WORK PACKAGE 9: PRACTICAL BRIDGE MANAGEMENT

Task 9.3 Recommendations for Bridge Management

D.9.3.1 "Applicability of Guidelines."

April 2005

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Applicability of Guidelines.

DRAFT

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Preface

This report is a deliverable from the Growth Thematic Network “Structural Assessment, Monitoring and Control “ (SAMCO), which was initiated in October 2001.

The present report constitutes the deliverable D.9.3.1*“Applicability of Guidelines”* under task 9.3 “Recommendations for Bridge Management.”

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Table of contents

1 INTRODUCTION

The SAMCO network covers all the relevant the fields of structural assessment, monitoring and control as a part of the bridge management. The network includes a total of 9 work packages, where WP 9 deals with Practical Bridge Management and the task 9.3 deals with the End-users recommendations for bridge management.

The WP 3 drafted a number of guidelines in September 2004, covering monitoring and assessment of structures. The final version of the guidelines will incorporate the results of this report.

The report presents the results of WP 9's evaluation of the guidelines applicability in practical bridge management. The report focuses on an evaluation of the applicability of the guidelines from the end-users point-of-view and does not to look into any theoretical background, documentation or similar. The reports scope is therefore solely to check if the guidelines are applicable for practical bridge management, if they cover the end-users needs and if something important is missing.

2 END-USERS REQUIREMENTS

A number of end-users are represented in WP 9, but it was decided to start the WP 9.3 by issuing a questionnaire in order to get a feedback on the end-users requirements from interested parties outside WP 9.

2.1 Questionaire on "End-users requirements to Guidelines for use in practical bridge management".

The questionnaire enclosed in Annex A was therefore sent out to a number of selected members and partners in the SAMCO-network, as well as handed out during the SAMCO workshop in Rome June 2004.

2.2 The importance of the guidelines.

The answers to the questions showed that the guidelines for monitoring were the most important, whereas the guidelines for assessment had a lower importance. The guidelines for the structural control were considered to have a significantly lower importance than the other guidelines.

How important are the following guidelines for you ?	Rating
Guidelines for monitoring (use of sensors, collection of data, translation into structural conditions).	4.1 (1 to 5)
Guidelines for assessment (visual, NDT, evaluation of structural conditions).	3.8 (2 to 5)
Guidelines for structural control.	2.5 (1 to 5)

Table 1.1. Importance of guidelines, rated from 0 (Not relevant) to 5 (Very important).

The ratings indicated in Tables 1.1 and 1.2 are the average ratings, with the ranges of the submitted ratings indicated in brackets.

2.3 The focus on the evaluation of the applicability of the guidelines.

The questionaire shows that the points of implementation in practice and the use of the obtained information in practical bridge management should have the highest focus.

Which focus points should the evaluation of the applicability of the guidelines have ?	Rating
Implementation in practice of methods and equipment	4.5 (3 to 5)
Use of the information in practical bridge management	4.1 (3 to 5)
Deterioration risks and rates	3.9 (2 to 5)
Damage detections	3.9 (2 to 5)
Safety surveillance of structures	3.9 (2 to 5)
Elongation of service life (keeping the structures in service longer)	3.9 (2 to 5)
Control of repairs quality	3.7 (2 to 5)
Cost reductions	3.7 (2 to 5)
Verification of design assumptions	3.6 (2 to 5)
Verification of the performance of a new structure	3.4 (2 to 5)
Verification of the quality control of contractors design, planning or work carried out	3.4 (2 to 5)
Explanation of theoretical background of methods and equipment	3.2 (1 to 5)
Improved planning of repair works	3.1 (1 to 5)
Reduction of traffic regulations	2.8 (1 to 4)
Others (please specify)	See notes

Table 1.2. Rating of focus points.

A number of additional comments were given in the questionaires, representing a wide range of opinions and needs:

> "The emphasis is clearly on end user requirements, since ultimately they are the most important decision makers. However, it would also be of benefit to develop an annex in which the theoretical background is given, with emphasis on how results should be interpreted. This can be amplified by case studies, demonstrating effectiveness (and possible "failures") of monitoring applications."

