Data collection for Swiss road tunnels maintenance

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Data Collection for Swiss Road Tunnels Maintenance

F. Sandrone, V. Labiouse, J.-F. Mathier

Abstract

Collect and store information, after tunnel construction and during operation, may help the tunnel owner to follow the structure evolution with time. Long term serviceability and behaviour can be better evaluated by taking into consideration all tunnel features such as geometry, geological and hydrogeological conditions, age, construction techniques, operation conditions and material quality. Moreover, pointing out pathologies and deterioration location and causes, can improve maintenance planification.

Due to Swiss topography, the roads count a fairly large number of tunnels; moreover, considering that the Swiss National Roads began to develop in the 1960s, today a significant number of tunnels has already more than 40 years of operation and needs maintenance to assure everyday serviceability and safety.

The Rock Mechanics Laboratory (LMR) of the Swiss Federal Institute of Technology in Lausanne (EPFL), in the framework of a PhD Thesis financed by FEDRO (Swiss Federal Roads Authority), has created a Data Base for collecting and examining information about tunnels of the Swiss National Roads.

Starting from the experience of other countries, together with a detailed literature review on tunnel deterioration and maintenance practices, this paper provides a description of the Tunnel Data Base and of the potential disorders that can affect tunnels on the long term. Moreover, the possibility of taking into consideration geotechnical and hydrogeological conditions by means of GIS Tools is described.

Preliminary results of data analysis point out how tunnel age and traffic can contribute to the pathologies development. In particular, it is shown that tunnels with longer service life are affected by a large number of disorders and that traffic seems also to determine the tunnel long term conditions.

KEYWORDS:
Road Tunnels, Long Term Behaviour, Maintenance, Data Base

Zusammenfassung

Das Sammeln und Speichern von Daten während und nach dem Bau ermöglicht es dem Tunnelinhaber, das zeitliche Verhalten der Struktur zu verfolgen. Langzeitliche Betriebsfähigkeit und Verhalten können durch das Einbeziehen von Daten, wie Geometrie, geologische und hydrogeologische Bedingungen, Alter, Bautechnik und Materialqualität zusammen mit Betriebsbedingungen abgeschätzt werden. Die Planung von Unterhaltsarbeiten wird auch durch die Beschreibung der Pathologien und die Lokalisation und Ursache von Beschädigungen optimiert.

Wegen der Topographie, gibt es in der Schweiz zahlreiche Straßentunnel. Da das Nationalstraßennetz ab den sechziger Jahren erstellt wurde haben heute eine große Anzahl dieser Tunnel bereits mehr als 40 Betriebsjahre und benötigen Unterhaltsarbeiten um ihren täglichen Betrieb und ihre Sicherheit zu gewährleisten.

Im Rahmen einer Doktorarbeit hat das Inst. für Felsmechanik der Eidg. Techn. Hochschule von Lausanne (LMR-EPFL) eine Datenbank mit den Informationen der Schweizer Nationalstraßentunnel geschaffen.

Gestützt auf die Erfahrung in anderen Ländern und einem ausführlichen Literaturstudium über Tunnelbeschädigung und –Unterhaltspraktiken, liefert dieser Artikel eine Beschreibung der Datenbank und der langzeitlichen potentiellen Tunnelbeschädigungen. Zusätzlich wird die Möglichkeit der Berücksichtigung von geotechnischen und hydrogeologischen Verhältnissen mit Hilfe von GIS Instrumenten beschrieben.

Erste Resultate zeigen, wie das Tunnelalter und der Verkehr zu den Pathologieentwicklungen beitragen. Insbesondere zeigt dieser Artikel, wie Tunnels mit vielen Betriebsjahren durch eine große Anzahl von Beschädigungen betroffen sind, und wie der Verkehr das Langzeitverhalten von Tunneln zu beeinflussen scheint.

STICHWÖRTER
Straßentunnel, Langzeitverhalten, Wartung, Datenbank

Introduction

With bridges and viaducts, tunnels are classified as "work of art" (11) and they can be considered one of the most expensive infrastructures of the transportation network. A tunnel, as all other kind of structures, changes its properties with time. After several years of operation, existing tunnels are affected by pathologies caused by ageing, weathering and, in some special cases, by defects due to improper construction techniques and/or difficult geotechnical and hydrogeological conditions.

