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Guidelines for assessing load carrying capacity

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This report is an output of Workpackage 2, which is concerned with methods of assessing the load carrying capacity of existing bridges. It is the fourth of four reports. The main body of work on bridge assessment carried out for Workpackage 2 is contained in the previous reports numbered D1, D5 and D6. This report is presented in the form of Guidelines for assessment describing the framework and principles recommended by the partners. Appendix 1 contains background material and a discussion of the proposals in the Guidelines.

SCOPE

All countries carry out bridge assessments but their methods and procedures differ. In general terms, the process is well known, and many of the principles and objectives identified in this report are self-evident. The Guidelines have been compiled using the best practices and procedures found in the BRIME partner countries. They are written in the form of proposals recommended to the relevant Technical Authorities in the countries concerned. They are not intended to be a manual for use by engineers to assess bridges.

SUMMARY OF GUIDELINES

The guidelines are presented in the form of objectives, principles and methodology.

The main objectives of assessment are to investigate bridge safety and determine load carrying capacity. Other objectives include the provision of cost-effective solutions for the treatment of sub-standard bridges and projections of future performance. For the purposes of bridge management, the objective is to provide consistent data across the bridge stock in a form suitable for the optimisation and prioritisation processes and effective use of resources.

The principal recommendations are as follows:

- National Technical Authorities should, for the present, specify their own assessment methods and standards rather than attempt to combine to develop European standards

- Standards for loading and resistance calculations should be less onerous than design standards where this can be done safely. Examples are where design traffic loading is higher than current loading because it includes an allowance for future increases and research shows that resistance calculations are too conservative or prescriptive for assessment.

- Assessments should be carried out using Limit State principles. Where countries use other methods for design and assessment, they should move towards this position.
- Inspection for assessment should be targeted at the confirmation or revision of the construction drawings and other records and the investigation of the presence and extent of deterioration in a manner that can be quantified structurally.
- Allowance must be made for the effect of deterioration on carrying capacity now and in the future. Several approaches are discussed briefly. Reference should be made to the output from Workpackage 3 (Report D11) but further development of methods is required.
- The Guidelines presume that all bridges will eventually be assessed systematically (Universal Assessment) and data used in the Bridge Management System for prioritising maintenance activities. However, this is a national policy decision, the alternative being to assess bridges as the need arises.
- