezza degli utenti e richiede pertanto interventi di manutenzione immediati.
La sigla aggiuntiva **"S"** è specificamente utilizzata quando la presenza di acqua è: (a) suscettibile al congelamento, ciò potrebbe portare alla formazione di stalattiti, superfici ghiacciate sull'asfalto o influenzare negativamente l'uso di dispositivi di sicurezza; (b) combinata con sostanze disciolte può ridurre l'attrito tra la pavimentazione stradale e i pneumatici e pertanto causare scivolamenti; (c) potrebbe rappresentare un pericolo per il traffico stradale, a causa dell'assenza o del blocco del sistema di drenaggio, inondando la carreggiata.

With this classification system, on the basis of previous investigations (e.g. TSS, georadar,structural and non-destructive tests, and visual inspections), of the historical documentation available, as well as of the results of the detailed inspection that allowed to update and evaluate the extent of degradation, it was possible, for each 10 m inspection segment, to classify the conditions of the tunnel and the related defects (see assessment in the document [4]).

In this final phase of assessment of the conditions of the tunnels, the assessment carried out in the Detailed Inspection Report[4]was updated, integrated and completed following the acquisition and interpretation of the evidence of the selective surveys analyzed in Cap. 0.

Below is the final assessment table of the tunnel with IQOA classification for each inspection segment of the length of 10 m and surface A = 200 m^2. Within each segment, a further subdivision was used if an identified defect (defined with its own surface extension) fell into a class different from that characterizing the inspection ashlar.

Table 20: *Final IQOA classification for tunnel segments*

N°	Prog.iniz. [m]	Prog.fin. [m]	DevelopmentL [m]	SurfaceA [m2]	IQOA - Civil Engineering					IQOA - Water			NOTES
					1	2	2E	3	3U	1	2	3	
1	0.0	10.0	10.0	200.0			200.0			200.0			
2	10.0	20.0	10.0	200.0		198.0	2.0			200.0			*(Static IQOA 2 in previous phase)*
3	20.0	30.0	10.0	200.0		190.0		*10.0*		200.0			*(Static IQOA 2 in previous phase)*
4	30.0	40.0	10.0	200.0		178.8	21.2			200.0			
5	40.0	50.0	10.0	200.0		180.0	20.0			200.0			
6	50.0	60.0	10.0	200.0		185.0	15.0			200.0			
7	60.0	70.0	10.0	200.0		120.0	65.0	*15.0*		200.0			*(Static IQOA 2E in previous phase)*
8	70.0	80.0	10.0	200.0		125.0	65.0	*10.0*		200.0			*(Static IQOA 2E in previous phase)*
9	80.0	90.0	10.0	200.0			200.0			200.0			
10	90.0	100.0	10.0	200.0		157.5	30.0	*12.5*		200.0			*(Static IQOA 2E in previous phase)*
11	100.0	110.0	10.0	200.0		*200.0*				200.0			*(Static IQOA 3 in previous phase)*
12	110.0	120.0	10.0	200.0		200.0				200.0			
13	120.0	130.0	10.0	200.0			200.0			200.0			
14	130.0	140.0	10.0	200.0			200.0			200.0			
15	140.0	150.0	10.0	200.0		200.0				200.0			
16	150.0	160.0	10.0	200.0			200.0			200.0			
17	160.0	170.0	10.0	200.0		200.0				200.0			
18	170.0	180.0	10.0	200.0			200.0			200.0			
19	180.0	190.0	10.0	200.0			199.0	*1.0*		200.0			*(Static IQOA 2E in previous phase)*
20	190.0	200.0	10.0	200.0		190.0	10.0			200.0			
21	200.0	210.0	10.0	200.0		149.9	40.0	*10.1*		200.0			*(Static IQOA 2E in previous phase)*
22	210.0	220.0	10.0	200.0			200.0			200.0			
23	220.0	230.0	10.0	200.0			200.0			200.0			