Men have been excavating tunnels for more than 4000 years. The oldest tunnel constructed with communication purposes was built in the ancient Babylon (15). Today, in Europe and North America the transportation network is quite well developed and the majority of tunnels has already been excavated. Considering the age of the road and railway infrastructures, the main task in the near future for network owners will deal more with old tunnels maintenance and rehabilitation than with new tunnels construction.

Tunnel Conservation Procedures

Manuals and guidelines on tunnel surveys, controls and conservation techniques can be considered important sources for identifying and understanding some typical long term pathologies and preserving the tunnel serviceability conditions during operation. Thus, by comparing the available sources for several countries it is possible to point out principal goals of tunnel conservation:

- Guaranteeing human and structural safety during operation,
- Maintaining the tunnel condition up to an acceptable serviceable limit,
- Assuring tunnel durability,
- Guaranteeing the tunnel economical value,
- Controlling any environmental interaction.

To fulfil these goals, the tunnel owner should regularly perform a technical survey of the structure and decide about ordinary procedures of maintenance and/or major repairs. In Switzerland, in particular, the tunnel owner has to follow a specific succession of processes as shown in Figure 1.

Regular tunnel surveys (e.g. principal inspections once every 5 years and routine inspections once a year as recommended by (12)), are fundamental to follow the evolution of time dependent problems (cracks, deformations and water damages). Specific and periodic controls of structures give information about the tunnel's performance in the future. When no relevant problem is identified the serviceability is guaranteed by means of simple interventions of routine maintenance (e.g. drain flushing, ice and tile removal and tunnel washing). If inspections reveal major problems, by means of verification, (i.e. detailed investigations and structural analyses) it is possible to identify the real extension of the damaged area and establish the possible causes of deterioration. Once the verification is completed, a diagnosis about the possible modes of failure and the tunnel future life expectancy is done. The diagnosis leads the tunnel owner to choose and, then, realize appropriate interventions, reactive rehabilitation procedures (repairs) and/or structural improvements, as refurbishment (renewal).

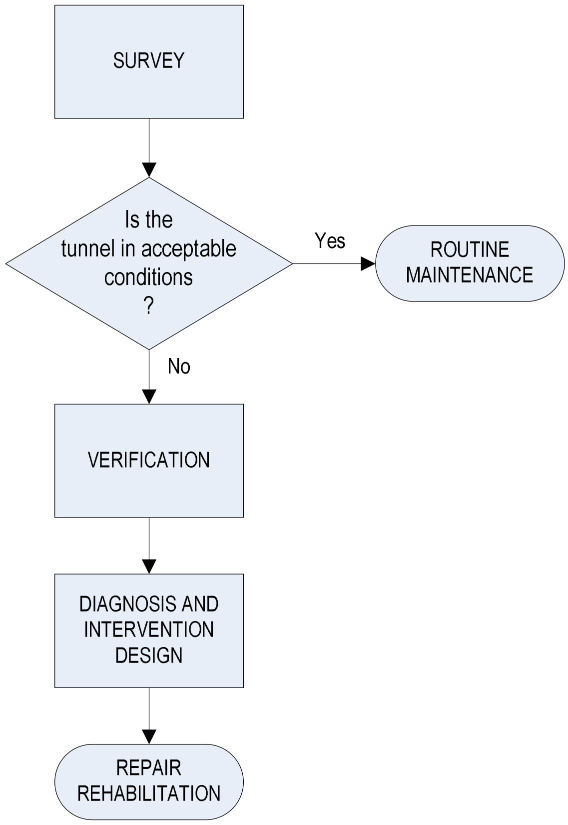

Figure 1: Tunnel Conservation procedure in Switzerland, according to (12).

Bild 1: Unterhaltsvorgehen det Tunnel in der Schweiz, nach (12).

According to (10), evaluate the tunnel conditions and predict its long term performance are the most difficult tasks for a tunnel owner. An evaluation of tunnel global conditions in terms of safety, serviceability and durability may require a detailed analysis of each part of the lining structure and the excavated rock mass. This analysis should allow a global assessment of the tunnel and an evaluation about its expected life span. Collect and store up-to-date information about tunnels, after their construction and during operation, may help the tunnel owner to better evaluate the actual behaviour of the structure, follow its evolution and identify the possible origins of pathologies. Moreover, this can improve also planning of maintenance and repair activities during tunnel service life. Data about structures on the road network can be collected in appropriate data base as Table 1 summarises for several countries.

