Review of the current state of standardisation on monitoring, data-informed safety assessment and decision-making regarding maintenance of the transport infrastructure

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Abstract

Road and railway infrastructure networks form the backbone of European transportation systems, carrying more than 80% of passenger and 50% of goods transport in Europe. Bridges and tunnels which are critical elements of the transport infrastructure networks, have in many cases reached their design service life and keep ageing, with the maintenance needs constantly increasing. Besides, transport infrastructure currently carry significantly more traffic loads than what it has been originally designed for and the topology of traffic keeps changing e.g. due to introduction of platooning or autonomous vehicles. Such conditions bring safety risks to bridges and tunnels. In the last two decades there have been nearly 30 major failures of road and railway bridges and tunnels in Europe, with hundreds of people killed and injured. At the same time, resources and capacity for conservation and care are too limited and should be used in an optimised way to counteract the growing backlog of maintenance. There is a strong conviction that use of novel technologies for condition survey may aid the task of managing the safety risks to transport infrastructure. Despite increasing amount of good practise, uniform approach to data-informed safety and risk assessment, and maintenance decision-making is however missing.

This contribution presents the review of the current state of standardisation on monitoring, data-informed safety assessment and maintenance policies of bridges and tunnels in the European countries. This forms an essential step in the development and implementation of harmonised standards across Europe, which is believed to be a key strategy to increase the safety level of the transport infrastructure.

Keywords: standardisation, bridges, tunnels, monitoring, data-informed safety assessment, maintenance.

1 Introduction

Bridges, tunnels and other large infrastructures on are the most vulnerable elements of the road and railway networks. Due to insufficient quality control during construction, progressive ageing and deterioration of materials, high traffic loads, and additional risks originating from climate change or man-made hazards, an increase of the safety risks seems inevitable. On top of that, weak diagnostics of structures, suboptimal maintenance strategies and deficiency in execution of interventions, further escalate the situation. Incidents such as Genoa bridge collapse cannot be singled out: in the last two decades, around 20 bridges in different European countries have collapsed or got severely damaged. Although the major tunnel disasters in Europe are related to catastrophic fire events, two years ago severe damages have occurred in the Berté tunnel where heavy concrete tunnel lining fell down and caused a major traffic disruption. At the same time, resources and capacity for maintenance of infrastructure are limited. Therefore an optimized utilisation of the narrow resources for conservation and care should be put in place through to significantly slow down or contain the consequences of major threats to infrastructure.

There is a strong conviction that use of novel technologies for condition survey may aid the task of managing the safety risks to transport infrastructure. Despite increasing amount of good practise, uniform approach to data-informed safety and risk assessment, and maintenance decision-making is however missing. Aiming to ensure the safety of the transport infrastructure during operation through the improvement of maintenance policies across Europe, the European Commission opened the call for the Coordination and Support Action (CSA) "Monitoring and safety of transport infrastructure". The main goal of this Action is to support the preparation of the mandate for CEN standard for the maintenance and control of the European transport infrastructure. The execution of this Coordination and Support Action was granted to the IM-SAFE project consortium.

IM-SAFE project [1] envisions a paradigm shift from the corrective maintenance towards condition-based maintenance, which is set within a risk-based framework for maintenance management and integrated with data-informed safety assessment and maintenance decision-making.

IM-SAFE aims to realize this vision by assisting in the development of the future-oriented European standards. . The objective of the first stage in the IM-SAFE project is to formulate the basis the for harmonization of the rules between the EU countries by evaluating the current practice in standardisation, as represented by standards, guidelines and other regulations.

2 Current status of standardisation

The review of the current standardisation relevant for transport infrastructure, in particular bridges and tunnels, is performed with primary focus on the following aspects: through-life maintenance of structures, safety assessment of existing structures and structural monitoring.