N°	Prog.iniz. [m]	Prog.fin. [m]	DevelopmentL [m]	SurfaceA [m2]	IQOA - Civil Engineering					IQOA - Water			NOTES
					1	2	2E	3	3U	1	2	3	
24	230.0	240.0	10.0	200.0		200.0				200.0			
25	240.0	250.0	10.0	200.0		200.0				200.0			
26	250.0	260.0	10.0	200.0		200.0				200.0			
27	260.0	270.0	10.0	200.0		200.0				200.0			
28	270.0	280.0	10.0	200.0		200.0				200.0			
29	280.0	290.0	10.0	200.0		200.0				200.0			
30	290.0	300.0	10.0	200.0		193.0		*7.0*		200.0			*(Static IQOA 2 in previous phase)*
31	300.0	310.0	10.0	200.0			200.0			200.0			
32	310.0	320.0	10.0	200.0		192.8		*7.2*		200.0			*(Static IQOA 2 in previous phase*
33	320.0	330.0	10.0	200.0		200.0				200.0			
34	330.0	332.0	2.0	40.0		40.0				40.0			

As can be seen in Table 20Notes" column the possible variation of the static IQOA value is reported, as well as the classification attributed in the previous phase, i.e. following the detailed inspection [4]. It is thus immediate to identify the areas for which the analysis of the results of the selective survey (Ch. 0) contributed directly to the update of the final assessment. Table 21 summarizes these areas and the observations/interpretations that have made it possible to update, integrate and complete the final assessment of the tunnel.

Table 21: *Update and integration of IQOA classification following analysis of selective survey results*

Concio	Prog.iniz. [m]	Prog.fin. [m]	Development L [m]	Sup.A [m^2]	IQOA PHASE 1	IQOA PHASE2	OBSERVATIONS/INTERPRETATIONS FROM SELECTIVE SURVEY ANALYSIS
2	10.0	20.0	10.0	200.0	2	2E	Crawl space and exposed bars in B (Table 14)
3	20.0	30.0	10.0	200.0	2	3	Fractured cls and open fissure in C (Table 4); Vacuum on the back in shell (GPR2020)
7	60.0	70.0	10.0	200.0	2E	3	Shell cavity (GPR2020)
8	70.0	80.0	10.0	200.0	2E	3	Shell cavity (GPR2020)
10	90.0	100.0	10.0	200.0	2E	3	Vacuum on the back in shell (GPR2020)
11	100.0	110.0	10.0	200.0	3	2	Absence of defects
19	180.0	190.0	10.0	200.0	2E	3	Vacuum on the back in A (Table 3)

Concio	Prog.iniz. [m]	Prog.fin. [m]	Development L [m]	Sup.A [m²]	IQOA PHASE 1	IQOA PHASE2	OBSERVATIONS/INTERPRETATIONS FROM SELECTIVE SURVEY ANALYSIS
21	200.0	210.0	10.0	200.0	2E	3	Cavity (sub thickness concrete) in C (Table 3); resonance joint detachment to be attentive in C (Table 14)
30	290.0	300.0	10.0	200.0	2	3	Vacuum on the back in B (Table 3); vacuum on the back in C (GPR2020)
32	310.0	320.0	10.0	200.0	2	3	Resonance joint detachment in C-D (Table 14)

During the detailed inspections, no portion of the furnace with static IQOA index S (therefore 2ES and/or 3S and/or 3US) was classified.

The final assessment of the tunnel leads to the surfaces and global percentages in IQOA classes present along the development of the tunnel. These quantities are summarised in the table below for static conditions and water inflows respectively.

Table 22: *Overall assessment of IQOA-rated tunnel condition*

		IQOA - Civil Engineering					IQOA - Water		
		1	2	2E	3	3U	1	2	3
Area A [m²]	6640.0	0.0	4300.0	2267. 2	72. 8	0.0	6640.0	0.0	0.0
% attribution	100,0%	0. 0%	64. 76%	34. 1%	1. 1%	0. 0%	100.0%	0.0%	0.0%

8. SURVEILLANCE AND TONING ACTIVITIES

The tunnel shall be subject to permanent observation based on inspections and investigations systematically and regularly carried out on a regular basis.