Table 1: Data recording methods for road infrastructures in several countries.

Country	*Bibliographical Source*	*Tunnel Data Recording*	
		System	Description
Switzerland	(3)	BDR (Roads Data Base)	General collection of data about roads infrastructures. It collects all kinds of information for describing the road network conditions and scheduling maintenance and repairs.
	(11, 12)	KUBA-DB/KUBA-MS	Road structures data base (e.g. bridges, retaining walls, etc.). It contains general data about the structures, their stability conditions and degradation types and materials quality. At present, there isn't a specific data base for tunnels.
France	(1, 2)	DICOS+BDT	Road infrastructure data base with a detailed appendix about tunnels. It contains data about structures since their construction and during operation, as well as inspections data. It is used to manage and schedule tunnels maintenance and repairs.
Italy	(9)	National Road File	Tunnel data collection since their construction and during operation (the data are stored in GIS format). The aim is mainly to obtain a tunnel classification related to road security.
UK	(7)	Asset Management Software	Computer software (associated with a data base) that assists in fast and effective facility management. It requires general information about the tunnel and up-to-date maintenance and inspection documentation.
USA	(4, 5)	Inventory Data Base	Computerized data base system developed to assist with the storage and management of tunnel conditions data and to help tunnel owners in maintaining their structures by prioritising repairs.
South Africa	(14)	Facility Diagnostic File	General information and tunnel data collection, which is updated after each principal inspection.

By analysing available literature on tunnel degradation and conservation procedures (e.g. 1, 8, 14 and 15), it is possible to outline the main features for creating an appropriate tool to manage data about tunnels:

- Both past and present (i.e. construction and operation) data are necessary to describe the actual tunnel conditions.
- According to several authors (1, 7, 8), one of the major problems encountered by the tunnel owner in evaluating actual tunnel conditions is the fact that only the intrados of the definitive lining can be regularly inspected. In spite of this intrinsic tunnel feature, it is important to keep in mind that a lot of tunnel pathologies develop at the interface between the excavated rock mass and the lining, especially due to their interaction. Thus, it is necessary to search for all information about geological and hydrogeological conditions, material quality and construction data.
- Important information about the general conditions of the tunnel is a direct result of survey activities (4, 5, 7 and 14). Though the inspections generally focus on lining visible surface, the observation can reveal particular behaviour of the excavated rock mass.

Swiss Road Tunnel Data Base

Due to Swiss mountainous topography, the roads count a fairly large number of tunnels. At the beginning of the year 1999, there were 169 km of tunnels on the 1638 km of National Roads, divided into 188 tunnels. In 2005, the number has increased to 213 tunnels with a tunnel incidence on the total length of the network of about 9.4% (13). Moreover, considering that the Swiss National Roads began to develop in 1960s, today a significant number of tunnels has already more than 40 years of operation and needs maintenance to assure everyday serviceability and safety.

In Switzerland, data collection for road structures is managed by means of a special data base: KUBA-DB (see Table 1). In order to become useful for tunnels, this inventory/software still needs some improvements. The Rock Mechanics Laboratory (LMR) of the Swiss Federal Institute of Technology in Lausanne (EPFL), in the framework of a PhD Thesis financed by the Swiss Federal Roads Authority (OFROU), has created a specific data base for collecting and analysing information about Swiss National Roads tunnels.

At present, the Swiss Tunnel Data Base stores information about more than 150 tunnels. In order to collect data from several cantons, a technical sheet has been sent to each local operator responsible for tunnel management. The majority of data, however, has been collected directly by LMR people consulting cantonal archives.

Structure of the data base

Starting from the considerations of the previous chapter, in the data base, apart from general information, it is possible to identify three main sections of data: Construction, Environment and Operation, Maintenance (Table 2).

Table 2: Swiss Tunnel Data Base Structure.

