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Maintenance and Repair of Transport Infrastructure TECHNICAL GUIDE

PART II - STRUCTURES MANAGEMENT

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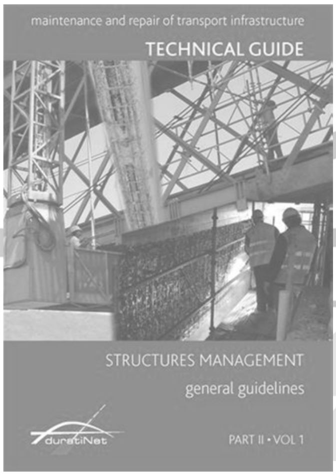
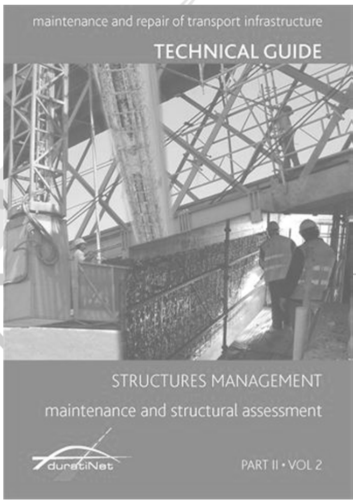
Part II - Structures Management



Volume 1 - General guidelines



Volume 2 - Maintenance and structural assessment

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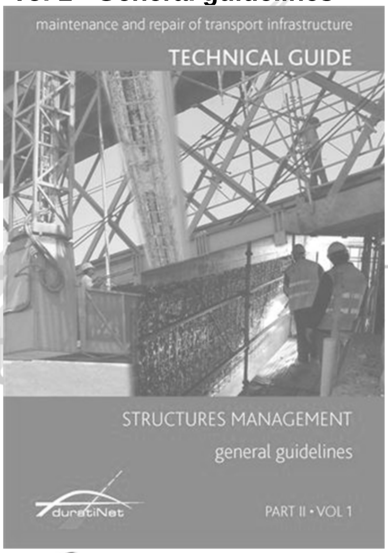

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Part II - Structures Management - Vol 1 - General guidelines

1. Executive summary

- Maintenance Requirements
- Maintenance Backgrounds
- Appropriate maintenance and planning activities

GENERAL GUIDELINES

1 Executive summary

This volume provides general guidelines for the planning of activities relating to the inspection, maintenance, assessment and testing of steel and concrete structures within the framework of an infrastructure asset management system. Independent of the specifics and details of particular management systems, a multi-level hierarchical methodology is presented to facilitate optimised maintenance management and investment prioritisation.

Perfect optimisation of maintenance management takes place when complete information regarding the infrastructure network and actions on such network is available at all points of time. In reality, significant uncertainties exist and the estimate of true safety and the evolution of such safety are inherently fully probabilistic. Consequently, the maintenance management planning, in principle, is carried out through risk management. Fundamentally, this can be achieved by managing reliability indices of the components of the infrastructure network. However, in practice, maintenance management planning is carried out through the incorporation of appropriate structural condition rating at various levels of complexity or detail.

Although specific methodologies of inspections and testing are different for different maintenance management systems, the broad principles are the same and the condition ratings are related to the real safety and the evolution of such safety for engineering purposes. Judicious analysis, interpretation and choice of assessment methods allow rapid condition rating of structures, efficient operation of infrastructure maintenance management systems and cost minimised decisions without having to directly address probabilistic methods. Maintenance management planning is dependent on a four stage process, related to the existence, location and extent of deterioration of infrastructure components and the consequent estimation of remaining service life. Results or decisions of this process can be updated at any given point of time in the light of new information in the form of archived documents, inspection, testing or analysis.

Structural inspections are broadly classified into two levels based on the levels of detail. Limited, simple tests can be accommodated within inspections. Detailed testing of structures may be invasive, non-invasive or semi-invasive and cover very diverse multidisciplinary fields of knowledge. There is a sharp rise in new technologies related to structural testing and often the tests require specific and complex expertise. It is recommended to present relevant testing for maintenance management planning in a format suitable for practising engineers, owners and managers without compromising the actual rigour or detail of such testing. Qualitative and quantitative interrelationships among various levels of inspection and testing are encouraged to be investigated while analysing the condition of infrastructure elements.