2.1 Through-life maintenance of structures

Decisions on maintenance of bridges and tunnels in the European countries are supported by guidelines drafted at the national or even by the infrastructure operators. The current standardisation of maintenance aimed at ensuring an adequate level of structural safety is mainly focused on bridges, while a limited number of guidelines has been drafted for the structural safety management of tunnels. The reason is that road safety or securing value of the asset are often the key drivers for maintenance of tunnels instead of aspects related to structural safety. The national guidelines refer to existing international standards [2-7] with regard to terminology and general principles of asset and risk management and maintenance. The most recent guidelines implement lifecycle-oriented management approaches and predictive maintenance strategies. As an example, the recent UK guidelines for the management of bridges [8-10] make use of a risk-based approach to support decision-making regarding prioritisation of the interventions and of the risk management measures, including maintenance. In these provisions, the risk assessment is based on predefined qualitative risk evaluations depending on the bridge typology, predefined lists of hazards and vulnerable structural details, qualitative estimation of the likelihood of adverse events and consequences of these events. A variety of hazards are considered in terms of material, durability and structural deficiencies, insufficient past maintenance and incomplete past assessments. Information about the structural conditions from inspections and monitoring are considered in the evaluation of the likelihood of risk events.

Prioritisation of structures is facilitated by simplified risk rating indicators. However, the national guidelines largely differ in how they include condition information from inspections and monitoring in the evaluation of the likelihood of risk events and in prioritization of structures for maintenance.
The maintenance framework for concrete structures described by EN 16311:2014 [5] is directed based on the identified condition of the structure. It encompasses the following tasks: i) setting up the maintenance plan; ii) performing the assessment (including needed investigations, inspections, predictions with regards further deterioration, structural integrity evaluation, and decision-making); iii) executing of intervention tasks. In EN 16991:2018 "Risk-based inspection framework" [11], a shift from prescriptive, condition-based, to a risk-based inspection and maintenance of engineering systems is made. The decision-making in regards to undertaking inspection or maintenance depends on the predefined risk acceptance criteria and the determined level of risk, while the maintenance strategy is ascertained and/or revised based on the feasibility of planned intervention measures. This decision-making is supported by a multi-level risk analysis, which allows risk assessment on various level of complexity – from a simple qualitative risk screening, up to a detailed quantitative assessment of relevant hazards, degradation mechanisms and failure modes.

The Guidelines on Performance-based Risk Analyses by the Dutch Ministry of Infrastructure and Waterway Management (Rijkswaterstaat) [12] follow a similar approach and introduces performance-based asset management as a basis for maintenance tasks, where Performance-based Risk Analysis (PRA) must be used during construction or maintenance of infrastructure objects in The Netherlands. Three different types of risk analysis, with different maintenance plans are covered: i) a qualitative maintenance plan (MP) set up to reduce risks identified with a qualitative risk analysis where the probability and severity of risks are ranked in terms of aspect requirements reliability, availability, maintainability, safety, security, health, environment, economics, and politics (RAMSHE€P); ii) a performance-based maintenance plan (p-MP) where a quantitative risk analysis is used to model the probability of system failure and to determine performance and maintenance requirements; iii) a comprehensive quantitative maintenance plan intended for critical infrastructure, such as storm barriers and tunnels (known as ProBo).

2.2 Safety assessment of existing structures

CEN/TC 250 has recently published the technical specification CEN/TS 17440:2020 "Assessment and retrofitting of existing structures" [13] resulting from the mandate M/515 EN "Mandate for amending existing Eurocodes and extending the scope of structural Eurocodes". This technical specification provides provisions to EN1990 regarding the assessment of existing structures. However, in some countries the standardisation process at the national level started earlier than at the European level. For example, at the beginning of last decade the Netherlands and Switzerland developed national standards dealing with the safety verification of existing structures. In the Dutch standards NEN87000-serie [14]: "Toetsing van constructieve veiligheid bestaande bouw en verbouw", two assessment levels are defined: disapproval and repair. The first level is used to assess if the structure is fit for use, while the second one concerns the safety in case of repairs. The reliability requirements prescribed by the Dutch standards are differentiated with respect to the assessment levels and consequence class. The differentiation with respect to the assessment levels results in lower partial factors for the actions compared to those used for the design of new structures. This differentiation is based on the consideration that lower target reliability levels may apply for existing structures because the cost of safety measures aiming to increase the reliability of existing structures is higher than for new structures.