> "Guidelines should establish a "common language" in order to improve quality, understanding and a starting point for future development. Focus should be paid to serious work, which could be done by vibration technology to enhance and keep client confidence."

"As a fundamental part of the monitoring process and, specifically of dynamic-based assessment of structures, guidelines should be very specific about the definition/management of all the assessment stages. Theoretical background about both signal processing and model updating should be clearly stated and straightforward applied. Guidelines on such a topic should be enough detailed to allow people with sufficient experience to carry out an accurate assessment of the structure as well as to match the experimental information."

"The guidelines should present a spectrum of investigation methods – from very simple and cheap to sophisticated ones – even if they are intended for the same purposes. The methods of investigation should have been given the "value" assessment to show the end-user how good results he will get with the method. It is very important for countries, which are not so familiar with the most modern technologies."

"Guidelines should specify standard services"

"New guidelines and codes should only address fields and methods, not already covered by standards. A large spectrum of methods (from cheap and easy to complex and expensive) may be used in different situations and according to the problem and all must be covered by guidelines. There is not only one good method for everything."

These comments are quite different, but many points out that a number of methods are available to cover the same problems and that the methods chosen must depend on the actual case, the requirements for accuracy and the funding available.

2.4 Resume

The most important guidelines is the guidelines for monitoring, followed by the guidelines for assessment. The guidelines for structural control have a significantly lower interest for the end-user.

The main focused during the assessment of the guidelines must be:

- Is the implementation of methods and systems in practice described?
- Do the guidelines provide the information needed for the practical bridge management?
- Do the guidelines describe how the results are used?

3 APPLICABILITY OF GUIDELINES FOR MONITORING

The drafted guidelines in annex B are very restrictive in their field of application, i.e. automated permanent monitoring. In addition, the target audience of the document has not been identified and the text has accordingly not been adapted to any particular reader. As such the draft is a combination of basic and highly technical information and is unsatisfactory for an end-user, consultant or instrumentation firm.

The draft does contain much useful information, but the written language needs improving. The large development in monitoring during the last 5 years is not well represented in the references, which needs updating.

While the introduction to measurement techniques is adequate for the restricted areas defined within the draft, a discussion concerning the incorporation of a monitoring system into a management system is lacking. Corrosion and damage mechanisms should also be discussed in more depth.

A section covering the monitoring process is lacking: philosophy, objectives, procedures, quality control, redundancy of system, redundancy of measurement points, etc. In addition, a chapter on implementation is lacking. In other words, the following is missing from the draft:

- organisation
- financing
- distribution of responsibilities
- interface between contractor/instrumentation firm/end-user
- health and safety aspects/plan
- specifications
- calibration certificates
- guarantees
- insurance
- testing/calibration of monitoring system with known load(s)
- responsibility for maintenance and repair
- operation & maintenance journal. How are changes in the system logged? How are new calibration factors/new positions/new sensors incorporated into the system?
- backup of files
- etc

A number of additional and detailed comments and remarks are indicated in the reviewed draft in annex B.

3.1 Resume

The draft report resembles more an “Introduction to structural dynamic monitoring” than a “Guideline for Monitoring of Structures”. This is a fundamental issue and may require renaming of the report or several new chapters.

It is, however, required to mention, that the evaluated guidelines were a draft, which will be corrected and improved later in the project.

4 APPLICABILITY OF GUIDELINES FOR ASSESSMENT

The purpose of the draft in annex C is to provide guidelines for the assessment of civil engineering structures. The draft does not make clear who the guidelines are aimed at, but presumably it is bridge managers as the typical end-user.

The codes developed for structural design are often not appropriate for assessment because of the different uncertainties for design and assessment. Furthermore designs tend to be conservative since this adds little to construction costs whereas a conservative assessment may result in costly and unnecessary repairs or replacement. Thus there is a clear justification for the development of technical rules for the assessment of existing structures.