The importance of health and safety aspects during inspection and testing is emphasized.

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2. Introduction

GENERAL GUIDELINES

2 Introduction

The importance of inspection, testing, m
transportation structures can rarely be

transport infrastructure is ageing and deteriorating throughout the world and often they are being used to resist loads which they were not originally designed for. Investment on any transportation infrastructure is limited and prioritisation of maintenance management, rehabilitation of transport structures and optimised intervention times are critical for managers and owners and key to sustainable operation of transport infrastructure networks. Additionally, transport infrastructure is usually funded by the government and thus financially affects the end-user as well. The importance of infrastructure maintenance management programmes has already been emphasized by a number of European Union (EU) projects [1H9]. Support has been expressed in favour of a Centralized Infrastructure Maintenance Management Programme [8]. Within the EU/EFTA (European Free Trade Association) region, such maintenance management programmes have also been related to the economic growth since a robust transport infrastructure network directly incentivises potential investment and increased trade. This is particularly true when the economic zones like EU contain countries with extremely variable maintenance and management plans or current status.

Optimised infrastructure maintenance m
thus attempts to maintain a minimum leve
for all the elements while minimising the i
network level. The fundamentals behi

suited to the direct use of personnel involved with such maintenance management on a regular basis. Variability in details and methodology in expected in different countries in this regard. Nevertheless, uniform broad guidelines, often qualitative, form an extremely important part of a generic infrastructure maintenance management framework. The Part II of the TG attempts to delineate such broad and generic recommendations.

Fig. 1 summarises the main principles of infrastructure maintenance management. It is observed that infrastructure maintenance management is probabilistic by nature, interactive by requirement and hierarchical by resource and information limitations. The methodology, independent of management specific details, can always be divided into three main interrelated zones. These are depicted as the Inspection and Testing Zone, Computation Zone and Decision Zone. The Decision Zone is directly influenced by the information, analyses and recommendations available from the two other zones. This volume of TG specifically targets the inspection and testing zone from the

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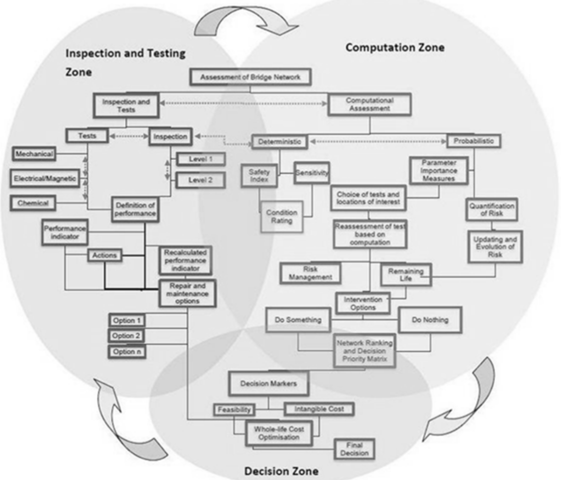

Interactive Infrastructure Maintenance Management: Hierarchical "Mandala"

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3. Structural Inspection

- Inspections process steps
- Inspections type
  - Visual Inspections
  - Detailed Inspections
- Personnel training
- Bridge Management Systems

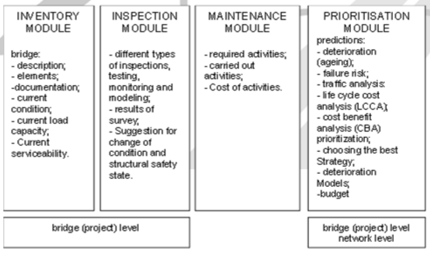

Fig. 1. Structure and information flow scheme of Bridge Management System.

GENERAL GUIDELINES

3 Structural Inspection

Structural inspections allow rapidly estimating the condition of a structure under consideration with respect to a set of performance criteria. The underlying assumption behind inspection lies in the fact that a tendency towards a compromised level of safety, brought about by deterioration (sudden or gradual) can often be observed as visual symptoms on the structure. Structural inspections also accommodate comparing the condition of a number of structures and their estimated projections in the future. These inspections are often dependent on the training and interpretation of the personnel responsible.