This system involves the execution of an in-depth inspection carried out by means of Tunnel Scanner System technological survey (which integrates photographic, geometric and thermographic survey), carried out annually, aimed at the graphic mapping of the defects present on the final coating, functional to the evaluation of the evolution of the extension and intensity of the same based on historical data. In addition, surveillance inspections are carried out three times a yearand to verify the possible occurrence of new anomalies or marked developments of what is already known (see chapter §8.3)).

8.1 Completion of the investigation plan

As part of the extraordinary inspection activities, the investigations provided for in the investigation plan were carried out ([[1][3]FG72 0-D1 – Detailed inspections: Prescription Selective Investigations). As explained in chapter §0

In order to improve the level of knowledge of the tunnel, it is recommended to provide in the planning of future areas of surveillance the completion of the overall investigation plan with optional investigations. As explained in chapter §0 it is recalled that the "priority" surveys are considered more relevant than the remaining (optional surveys), for the purpose of assessing the state of the tunnel. For the definition of "priority" or "optional" surveys, refer to what is specified in §0.

The assignment of future priorities to investigations still to be carried out can follow the following order: first I-POT, I-ARM, I-CLS, I-PERF, I-GEO and then I-PUL and I-BS. The removal of reinforcements (I-ARM) and the related potential investigations (I-POT) can be performed in correspondence with the sections where a more modest iron cover has been identified (progressive 316, critical zone 19, and 325 in C, critical zone 20).

8.2 Definition and monitoring of "areas to be watched"

With reference to the results obtainedfromdetailed and selective inspections, the specific areas requiring particular surveillance and monitoring have been defined, here called "areas to be watched".

These areas have been classified with IQOA index "static" 3 and 3U and / or IQOA index "water" 3 and for the fornix in question are the following:

Table 23: *Areas to watch out for*

Ashlars	Progr. initi. [m]	Progr. fin. [m]	Development L [m]	Sup. A [m²]	Static IQOA	DEFECTS TO BE PAID ATTENTION TO	SAFETY INTERVENTION PLANNED IN THE FIELD			
							Progressive [m]	Position	Intervention	State
3	20.0	30.0	10.0	200	3	Fractured cls and open crack in C (I-PERF); empty on the back in shell (GPR2020)				
7	60.0	70.0	10.0	200	3	Shell cavity (GPR2020)				
8	70.0	80.0	10.0	200	3	Shell cavity (GPR2020)				
10	90.0	100.0	10.0	200	3	Vacuum on the back in shell (GPR2020)				
19	180.0	190.0	10.0	200	3	Vacuum on the back in A (I-GEO)				
21	200.0	210.0	10.0	200	3	Cavity (subthickness concrete) in C (I-GEO); joint detachment and resonance detachment to be paid attention to in C (I-TM)				
30	290.0	300.0	10.0	200	3	Vacuum on the back in B (I-GEO); empty on the				

Ashlars	Progr. initi. [m]	Progr. fin. [m]	Development L [m]	Sup. A [m²]	Static IQOA	DEFECTS TO BE PAID ATTENTION TO	SAFETY INTERVENTION PLANNED IN THE FIELD			
							Progressive [m]	Position	Intervention	State
						back in C (GPR2020)				
32	310.0	320.0	10.0	200	3	Resonance joint detachment in C-D (I-TM)				

The "areas to be watched" will have to be monitored by means of in-depth inspections with TSS survey (annual basis) and surveillance inspections (quarterly). If an evolution of defects is found, we will proceed simultaneously with the updating of the inspection cards and the IQOA classification of the portions of the furnace to be paid attentionand the possible installation of safety devices where deemed necessary.