In the UK assessment codes and guidelines are available, but this is not typical of other European countries. The guideline draft presented provides a methodological framework for assessment based on a stepwise process of increasing complexity similar to that used in the UK. The draft also summarises the methods for structural assessment.

The overall aim is to help practicing engineers to find a suitable assessment procedure for specified objectives and boundary conditions so that different structures are assessed in a unified way giving results that are comparable amongst different regions, authorities and countries. The guidelines are applicable to all civil engineering structures, any construction material and to all design procedures. Fire resistance is the only limitation to the scope of the guidelines.

Structural Assessments may be required due to a change in resistance caused by deterioration (e.g. corrosion, fatigue) or, accidental structural damage or a change in loading caused by change in use, an extension of life or the passage of an exceptional load. Assessments are also used to test the structural reliability for hazards such as earthquake or extreme winds.

The objectives of structural assessment are clearly explained to be:

- To determine the reliability of existing structures for current and future loads in terms of safety and serviceability.
- To minimise maintenance costs.

It is important to clearly specify the assessment objectives in order to identify the most important limit states together with the structural variables that should be investigated and the appropriate assessment procedure to use.

Structural safety assessments are carried out for ultimate limit states and serviceability for serviceability limit states. Examples of ultimate and serviceability limit states are given. Increase in the maximum live load limits and change of use are sited as the most common reasons for carrying out assessments. The effect of deterioration on the resistance is considered and it is stated that corrosion and fatigue are the main deterioration processes. The effects of deterioration are structure and site specific.

The role of assessment within structure management is discussed. The main objective is to provide information about the structural state so that the extent of inspection, maintenance and repair work can be optimised or prioritised within a group of structures to minimise costs and disruption of structural function. Assessment results should be expressed in a form suitable for management purposes.

The assessment methodology is clearly laid out. Important points are:

- To assess the current and future performance with maximum accuracy and minimum effort.
- To avoid undue conservatism, but too lax restrictions should also be avoided.
- To start with simple conservative routines and move to more sophisticated routines only when the load carrying capacity is insufficient.
- The technical authority is ultimately responsible for public safety and therefore has the final decision in the event of an assessment failure.
- A failed structure may remain in service if it presents a low risk, provided it receives regular monitoring.

The draft classifies assessment procedures into three categories:

- Measurement based serviceability
- Non formal
- Model based safety and serviceability

Only the latter is important for the context of this draft. The three main steps are:

- Acquisition of loading and resistance data
- Calculation of load effect using structural models
- Verification of safety and serviceability

The level of sophistication of each of these steps should usually be similar.

A system of assessment levels roughly based on the UK system is described. They consist of six levels (zero to five) ranging from non-formal qualitative assessment (level 0) to full probabilistic assessment (level 5). These levels are concisely summarised in a useful block diagram. This system of levels and the boundaries between them are not necessarily fixed.

The methods for data acquisition are considered and consist of:

- Study of documents
- Inspections and material testing
- Performance testing and monitoring
  - structural health monitoring
  - system identification by static and dynamic measures
  - proof lead tests

Structural health monitoring includes the permanent and periodic measurement of time variant factors such as displacement, strains and stresses. It can be applied to any structure at any age but is often used to monitor structures that have been assessed as just sufficient or just insufficient.

System identification by static and dynamic measures can be used when dimensions and material properties of the real structure cannot be measured due to inaccessibility or hidden damage. Structural properties such as stiffness of members and joints, flexibility of hinges or bearing conditions can be obtained by system identification. It is also claimed to be an efficient tool for damage detection and evaluation although this has not been convincingly established. System identification allows the assessment model to be refined so that it has the same characteristic behaviour as the real structure.

Proof load tests are advocated for assessing the load carrying capacity of existing structures. Different types of proof load test are described for the serviceability limit states but the practical limitations are not considered.

