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Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
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EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

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MONITORING AND SUPERVISION OF TUNNELS IN CROATIA

Katarina Ravnjak[1], Goran Grget[1], Mladen Garašić[2]
1Geokon-Zagreb, Zagreb, Croatia
2Zagreb University, Faculty of Civil Engineering, Zagreb, Croatia

Abstract

One of the most responsible and most challenging construction tasks are tunnel excavation and stabilization. Tunnel excavation and support system were developed back in the nineteenth century and significant advances in technology were achieved in the second half of the twentieth century. In order to reduce the risk safety management systems were established. Such system also includes the monitoring, apart from the design requirements on excavation and support and the assessment of stability during construction. Monitoring has the purpose frequently observation and adjustment of excavation and support system to actual soil conditions. Unfortunately, all measures of monitoring are defined only for the tunnel construction period. In Croatia, there are no technical standards for tunnel monitoring during the exploatation. The aim of this paper is to point out the importance of methodology and monitoring procedures that would detect changes in time and ensure the tunnel sustainability. Tunnel monitoring implies a set of operations that can promptly register the events and conditions that could affect the stability, traffic safety and tunnel durability.

Keywords: tunnel, monitoring, tunnel sustainability, traffic safety

1 Introduction

Tunnel excavation and stabilization immediately after excavation is one of the most responsible and most challenging engineering tasks. Especially when dealing with complex engineering geology conditions [1] and tunnels with and large cross-section [2]. New excavation support system was designed by Austrian engineers in fifties. Today it is known as "New Austrian tunnelling method" or NATM and it applies in Croatia. NATM introduced obligatory strain measurement of the tunnel opening ("convergence measurement"), as the basic element of support verification. In Croatia the interactive design method applies in tunnel design [3]. Development and application of interactive geotechnical tunnel design started in Croatia in 1980. [4]. This methodology [5] integrates the empirical, rational and observational approach in the geotechnical design of the tunnel. The observation approach is the second phase of tunnel design defined in main design and carried out during the excavation of the tunnel. Verification of the tunnel support system and modification during the construction phase was done using the actual data obtained from the measurement and the monitoring. Geotechnical measurements combined with back analysis are basic part of interactive design concept [6]. Tunnel safety is ensured in the design at the beginning and continues with traffic regulation, tunnel installation check-up like; ventilation, fire protection, lighting and sewage. Continuous supervision or monitoring during exploitation is essential for assessing tunnel safety at any time.

2 Importance of tunnel monitoring

Geotechnical designing in Croatia is conducted in accordance with Eurocode 7, HRN EN 1997-1 [7]. This standard is dealing with the geotechnical design in order to ensure the construction strength, stability, serviceability and durability. This standard envisages the elaboration of the design complexity and monitoring in three geotechnical categories. Minimum geotechnical requirements for each category are established based on the construction complexity, ground conditions and risk. Tunnels in general are classified in category 3. Exceptions are the tunnels in a solid rock classified in category 2. Monitoring programme is defined depending on the geotechnical category. For example, for geotechnical category 1 monitoring programme can be limited to inspection, simple quality controls and qualitative assessment of the structure behaviour. For geotechnical category 2, measurements of ground properties and the structures behaviour sholud often be required. And for geotechnical category 3, additional measurements are required with complex analysis and interpretation of the measured values. Figure 1. shows a crack in secondary concrete tunnel lining detected during exploataion. This crack is an example of tunnel condition which should be monitored and measured, because it directly affect the tunnel safety.

Figure 1 Crack in secondary concrete tunnel lining

Tunnel monitoring and maintenance according to standard [7] is process defined in the geotechnical design. Geotechnical design should clearly determine what to monitor during the construction and maintenance during the exploatation (HRN EN 1997-1: 2.8.(4)P). Matešić and Mihaljević [8] gave guidelines for minimum requirements to define monitoring equipment, number and position before construction and to anticipate the costs for equipment installation and measurements.
As well as the technical monitoring can promptly identify and register all the events and conditions that could impact the safety and surrounding area for what the technical monitoring is really important is the rational maintenance. Remediation of these structures is very expensive and it is important to identify and remove any damage in time.
Maintenance costs and security and construction usability are strongly connected. In order to achieve a constant level of construction security the maintenance costs are necessary. Figure 3. is showing the connection between the cost of preventive maintenance (line 1 ‘), which are necessary to continuously maintain the designed security level (line 1). When maintenance is irregular the security level is constantly decreasing (line 2) and by activation of corrective maintenance (line 2 ‘) at a critical point, the costs are higher than the preventive maintenance in order to restore and maintain the construction security.
On the Chekka tunnel experience the importance of even minimal technical monitoring is shown. Sometimes the forced abandonment of important infrastructure funds for the structures maintaining can lead to serious damage that are too expensive to repair [9], and the

impact of structures on the surface or in the vicinity of the tunnel is given in the example of removal of a building of 14 floors which caused the unloading of soil and underground structures. Due to the unloading of the soil underground had lifted for about 2 cm [10].