Section	*Data*
General Information	Tunnel Name Town, Canton Road Local Operator Commissioning (Operation) Year Coordinates X,Y (centre point) Lane Nr.
Construction Information	Construction Year Geometrical data (depth, length, section size, interaxis) Excavation Method First support (type, length along the tunnel) Definitive lining (type, thickness, length) Waterproofing and drainage Accidents during construction Geological profile and description Geological difficulties during excavation
Environment and Operation Information	Accidents during operation Traffic Temperature Humidity Chemical composition of tunnel atmosphere Chemical composition of groundwater Groundwater level and circulation type Technical equipment (ventilation)
Maintenance Information	Inspection (date and frequency) Monitoring Routine maintenance (type and frequency) Pathologies (date of observation, possible cause, area, eventual repair) Renewal / Refurbishment (intervention date and type, area, cause)

In some cases, the particular behaviour of a tunnel is directly connected with its origins (8), for example, accidents during excavation may inform about future tunnel behaviour and weaknesses. “Construction information” regroups structural and geometrical data, building materials and construction method and quality. All these data depend on both tunnel age and geotechnical conditions.

“Environment and operation information” includes operation, loads and environmental/surroundings conditions that may influence tunnels deterioration and future behaviour. According to (1), road tunnels can be exposed to a wide range of aggressive chemicals that deteriorate concrete. The variety of chemical attacks depends on several factors as material quality, groundwater composition and operational conditions. For example, temperature affects concrete and rock mass by thermal expansion and contraction and by freezing-thawing cycles. Frozen water (both from environment moisture and groundwater) induces internal stresses and consequent cracking and/or spalling. Moreover, according to (6), this process is a catalyst for de-icing salts corrosion: as a matter of fact, an increase in lining permeability increases Chlorides penetration speed in the concrete lining.

“Maintenance information” groups data about all conservation procedures. Using information from inspections, maintenance and repair activities, it’s possible to identify tunnel pathologies, determine their causes and recognise possible recurrences.

An important feature that characterises the data base, as it is possible to read in Table 2, is the heterogeneity of collected information. Two typologies of data are used to describe each tunnel:

- Qualitative information (e.g. pathology description, geology, etc.), and
- Quantitative information (e.g. structural and geometrical data).

In particular, in order to maximise the compatibility between tunnels during data analysis, for each factor (i.e. variable) several modalities have been identified and coded. This could be done after a detailed bibliographical research improved by tunnel inspector’s advices (e.g. people from CETu, France and Bureau Perss, Switzerland). Table 3 shows an example of variable and modalities used for collecting data in the Swiss Tunnel Data Base.

Table 3: Example of qualitative variable and modalities in the data base: different kinds of pathologies that can be identified during principal inspections.

Variable	*Modality*	
Disorder – Pathology identified during principal inspection	[1]	Water leakage
	[2]	Efflorescence
	[3]	Local deformation (crown, walls)
	[4]	Invert heave up
	[5]	Cracks
	[6]	Frost damages / Ice formation
	[7]	Impact damages
	[8]	Corrosion of steel bars (reinforced concrete)
	[9]	Voids behind the lining, hollow area
	[10]	Concrete spalling, delaminated concrete
	[11]	Rock pocket / Honeycomb
	[12]	Calcareous concretion
	[13]	Obstruction of the drainage system caused by sand, clay infiltration or calcareous concretion
	[14]	Weathered surfaces, staining, scaling
	[15]	Track scaling
	[16]	Concrete lining crumbling, blocks fall

GIS Tools

By means of an appropriate software (i.e. Manifold System 6.50 by Manifold Net LTD), using the coordinates X, Y of the centre point of each tunnel, the information collected in the Swiss Tunnel Data Base is associated with a spatial definition. This allows representing on a geographic model (e.g. a map) the actual conditions of each tunnel and provides the possibility of analysing the information by means of G.I.S. tools. Moreover, by superposition of layers as, for example, a geotechnical or a hydrogeological map, it is possible to make some general statements about pathologies development (i.e. pathology scenario identification). Anyway, it is important to point out that the reliability of this method, which represents shallow information, is mainly based on the fact that the majority of Swiss National Roads Tunnels is less than 80-100 m depth.