Methods for structural analysis are categorised into:

- Simple methods e.g. frame and grillage analysis
- Complex methods e.g. finite element and non-linear methods such as yield line analysis
- Adaptive methods e.g. updating stiffness parameters automatically using measurements such as displacements, strains and crack widths

Three methods of reliability verification are discussed:

- Deterministic verification with global safety factors
- Partial safety factors
- Probabilistic verification

The first method is not recommended because it involves a considerable amount of uncertainty and reflects reality insufficiently. The partial safety factor approach is a semi-probabilistic Level 1 method. The factors are determined by reliability analysis for a specific target reliability. The basic variables are specified with one characteristic value. This approach better reflects reality because uncertainties can be taken into account although it has a tendency to be conservative that while acceptable for design is less desirable for assessment.

For probabilistic verification the measure of structural safety is the probability of failure or the equivalent reliability index. It is necessary to measure the real values of design parameters in order to reduce uncertainty. This method of verification is highly sensitive to:

- The choice of probability distribution for the random variables
- Analysis methods and models used for calculating load effects

An expert is required to assess the sensitivities of variables on the result.

The target reliability level used for verification of an existing structure should take account of economic, social and sustainability considerations as well as structural ones.

The draft provides the basics of Levels 1 to 5 structural assessment routines. Performance Assessment (Level 1) is the most straightforward formal routine, Levels 2 – 4 are based on partial safety factors while Level 5 is fully probabilistic.

Assessments based on documents and visual inspections are Level 2. When supplementary investigations are needed to measure material properties and dimensions in-situ the routine is Level 3. Information for Level 3 routines can also be obtained from system identification or live load models although this is much more difficult to accomplish in practice. These difficulties were not adequately explained.

Level 4 routines involve partial safety factors modified to represent an adjusted safety margin. Factors that are modified include loading history, consequences of failure, reserve strength and redundancy and warnings of failure.

The probabilistic assessment routine (Level 5) is usefully compared with the partial safety factor methods. For partial safety factor the design parameters are definite and uncertainties are guarded by safety factors whereas for full probabilistic assessment failure depends directly on the uncertainties in load and resistance parameters. Probability distributions model the uncertainties and the probability of failure is calculated for structural components and the whole structure, although the problems associated with assessing the whole structure as a single entity are not discussed. The draft briefly describes the different types of uncertainty and points out that the probability of failure is a notional rather than an absolute measure of safety or serviceability and should not be interpreted as a frequency of failure during service. It should only be used for comparison with acceptable criteria.

The draft clearly describes a five-step procedure and the principles for probabilistic assessment. The theory is extended to take account of time variability in live load resistance when a structure deteriorates with age. The difficulties associated with taking account of time variability are not adequately explained. The use of Baye's theorem to take account of additional information from inspections, tests and monitoring to give updated values of probability of failure is discussed. This approach can also be used to take account of proof load tests and past service loading although the explanation given would be difficult for most practicing engineers to understand and apply.

The draft also describes the probabilistic assessment of systems of structural components although there is not enough explanation to permit application by engineers.

The draft lists nine references, which could be extended.

Annex A provides a very useful and concise Classification and Structure of the Assessment Process. Annex B describes Methods for Calculating Failure Probabilities. This annex would be outside the experience of most practicing engineers and would be difficult to understand. A reference to a document providing more explanation would have been useful.

Annex C provides useful guidance on the selection of target reliabilities. Annex D gives procedures for:

- Updating failure probability
- Updating probability distributions
- Evaluating characteristics and design values

This annex also lies outside the experience of most engineers and would be difficult to apply.

4.1 Resume

In general the draft provides excellent guidance for engineers for the assessment of existing structures. All the explanations are clear except for those relating to the full probabilistic approach, which soon become difficult to follow. The difficulty is that to give an explanation that is both comprehensive and easy to understand would require a separate and lengthy document. These guidelines would be easier to apply if they were accompanied by worked examples of assessments made at each level. The guidelines gave the impression that all steps were straightforward and the practical difficulties of applying the assessment procedure appeared to be avoided notably in the discussion of measurement based on system identification and proof load tests.

