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A GIS based approach for analysing geological and operation conditions influence on road tunnels degradation

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ABSTRACT

Adopting effective maintenance strategies for transportation infrastructures requires good prediction of their long-term behaviour. For planning interventions without affecting the entire network's capacity, tunnels in particular require a good overview of expected problems. G.I.S. tools are helpful for managing transportation networks since they allow immediate identification the influence of tunnel location on development of specific disorders. A G.I.S. based approach for analysing and predicting degradation processes affecting roads tunnels is presented. The results show how tunnels location may inform on main problems observed in concrete lined tunnels during their service life. The agreement of analyses results and disorders identified during inspections allows considering G.I.S. promising tools for pathologies detection and decision about preventive maintenance.

1. Introduction

During its service life a tunnel interacts with surrounding environment with consequent degradation of the structure itself. The main symptoms of this process, affecting both lining structure and surrounding rock mass, may be identified during visual inspections of the tunnel. All the problems affecting the drainage system and tunnel invert may weaken the tunnel until it is necessary operating minor repairs or, in worse cases, a complete tunnel refurbishment. Since repairing damaged tunnels often hinders normal operation, it becomes more and more important to develop appropriate procedures and tools for managing information about tunnel conditions and thus helping asset manager in maintaining safe and reliable connections (Frangopol and Liu, 2007; Frangopol et al., 2012). Due to its central position in Europe, Switzerland plays an important role in terms of traffic and transportation. National Roads, (*Routes Nationales*, RN) have an extension of about 1800 km (Federal Statistical Office OFS, 2016), with a relevant number of tunnels. Due to mountainous topography, for more than 200 km of National Roads there are 220 tunnels, thus about 1 km tunnel each 9 km road. Today, after more than a half century of service life, a significant number of those tunnels show an increasing demand for maintenance.

2. Tunnel asset management tools

The Asset owner operates mainly in two interactive domains: operation and conservation. As a matter of fact, the tunnel owner should ensure that each tunnel is safe and allows uninterrupted operation. According to 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. Data collection and analysis play thus a fundamental role in tunnel asset management. Collect and store information about tunnels, after their construction and during operation, may help the tunnel owner to follow the evolution of the structure and identify the possible origins of pathologies. This improves also maintenance and repair planning during tunnel service life. As reported in Sandrone (2008) the tools for Asset Management can vary from country to country: for example, France, Switzerland, Portugal and US mainly use specific databases for collecting detailed information about their transportation infrastructure, while in UK the road infrastructure manager is using a specific tool for asset management associated with data collection (Highways Agency et al., 2003).

Whenever available, the way the information can be used, strongly depends on the way it is collected. Though, as recommended by the Swiss Federal Road Authority (Office fédéral des routes, 2005), the

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diagnosis of tunnel conditions should result from detailed survey activities, preliminary data analyses done with Geographic Information based System (GIS), may however reveal interesting for prioritising interventions and deciding about preventive maintenance. As considered by Schultz (2012), for example, in the case of water utilities (underground pipelines, both horizontal and vertical ones) the integration of GIS tools highly improved the management of the asset itself. As a matter of fact, by introducing the possibility of performing analyses of spatially related data, GIS tools actually allow taking decision about required maintenance based on main relevant factors according to a specific asset. At present, only few countries are using these tools mainly for centralising, storing and processing general information related to transportation network infrastructures (Sandrone, 2008; Kusano et al., 2011). In Italy, for example, for a better management of the infrastructure safety, all the information concerning National Roads is stored in a GIS format (La Monica, 2001).

A good asset management requires a good estimation of durability of the structures. The tunnel durability depends on complex interactions between rock mass, ground-water, concrete lining as well as traffic and environment inside the tunnel during operation. For improving the management of available information about Swiss National Road tunnels a specific data base has been created. The aim of the Swiss Tunnel Data Base (Sandrone et al., 2007a,b; Sandrone and Labiouse, 2011) is to compile detailed data recorded during tunnel construction, together with information characterising tunnel operation conditions, as well as main disorders observed in the tunnel during its service life (Table 1).

In order to complete the existing data and aiming at identifying potential pathologies affecting road tunnels during their service life, this paper describes how a GIS-based tool has been developed, coupling information collected in a data base with specific thematic maps describing tunnel initial and operation conditions. Such a tool can enhance the efficiency of maintenance by identifying major problems and finding appropriate solution for extending the tunnel service life at the asset scale.