Figure 2 shows an example of representation of data on a geotechnical map. The colour contour is based on the potential delayed behaviour of the rock mass. For example, tunnels excavated in marl and clayey media (red colour) can potentially show long term pathologies connected with an increase of pressures acting on the lining (e.g. convergences, longitudinal cracks and invert heave up). The analysis to verify the correspondence between potential pathologies, identified by means of this tool, and real disorders, observed in tunnels during survey activities, is in progress. Other analyses can be done by using, for example, climatic and traffic data.

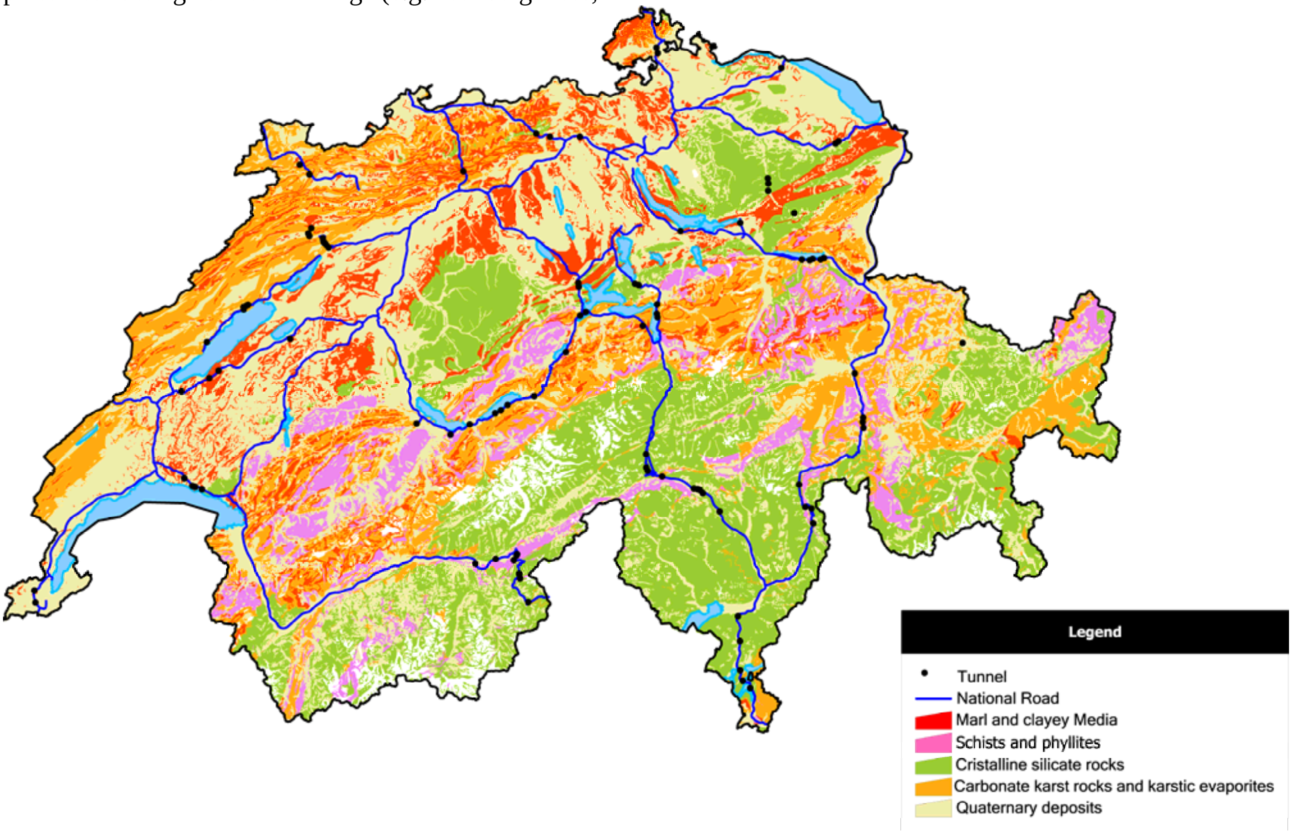

Figure 2: An example of G.I.S. map. The 152 tunnels of National Roads, at present recorded in the data base, are represented by means of black points; the road network is represented by a blue line (source: VECTOR25 – Swisstopo, last update: year 2000). The background is a geotechnical map (source: Swiss geotechnical map – OFEG). The colour contour represents the potential of the rock mass to show pathologies related with swelling behaviour (i.e. Red = high potential, Green = low potential) and/or weathering of the rock mass (i.e Orange = high potential, Beige = low potential).