Clearly bridge managers need to know whether their structures are safe and serviceable both now and at various times in the future in order to inform decisions about maintenance, repair and eventual replacement so structural assessment plays a crucial role. The guidelines provide a clear and structured approach for deciding the most appropriate assessment methods to use for specific structures. The Bridge Manager would however still need additional expert help with the more complex methods say Levels 3 to 5. One of the most difficult problems remains the prediction of load carrying capacity in the future due to our inability to make reasonable quantitative estimates of the rate of structural deterioration especially when the defects are hidden.

5 APPLICABILITY OF GUIDELINES FOR STRUCTURAL CONTROL

No guidelines for Structural Control were available during the time schedule of WP 9.3.

The guidelines for structural control has, however, been identified as of very low interest for the end-users and it is therefore the recommendation of this report, that the work of the guidelines focus on monitoring and assessment and deals less with the Structural Control.

6 CONCLUSIONS

The drafted guidelines for monitoring need a significant revision in order to fulfil the end-users requirements.

The drafted guidelines for structural assessment are quite good from the end-users point of view, but should incorporate a clear identification of the situations and cases, where monitoring may be a relevant strategy for the following maintenance management planning.

The guidelines for structural control will probably have a very limited interest for most end-users, however, they may be of relevance for special structures.

7 REFERENCES

/BRIME, 1999/ "Deliverable 4: Review of existing BMS and definition of input for the proposed BMS", BRIME, February 1999, downloaded from http://www.trl.co.uk/brime/deliver.htm.

/Di Mascio et al, 1998/ P. Di Mascio and L. Pardi: "Ponti e viadotti stradali: raccolta ed analisi dei dati di degrado", Industria Italiana del Cemento, 1998.

Annex A.

Questionnaire on End-users requirements to Guidelines for use in practical bridge management.

The enclosed questionnaire was sent out to a number of selected members and partners in the SAMCO-network, as well as handed out during the SAMCO workshop in Rome June 2004.

QUESTIONNAIRE:
End-users requirements to guidelines for use in practical bridge management

The SAMCO Guidelines

SAMCO will produce **Guidelines for Structural Assessment, Monitoring and Control**.

The applicability of the guidelines shall be evaluated from the point-of-view of the end-users in WP9 "Bridge Management in Practice".

We would appreciate your opinion on what our evaluation of these guidelines should focus on.

To facilitate your commenting and input, we have set up the brief questionnaire, which we hope you will fill out and return it **during the workshop in Rome 7-8 June 2004** (or later by fax) to:

Livia Pardi, Autostrade S.p.A. at lpardi@autostrade.it
+ 39 06 4363 2559

or:

Per Goltermann, RAMBOLL at peg@ramboll.dk
+ 45 4598 6302

Please feel free to give the questionnaire to anybody, who may have an interest in the field of monitoring, assessment and control of bridges.

Your input will be appreciated.

Your company, **institute or organization:**	
	Non-profit organization
	Private company
	Public company
	Research Institution
	University
Contact person:	
Address:	
Telephone: **Fax:**	
e-mail:	

How important are the following guidelines for you ?	***Degree of importance 0 (Not relevant) to 5 (Very important)***
Guidelines for monitoring (use of sensors, collection of data, translation into structural conditions).	
Guidelines for assessment (visual, NDT, evaluation of structural conditions).	
Guidelines for structural control.	

Which focus points should the evaluation of the applicability of the guidelines have ?	***Degree of importance 0 (Not relevant) to 5 (Very important)***
Explanation of theoretical background of methods and equipment	
Implementation in practice of methods and equipment	
Use of the information in practical bridge management	
Verification of design assumptions	
Verification of the performance of a new structure	
Verification of the quality control of contractors design, planning or work carried out	
Control of repairs quality	
Deterioration risks and rates	
Damage detections	
Safety surveillance of structures	
Elongation of service life (keeping the structures in service longer)	
Improved planning of repair works	
Reduction of traffic regulations	
Cost reductions	
Others (please specify)	

My thoughts/ideas for the guidelines are: (please insert below):