The methods and timing of surveillance of the temporary safety devices installed and/or required under paragraph 0 and the areas to be monitored in Table 23 is dealt with in the specific Surveillance Plan.

8.3 Safety measures and activities to be planned

Table 23specifically the inspection segments No. 3, 7, 8, 10, 19, 21, 30 and 31 (IQOA 3). In these areas, in accordance with the planned timing of prioritization and intervention, it is considered necessary to plan the installation of *provisional safety measures* as defined in the table below.
Table a shows the location and extent of the portions of inspection segments classified with IQOA 3 (see Table 20: Final IQOA classification for tunnel segments in chapter §8) for which the planned interventions are necessary.

Table 24: *Recommended temporary safety measures following the assessment process*

Concio	Prog.iniz. [m]	Prog.fin. [m]	Development L [m]	Sup.A [m²]	Final IQOA	Category/intervention	SERVICE LIFE
3	20.0	30.0	10.0	10.0	3	Intervention type Aa bis	*3 years*
21	200.0	210.0	10.0	10.1	3	Intervention type Aa bis	*3 years*

The safety measures proposed for segments 3 and 21 are intended to avoid detachment and release of material into the roadway and are not decisive for the original construction defects found.

Finally, it is recalled that geotechnical data are a fundamental prerequisite for the design and planning of rehabilitation and / or restoration interventions and / or structural reinforcement and / or consolidation of the final coatings and, where necessary, of the surrounding cluster. Therefore, preparatory to these activities, it will be necessary for the specific areas of interest to plan and execute a geotechnical survey plan in order to achieve the geotechnical, geomechanical, hydrogeological and geophysical characterization of the cluster in which the work was carried out.

For construction details and technical specifications regarding the materials , please see:

- To the drawings of: Type A [[7]Type Abis [8];
- To the Technical and Calculation Report [6]drawn up in compliance with the Ministerial Decree of 17 January 2018 "Update of the "Technical standards for constructions"", which must be followed during the execution phase.

9. CONCLUSIONS DOWNSTREAM OF THE ENTIRE ASSESSMENT PROCESS

The construction/commissioning of the tunnel dates back to 1995.
The tunnel has a total length of 332 meters. Both entrances have a flute beak of about 4 m. There are no project drawings and / or as bulit that allow the geometric and constructive characterization of the fornix. The selective georadar surveys (I-GEO) and the massive georadar survey have made it possible to highlight how the natural tunnel presents the final reinforced concrete coatings for the entire length of the kiln; moreover, there are considerable irregularities regarding the thickness of the iron cover of the reinforcements with variations from a minimum of 10 cm to a maximum of 35 cm affecting the stretch of fornix between progressive 110 and 283. Through the videoendoscopic investigations performed in control holes and calibration of the massive georadar surveys it is possible to estimate the thickness of the final coating of 57-85 cm andthrough the selective videoendoscopic investigations (I-PERF) it was possible to identify the presence of a waterproofing sheath on the back of the final coating.

The resistances of the building materials, obtained from the tests conducted, are good and specifically:

- In general, the measured compressive strengths showed variable values around 28.2-50.6 N/mm^2 (§6.4) and there are no portions of the furnace with critical values that suggest a localized deterioration of the concrete5.4

Information on the geological and hydrogeological conditions of the cluster surrounding the fornix is not available.

Below is a summary of the main defects found with the detailed investigations carried out (December 200):

- The cracking framework is modest and evolving, with lesions mainly punctual and open, mostly horizontal (close to the key) and vertical (at the piers), always less than 2 mm wide;
- There is a detachment with visible irons in correspondence of the left facing to the progressive 10. There are also further punctual and isolated detachments of some joints;
- The piers are mainly in a fairly good state of preservation, except for some superficial defects and isolated crawl spaces;
- The coating of the fornix is mainly dry, with the widespread presence of salts and efflorescence and with few traces of moisture localized at the foot of the pedestals.