Fundamentally, structural inspection and assessment address a four step process leading to optimised maintenance management. The four step process, as advocated by Rytter involves establishing the existence, the location and the extent of damage and is followed by the estimation of remaining service life. The first three steps are very closely related in this process while the fourth step is considered to be a separate problem by itself. The service life is usually a single agreed number.

Due to the presence of a very large number of structures in an infrastructure network, inspection formats are almost always hierarchical. The requirement of cursory visual inspections is applicable to all infrastructure network elements and such inspections form the bottom rung of this hierarchy. Typically, these inspections ensure the location and the existence of specific structures in an infrastructure network and attempt to visually ascertain any significant change, deterioration or damage to the structure since last visit. Experience and photographic evidences are mainly involved in this inspection level. These inspections allow covering a large number of structures in a relatively short period of time and help identify specific structures for a detailed visual or other investigation. Additionally, this level of inspection can be used to report or accommodate the existence of new or additional structures within a network unless such provision is already present at a higher level. These inspections are particularly important in light of disaster management where a very high number of infrastructure elements are required to be assessed very rapidly and decisions are required to be taken within an extremely tight timeframe. Very limited measurements and hammer tapping can be made a part of these inspections. The frequency of inspections at this level is a maximum. A quantitative rating of structures is generally not associated with this mode of inspection although ranking or clustering of structures may be carried out. Automatic acquisition of photographs at a regular basis can also carry out at this level. Access requirements to infrastructure elements are relatively limited.

Detailed inspection is carried out based on the importance and the consequences of failure of the structures to meet certain performance criteria. Ideally, detailed inspection should not be completely directed by or dependent on inspections at a lower level. This independence is present for a number of reasons. Detailed inspection accommodates a significantly wide range of inspection tools and allows for a relatively detailed rating of structure. Detailed inspection divides a structure into its various structural components and carries

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4. Structural Testing

- General Guidelines (TG – Part III and Part IV)
- Testing repository documentation
- Retaining and Archiving raw data
- Appropriate structural testings'

STRUCTURES MANAGEMENT

4 Structural Testing

Structural testing stems out from specific and special requirements related to the safety, serviceability and durability of infrastructure elements. The requirement of tests also encompasses Forensic analyses and disaster management. Health monitoring of infrastructure systems also allow significant testing to be carried out.

Structural testing is possibly the most diverse and interdisciplinary among all of the different levels in infrastructure maintenance management. The advantages of such interdisciplinary nature are observed through data fusion and comparison at various levels. However, it is the same interdisciplinary nature that can be attributed to the difficulty of understanding or interpreting the results by a practising engineer. General guidelines are available in the literature for assessing various tests. This report recommends the development of a testing repository with complete documentation of testing protocol, calculations and interpretation of results within an infrastructure maintenance management framework. Such a measure will ensure that any decision or interpretation is independent of the inspector, can be traced back to agreed and understood principles or limitations and the fact that a rigorous protocol for the collection of data has been followed.

Structural testing usually relates to the geometric, mechanical, electromagnetic and chemical properties, although tests related to optical and thermal properties are also present. Chiefly, the tests can be divided between laboratory and in-site conditions. Based on the impact of testing on structures, the tests can be divided into invasive, non-invasive and semi-invasive categories. These are also known as destructive, non-destructive and semi-destructive tests respectively in common parlance. An invasive test significantly enters into the structure and great care should be taken to ensure that the invasion and testing is carried out throughout without compromising the performance criteria of the structure at any given point of time. The structure is to be repaired to its original level of performance (or better) following invasive testing. Invasive testing often provides one of the best in-situ markers of performance of a structure in its as-built condition. A non-invasive test does not affect structures at all and can be related to methods that perform on the basis of non-contact action, typically through optical, sound-based or electromagnetic principles. These have the obvious advantage of working at a distance and not affecting the structure. The technologies of such non-invasive tests are developing rapidly. A semi-invasive test requires minor invasion to structure. These can be in the form of invasion to affix instruments or small samples being taken from a structure for further testing. Semi-invasive tests have the advantage of being able to integrate a significant amount of opportunities arising from non-invasive tests, without having to completely forgo the option of invasion. As discussed before, the structure has to be appropriately repaired after testing and the level of performance cannot be compromised during testing.