Bild 2: Ein Beispiel einer G.I.S. Karte. Die 152 Tunnel der Nationalstrassen, die sich zurzeit in der Datenbank befinden, sind durch schwarze Punkte dargestellt; das Straßennetz ist durch eine blaue Linie dargestellt (Quelle: VECTOR25 – Swisstopo, letzte Version: 2000). Der Hintergrund ist eine geotechnische Karte (Quelle: schweizerische geotechnische Karte – OFEG). Die farbliche Konturen stellen das Potential des Felsen dar, um Pathologien zu zeigen, die mit der Ausdehnung Verhalten (d.h. rot = hohes Potential, grün = schwaches Potential) und/oder der Alterung des Felsen verbunden sind. (d.h. orange = hohes Potential, beige = schwaches Potential).

Preliminary Data Analyses

After collecting data, in order to identify pathologies causes it is necessary to investigate relationships between factors. Data analysis by means of multivariate statistical tools is in progress. These methods, combined with G.I.S. tools are useful to point out more easily the conditions for pathology development.

Age Influence

Considering that age plays an important role for all kind of structures, as it is pointed out by several documents (e.g. 1, 2, 8, 14 and 15), first analyses have focused on the influence of the age of the tunnel on its general conditions. By considering operation as the active cause in degradation phenomena, the age of the tunnel has been calculated in terms of service life, starting from the commissioning (operation) year. The tunnels have been divided into three age classes:

A. Very old Tunnels, operating for more than 35 years. This class represents about the 16% of the population of the data base;
B. Old tunnels, which started their service life between the year 1970 and 1990. This class represents the 52% of the total population;
C. Recent tunnels, operating for less than 15 years. This class represents the 32% of the total population of the data base.

Figure 3 illustrates the relationship between these tunnel age classes and the number of disorders. All values are normalised by considering the total population of the data base (i.e. 152 tunnels, at present), while the total number of disorders is calculated by considering only the disorders recorded during the last principal inspection (in order to avoid cumulative counting).

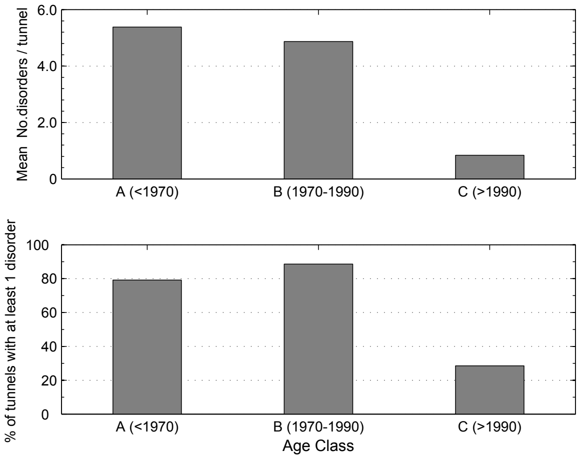

Figure 3: Influence of tunnel age on pathologies development. The upper graph represents per age class the mean number of disorders per tunnel. The lower graph shows the incidence of tunnels that are affected by at least one disorder on the total number of tunnels per age class [%].

Bild 3: Einfluß des Alters der Tunnel auf die Entwicklung der Pathologien. Die obere Grafik stellt für jede Alterklasse die Hauptanzahl an Probleme dar. Die untere Grafik zeigt den Prozentansatz von Tunnel dar, die von mindestens einem Problem betroffen sind, im Verhältnis zu der Gesamtanzahl von Tunnel pro Alterklasse [%].

As shown in the upper graph of Figure 3, the mean number of disorders per tunnel, recorded during the last principal inspection, is higher for very old tunnels if compared with recent tunnels. This is confirmed also by the lower graph of Figure 3, which represents the incidence [%] of tunnels that are affected by at least one disorder on the total number of tunnels per age class, and can be explained by a general tendency of very old tunnels to be affected by more than one disorder at the same time.

Traffic influence

Another factor which can play an important role in pathologies development during tunnel operation is traffic.