3. GIS based tool description and applications

As reported by Sun et al. (2008), in recent years GIS became a powerful computer based system for integrating data bases and spatial analyses. Mainly used for land use planning and vulnerability analyses, GIS systems are nowadays widespread also for applications in geotechnical and tunnelling fields (e.g. Chang and Park, 2004; Xie et al., 2006; Pantha et al., 2010; Yuan et al., 2012; Li and Li, 2014; Thum and De Paoli, 2015). Thanks to the development of hardware capacity, GIS based analyses may be used for managing huge amount of information, correlating several sources and different types of data and allowing a fast update of the collected information with immediate data analyses and comprehensive impact assessment.

In this framework, using GIS tools allowed an easier improvement of the Swiss Tunnel Data Base introduced in the previous section, which was created for managing information about tunnels belonging to the Swiss National Roads network. By means of GIS tools, the collected data

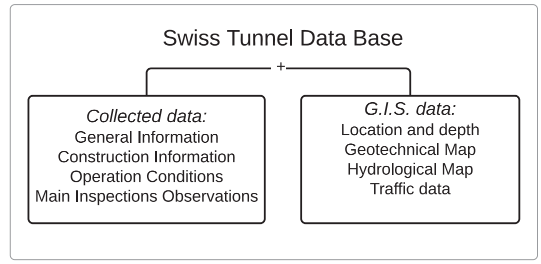

Fig. 1. Swiss tunnel data base, GIS based system architecture.

can be represented and visualised on a geographic model (i.e. a map). In particular, each tunnel belonging to the data base and characterised by an ID number can be identified also by its spatial definition (i.e. tunnel location), which corresponds to the coordinates of its central point located on the tunnel axis. This means an easier management of all the information stored in the data base. When there's lack of data, as it might happens in case old tunnels, where very often it is quite difficult to find detailed geological/hydrogeological information, another advantage of using GIS tools is related to the possibility to supply information by superposition of thematic maps. Fig. 1 shows the system architecture developed for this study by coupling specific data available at the tunnel scale (i.e. information compiled in the Swiss Tunnel Data Base) with more general information about tunnel depth, geological and hydrological conditions, temperatures and traffic volumes, available at the network scale in the form of thematic maps implemented in the GIS based tool.

In particular, the information collected in the Swiss Tunnel Data Base could be improved by integrating the following thematic maps:

- Digital terrain model (MNT25, Swisstopo – Federal Office of Topography),
- Geotechnical 1:200,000 map (Swisstopo – Federal Office of Topography)
- Hydrological 1:200,000 map (OFEV – Federal Office for the Environment),
- National Roads network, excluding 3rd class roads (Vector 25, Swisstopo – Federal Office of Topography),
- Traffic data (Personal communication, 2007, OFROU – Federal Roads Office),
- Meteorological data (Electronic dataset, 1945–2005. MétéoSuisse – Federal Office of Meteorology and Climatology).

Moreover, by performing spatial analyses focusing on specific influencing factors represented in the form of thematic maps, it is possible to identify tunnels which, according to their location, can be potentially affected by several types of degradation pathologies during their service life. The whole analysis procedure is described in Fig. 2. The analyses have been performed by means of a GIS software called Manifold System (Manifold®). With the proposed method it is possible to choose the most appropriate thematic maps to be used for each analysis, which allows adapting this procedure to a wide range of

Table 1
Information compiled in the Swiss Tunnel Data Base after Sandrone and Labiouse (2011).

Section	Data
General Information	Tunnel name/Town, Canton/Road/Local Operator/Commissioning year/Coordinates X, Y (tunnel axis centre point)/Lane Number
Construction Information	Construction Year/Geometrical Data (depth, length, section size)/Excavation method/First support (type and length along the tunnel)/Definitive lining (type, thickness and length)/Waterproofing and drainage systems/Accidents during construction/Geological profile and description/Geological difficulties encountered 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/Ventilation system
Maintenance Information	Inspection (date and frequency)/Monitoring systems/Routine maintenance/Disorders (date of observation, possible cause, area and eventual repair)/Renewal/Refurbishment (intervention date and type, area, cause)