Although structural testing cannot compromise the structural performance at any given time, such tests do tend to affect the performance of the structure

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5. Structural Condition Rating

- Discrete condition ratings
- Continuous condition ratings
- Remaining service life (reliability index – ß)

GENERAL GUIDELINES

5 Structural Condition Rating

Condition rating of structures is central to ensure a system optimal approach for minimised investment in infrastructure maintenance management while maintaining a minimum acceptable level of performance for all components of the network at any given point of time within the service life of the components.

Ideally, the rating should be carried out through a descriptor that can provide the true measure of safety of a structure at any given point of time. Practically, this is not possible due to natural and anthropogenic uncertainties and variability associated with any infrastructure network. The closest possible measure in this regard has been indicated in Part II Volume 2 of this TG to be the reliability index (β) associated with a structure that considers a full probabilistic approach and rates the probability of exceeding a certain performance criteria based on available information.

Although very accurate, computation of reliability index involves very significant knowledge, expertise, computational prowess and time which are not realistically available when considering maintenance management of large infrastructure networks. Consequently, from a practical viewpoint, descriptors of structural conditions have been developed for different infrastructure maintenance management systems at different levels of complexity and detail. These descriptors try to be faithful to the true structural conditions and are generally amenable to further analyses leading to interpolation and extrapolation of structural conditions.

It is generally attempted to make the descriptors cater to difference performance criteria and to enable relative ranking of structures. In reality, some of these conditions are not always satisfied. This disadvantage can often be traded off against the advantage of rapid condition rating without compromising with the safety and without affecting the financial implications of the final decisions on intervention options to a significant degree.

Fundamentally, all standard methods of condition rating are related to the true safety of the structure and relationships with reliability index can be made possible. Consequently, safety management of structures through reliability management may be carried out by considering surrogate condition rating under certain circumstances. Details related to reliability management are presented in Part II Volume 2 of this TG.

Structural condition rating may be discrete or continuous. Additionally, condition ratings may or may not relate to an interpretable physical quantity.

Discrete condition ratings are usually associated to visual inspections. Under such regime, the responsible personnel provide a rating to an infrastructure element based on some agreed methodology. Some amount of subjectivity is usually present in this method. In spite of the presence of such subjectivity, a discrete rating system allows a very rapid evaluation of the broad category of the condition of the infrastructure element. The method is independent of performance measures, can help in classifying and clustering infrastructure elements with similar levels of deterioration and can prioritise intervention or

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6. Archiving and Report

- Archiving
- Reports format

STRUCTURES MANAGEMENT

6 Archiving and Reporting

Archiving and the format of reports for an infrastructure maintenance management system is extremely important for a number of reasons. The importance of these two aspects go well beyond the specific structures or decisions on structures they are attributed to within an infrastructure network.

Archiving of data and reports within a central repository is critical in ascertaining the evolution of the condition of the infrastructure network as a whole. Central repositories are already available for cursory or detailed inspections. However, electronic archival of detailed testing, in conjunction with condition ratings and assessments of structures is generally absent. A central archival system can build objective and definite relationships and clustering of infrastructure elements within a network that can be used judiciously for future condition rating. On a more practical level, appropriate archiving of data to a uniform format allows rapid review and comparison of many structures on a network and appropriate decisions related to further inspection, testing or interventions can be carried out.

Similar to archives, the format of reports for various levels of inspection, testing and assessment are equally important for maintenance management planning. Reports related to visual inspections usually have an appropriate and uniform format within most infrastructure maintenance management system. Additionally, it is also possible to generated automated and formatted reports from central repositories when they are available. Such a well defined format is generally lacking for detailed testing and structural condition rating based on tests and assessments. In spite of an absence of uniformity of content, the archiving of all available test reports is strongly recommended. Additionally, it is extremely important to maintain video footages related to inspection or testing. Such archiving often involves significant conversion of degrading video footages to a more modern format. On the other hand, many tests in recent times involve downloaded or continuous streaming data that requires to be archived.