Tunnels have been divided into four classes of traffic, based on data of Mean Daily Traffic (T.J.M.) of 2005 (13):

- Very low: T.J.M.< 10000 vehicles, it represents the 16% of the total population of the data base;
- Low: 10000 < T.J.M. < 20000, it represents the 13% of the total population of the data base;
- High: 20000 < T.J.M. < 40000, it represents the 41% of the total population of the data base;
- Very high: T.J.M. > 40000 vehicles. It represents the 30% of the total population of the data base.

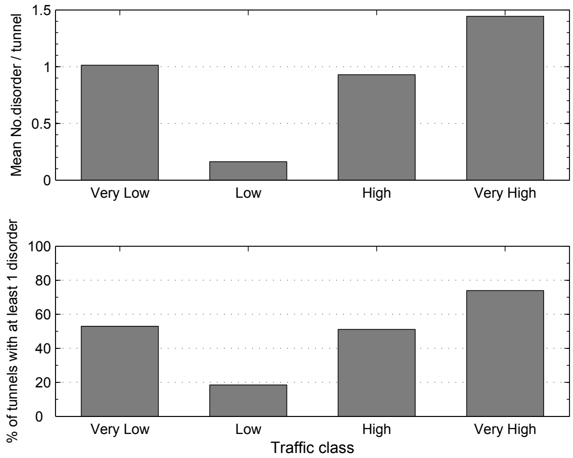

Figure 4: Influence of traffic on pathologies development. The upper graph represents per traffic class the mean number of disorders per tunnel. The lower graph shows the incidence of tunnels that are affected by at least one disorder on the total number of tunnels per traffic class [%].

Bild 4: Einfluß des Verkehr der Tunnel auf die Entwicklung der Pathologien. Die obere Grafik stellt für jede Verkehrklasse die Hauptanzahl an Probleme dar. Die untere Grafik zeigt den Prozentansatz von Tunnel dar, die von mindestens einem Problem betroffen sind, im Verhältnis zu der Gesamtanzahl von Tunnel pro Verkehrklasse [%].

Figure 4 shows the influence of traffic on pathologies development for the population of the data base. There is a clear tendency of the mean number of disorders to increase with traffic, but one may also observe that tunnels with very low traffic are affected by a remarkable number of disorders. This can be ascribed to the fact that the majority of these tunnels are very old. Analyses are in progress to differentiate the respective influence of both the age and traffic factors and to determine their interaction.

Further analyses of traffic influence on pathologies development focus on the type of disorders and on the zone of the tunnel where they appear. Indeed, traffic can cause truck scaling and it can be an important cause of impact damages. Furthermore, it contributes to the corrosion of gutter and walls (only up to 1.5 m high) due to the projections of water and particles of de-icing salts. Finally, the corrosive action of exhaust gases can contribute to the formation of efflorescence on the concrete of the lining.

Conclusion

Effective and appropriate routine maintenance and rehabilitation interventions in tunnels need a more precise evaluation of actual stability and serviceability conditions and an assessment of the durability of the structure. In order to achieve these objectives, it is necessary to improve deterioration predictability. A careful data collection may help on this task.

The Swiss Road Tunnel Data Base, developed at LMR – EPFL, collects information of different type and nature, related to the whole tunnel life. The paper provides some considerations about the importance of construction, environment, operation and maintenance data in tunnel conditions evaluation and diagnosis.

The information collected in the data base is associated with a G.I.S. tool to take advantage of geographic information (e.g. DTM, geotechnical and hydrogeological maps). In data analyses, this contributes to identify factors (e.g. respectively depth, rock type, water inflow) that are susceptible to induce some pathologies and to influence the long term behaviour of tunnels. Furthermore, whenever there is lack of information, by means of appropriate layers, it is possible to improve the data base.

The results of preliminary data analysis point out as expected the importance of tunnel age on the development of different kind of disorders: tunnels with a longer service life are affected by a large number of disorders. Moreover, traffic seems also to determine the tunnel conditions on the long term. In particular, some results show how traffic can increase efflorescence and impact damages and contribute to the development of concrete corrosion that affects the walls (up to 1.5 m high) and the gutter.

The relationships between these factors, (i.e. service life and traffic) and the total number of disorders point out the important role of operation and maintenance on the tunnel conditions.

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