The main significant defects along the furnace, as evidenced by the results of the selective investigations (September 2021), are the following:

- In some portions (segments 21 and 32) there are construction defects dating back to the construction period due to the period of construction that over time have evolved due to water infiltration, carbonation of concrete, lesions and swelling, and consequently the progressive deterioration of the concrete;
- The main defects found by hammering concern the presence of joint detachments, reported as areas to be attentive and with resonance, and the presence of exposed irons;
- Construction defects such as deteriorated and/or fractured concrete with discontinuities (open cracks), highlighted by videoendoscopic investigations (I-PERF), and the presence of sporadic cavities, voids on the back and deep crawl spaces (especially in segments 3, 7, 8, 10, 21 and 30), highlighted by I-GEO surveys and massive georadar (2020) , although not corroborated by the results of light and sample extended hammering investigations (no "resonant" portions of the coating were found).

At the same time as the detailed inspections and selective investigations, no pre-existing "obsolete" devices and/or installations were found that require appropriate safety measures, specified in chapter §7.

As regards the installation of the Abis typological in key of shell between the progressive 27.5-31, this safety intervention would not allow a reduction of the IQOA index because the defects in which to intervene, represented by fractured and vespa nous concrete, are not mitigated by the type of intervention proposed, for which an appropriate resistance check is recommended through load tests. The deep defect found (fractured concrete core) can also be restored with specific consolidation and / or definitive reinforcement interventions.

Following the tunnel assessment, it is recommended to:

- Perform geotechnical investigations (missing data) of characterization of the cluster to be located in the different geotechnical units that characterize the cluster to be followed by structural checks of the coatings for any thrusts exerted by the cluster in order to ascertain that the deep defects found are not such as not to affect the necessary static resistance and the stability, local and global, of the final coatings;
- Perform checks for the various defects found (e.g. voids and cavities, considerable irregularities of the iron cover), considering the defects of more severe intensity and extension;
- As a result of the verification, re-evaluate the IQOA classification of the areas classified with static IQOA index 3 and design appropriate consolidation and / or definitive reinforcement interventions, including injection of cavities and / or voids on the back with lightened mortar with high mechanical resistance.

10. SUMMARY OF THE ASSESSMENT PROCESS

This document presents the final assessment of the condition of the tunnel in question (final assessment). This evaluation is the result of a path of analysis that has allowed us to arrive at the state of knowledge of the work in different phases of in-depth analysis and investigation.

Initially, the historical documentation available on the tunnel was studied and the results of the massive georadar surveys were analyzed [1] [1]detailed investigation of the tunnel followed with the relative evidence found [2] [2][3][3]

Following these activities and thanks to a cross-analysis of the results of the detailed inspection, it was possible to provide a general overview of the work, defining the critical areas and providing an initial assessment of the state of the tunnel [4] (tunnel assessment). Chapter 0 provides references to this document.

In addition to the selective surveys required to investigate the critical areas found during the detailed inspection phase, the results of the selective tests carried out have been reported and interpreted in Chapters 5 and 6 . The latter have made it possible to update, supplement and complete (by means of the IQOA classification) the assessment of the state of the tunnel, defined primarily in the Detailed Inspection Report[4]and dealt with here in Chapter 0.

With reference to the summary of the IQOA classification shown in Table Table 22, along the development of the tunnel there are:

- as far as **static IQOA** is concerned, there are **8 zones classified as 3** for **an extension equal to 1. 1%** and **no zones classified as 3U**. The remaining areas have been given a 2E rating or lower;
- as far as **water IQOA is** concerned, there are **no areas classified as 3**. All remaining areas have been assigned a classification of 1.

Chapter 10 contains the conclusions on the state of the tunnel drawn following the completion of all the assessment phases mentioned above.

With regard to surveillance and monitoring activities, please refer to what is reported in Chapter 0 and for safety measures in Chapter 0.