The need of data management within an infrastructure maintenance management framework thus has a number of aspects. For historic data, a very significant amount is often in printed format. While securely archiving them, it is recommended to transfer core information from paper format to an electronic format in a phased manner. Similar recommendations are suggested for photographic or videographic data. Post processing of visual data employing modern technologies and software are encouraged. However, such work is envisaged to be long term. New inspections, testing and assessments are recommended to be archived electronically to a central organised repository as much as possible in addition to reports in paper format. Dedicated database or repositories to handle large scale data or continuous live streaming data is encouraged. An effective data management is expected to very significantly improve the quality of data, estimate of true safety of the structure and is expected to lessen the amount of work on various structures in future. Protocols and agreements for data access and data sharing should be in place from this aspect.

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7. Conclusions

- Importance of multi-level inspections
- Need of appropriate condition rating
- Presence and development of diverse and complex testing techniques
- Need of special training
- Maintenance planning

GENERAL GUIDELINES

7 Conclusions

This Part II Volume 1 of the TG outlines the fundamentals of assessing structures through inspection, testing and condition rating for infrastructure maintenance management and planning. The broad guidelines are directed to practising engineers, infrastructure inspectors, infrastructure owners, managers and policy-makers. The fundamentals are presented independent of specific maintenance management systems.

The importance of multi-level inspections, testing and their interrelationship is also emphasized. The underlying probabilistic aspects of infrastructure maintenance management are acknowledged in this regard. The requirement of appropriate rapid but representative condition rating markers is observed.

The presence and development of very diverse and complex techniques of testing in the field of maintenance management is acknowledged along with the emerging importance of data management.

Issues related to intangible costs to the users of the infrastructure and those related to the health and safety during inspections and testing are highlighted.

The requirement of special training for personnel related to infrastructure maintenance management is pointed out.

Maintenance planning through appropriate multi-level inspection, testing and condition rating is observed to be a feasible and manageable way to ensure system optimised management within an infrastructure network for their entire service life.

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Appendix

- National context on structures maintenance and assessment

  Overview

  Inspection Methodology

APPENDIX - National contexts on structures maintenance and assessment

1 France

1.1 Overview

The French general frame for the survey and maintenance principles of civil engineering structures is the Circular from the 19.10.79, which has been modified in 1995. The first part [1] is devoted to the concerned type of structures and public organisms, which could act (DDE – Departmental Direction of Transportation, LCPC, SETRA – Service for Studies on Transport, Roads and facilities, CETU – Study Center for tunnels). The second part [2] is devoted to the survey, which can be distinguished as continuous, periodical, or reinforced. The third part is focused on the maintenance and repair, which is separated in common or specialized maintenance and repair. The last part concerns the composition of the folder of the structure, including technical, administrative, juridical and eventually cultural parts. In the context of this report, we focus only on the second part that deals with inspection methodology adopted in France that is used for the survey of concrete roads and railway bridges.

1.2 Inspection methodology

The survey of concretes bridges is based on visual inspection program that involves three types of inspections:

Continuous inspection (annual inspection) is done by a local unit, from the Transportation Ministry or private companies in order to detect any anomaly as soon as possible.

The periodical survey corresponds to detailed inspection giving a global assessment of the structure. In 1995, the circular 19.10.1979 has been modified [3] in order to integrate mainly two points: a return of experiment to be valorised since 1979, and the integration of the approach IQOA (Imaging quality for civil engineering structure). The IQOA is a national strategic methodology for civil engineering structures survey and management (especially: bridges, wall and tunnels) occur every three years. The approach allows to the assessment of the structure state regarding structural and facilities elements and the security of the user. This visit is performed in accordance with the «visit guide» of the IQOA method. The visit consists in following a check-list of the common defects, observing their possible presence.

In case of visible disorders which could disturb the integrity of the durability of the structure, reinforced surveys become necessary inducing different surveys, monitoring, for an accurate expertise and a possible repair design.

In France, inspection personnel are certified at three levels: Team Leader (engineer in civil engineering + 3 years experience), Inspector (Basic university Degree + 5 years experience), and Inspector Agent (High school Diploma). To become certified, team leaders and inspectors must complete the training required for the job title and be examined by the certifying board.

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