The reliability requirements given in the Swiss code for existing structures SIA 269 "Existing structures - Bases" [15] depend on the efficiency of the interventions and the consequences of structural failure. While these standards provide rules for updating actions and material properties, the consideration of deterioration in the safety assessment is addressed by means of generic principles. On the contrary, the British guideline CS 455 "The assessment of concrete highway bridges and structures" [16] provides detailed guidance for assessing the resistance of existing concrete structures affected by corrosion of the reinforcement or degradation of concrete. Herein, a guidance is given for the assessment of the residual cross-sectional area of the reinforcement bars in case of corrosion of the reinforcement. With regard to the future development of deterioration, the guideline suggests to use available data, including any previous investigations and monitoring, to estimate the corrosion rate.

2.3 Structural monitoring

The recent standardisation documents on structural monitoring include a limited number of ISO standards [17-18], national standards [19-21] and guidelines [22]. These standards have been analysed with respect to the following aspects:

- definition of monitoring
- objectives of monitoring
- accuracy requirements
- guidelines on the design of the monitoring system
- guidelines on data acquisition, cleansing and pre-processing
- guidelines on use of monitoring data for structural diagnostics, safety evaluation and/or asset management

The standards and guidelines listed above define structural monitoring as the automated, temporary, periodic or continuous observation of the condition of structures by means of sensors. The main objectives of monitoring considered by the standards and guidelines are the identification of deterioration or damage, the control of the condition of the structure in operation and providing information to support maintenance planning. Furthermore, the Chinese standard GB 50982-2014 "Technical code for monitoring of buildings and bridge structures" [21] and the Austrian standard "RVS 13.03.01 "Monitoring von brücken und anderen ingenieurbauwerken" [20] consider also the control of the structural condition during the construction phases, in particular for structural typologies or structural dimensions considered close to the limits of the scope of the current design standards.

In terms of measurement accuracy, the Chinese [21] and the ISO 4866 [18] standards provide accuracy requirements for specific applications and sensing technologies in terms of percentage of the full scale and in terms of the frequency resolution. Other documents, such as the Italian guideline UNI/TR 11634:2016 [19] and the SAMCO guideline [22], provide guidance on the process for specifying of the required accuracy depending on the problem at hand and the objective of the monitoring activities. The Italian guideline is the only document among those analysed providing a detailed appraisal of the principles underlying the design of the monitoring system. These principles include the knowledge of the structural behaviour to be monitored, the physical properties to be measured, the choice of the data analysis methodologies and the decisions that should be supported by the monitoring system.

Regarding data acquisition, cleansing and pre-processing, standards and guidelines provide generic guidelines depending on the characteristics of the monitored process (e.g. low or high dynamic processes) and the external factors that might influence the measurements (e.g. temperature, noise) or faulty measurements.

Concerning the use of the monitoring data, standards and guidelines concern mainly structural diagnostic. In this respect, guidance is given in terms of the structural parameters and indicators that are affected by damage and deterioration (e.g. modal parameters). In addition, the Italian guideline provides the explanation of the principles of model updating based on monitoring data.

3 Conclusions

A review of the current state of standardisation structural monitoring, data-informed safety assessment and maintenance of bridges and tunnels is presented in this paper. The review shows that different European countries have drafted guidelines which address the complexity of standardizing procedures to be applied to highly diverse transport infrastructure assets based on the needs and well established experiences and approaches at the national level. This review forms the basis for formulating coherent and harmonised standards at the European level.

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