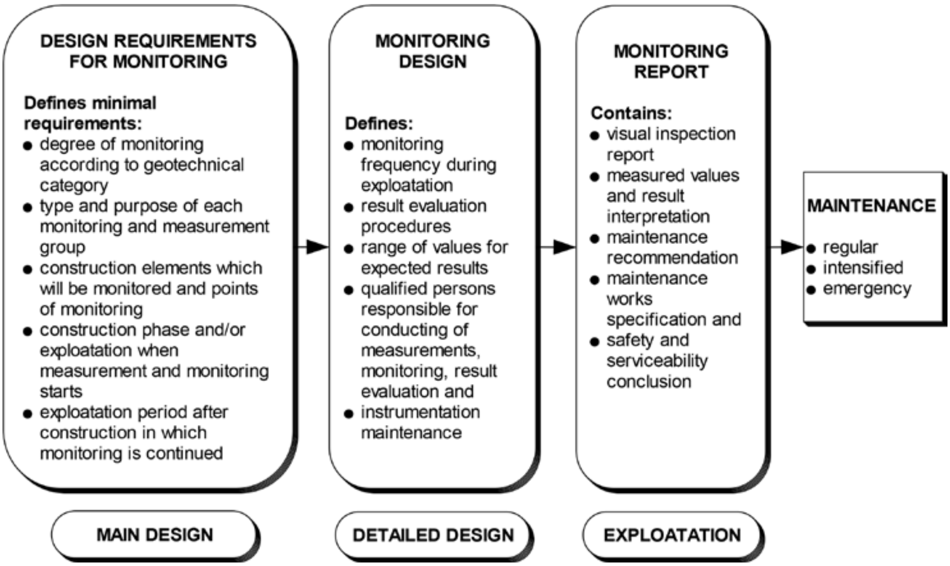

Figure 2 Monitoring and maintenance flowchart [8]

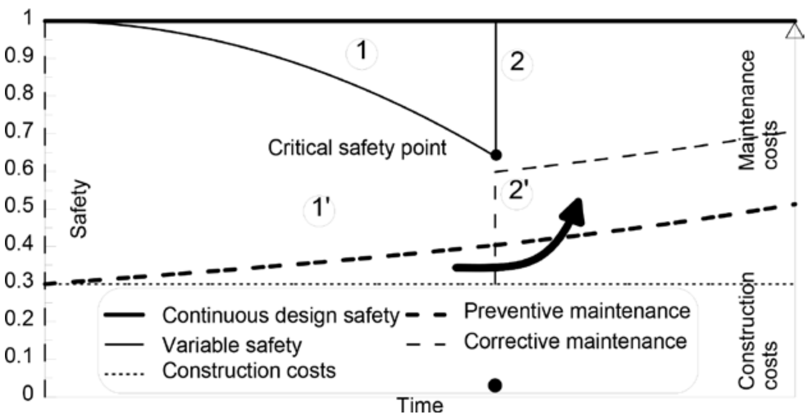

Figure 3 Time related connection between maintenance cost and safety level

3 Guidelines for the technical monitoring of tunnels

According to EN 1997-1 [7] in terms of supervision and behaviour monitoring, geotechnical design includes: the purpose of each group of observations and measurements, parts of the structure whose behaviour will be monitored and places that will be observed, the frequency of measurements, a way of evaluation results, the range of values within the results are expected, the period in which monitoring needs to be continued after the end of construction and the persons responsible for the implementation of measurement and observation, interpretation of results and maintenance of instruments. In order to obtain an overview of the tunnel behaviour and the behaviour of the tunnel sections a full range of monitoring should be applied. These monitoring includes; technical, seismological and hydrogeological observation. The part of the technical observations are visual observations which includes observations of the damage resulting from accident, temperature changes, fire, earthquakes, tunnel settlement or settlement out of the tunnel area. Cracks in concrete lining, bulges or depressions in the tunnel, landslides, slopes at the entrance of the tunnel or at the area of the tunnel, seepage or wet surface in concrete lining and condition of concrete surfaces are observed and monitored. Apart from visual observations, technical monitoring techniques are well advanced and uses devices for 3D measurements, extensometers, measuring anchors, pressure cells, deformeters, piezometers, magnetic extensometers, sliding micrometers and other field and laboratory tests. Monitoring frequency are different according to state standards. For tunnels and subways periods and scope of observation are defined in DIN 1076, BOStrab and RIL 853 [11]. DIN 1076 [12] includes the Main inspection, every 6 years, of all relevant objects like foundations, loadings, traffic signs, structural elements, corrosion etc. The standard inspection, every 3 years in order to review the relevant elements from the Main inspection and supervision, twice per year, which means visual observation to gather the information about the visual irregularities. The Special inspection is recommended after the incidents such as fire, earthquake or water breakthrough. Guidelines for the frequency of engineering inspection are given in the flowchart Figure 4. The results of the monitoring documentation are detected defects which are than classified into the three categories. ''Urgent'', which includes immediately repairs, then ''not urgent'' which requires repair in the medium term and the category ''further observation that involves repairs in the long term and the category of the ''further monitoring'' that includes the repairs in the long term. The ultimate success of monitoring depends of how regular, systematic, arrange and transparent the technical documentation is. Documentation of monitoring should be arranged and conduct in way that it allows the constant and complete insight into the observed tunnel condition at any given time. That means a set of all documents which are showing the actual constructed state of tunnel and whole technical monitoring net as well as a set of the documents during the life of the tunnel showing the state which is established by a systematic technical observations.

Table 1 Engineering inspection and supervision [11]

DIN 1076	DB Netz AG RIL 853	BOStrab
Supervision (2x a year)	Supervision (4x a year)	
Standard inspection (every 3 years)	Examination (if required)	
Main inspection (every 6 years)	Assessment (every 3 or 6 years)	Inspection (every 10 years)
Special inspection (if required)	Special inspection (if required)	

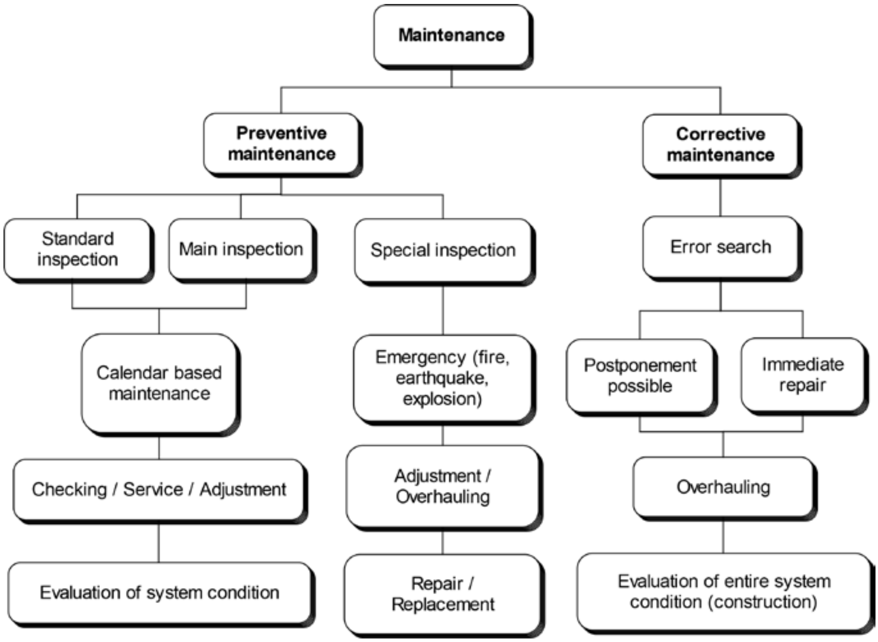

Figure 4 Time related connection between maintenance cost and safety level

4 Concusion

The main reason for the technical monitoring of tunnel is primarily for the public safety. It has the purpose to determine whether the construction behavior is normal, or whether there is a deformation or displacement, which could be a sign of structure disturbance, foundation, or nearby area. The other reason for the monitoring is because of rational maintenance. Remediation of these constructions is very delicate and expensive. Therefore there is a need to take any damage and undesirable phenomena detected as soon as possible and solved until any major proportions.
Besides technical monitoring of constructions in general and the tunnel as well is expected by the Croatian standard EN 1997-1 and the National Annex BS EN 1997-1:2008 / NA.
Since there are no national standards or regulations in Croatia this paper provides the guidelines for the technical monitoring by emphasizing the importance of using the same, and emphasizes the need to develop the regulations for technical observation of the tunnels.

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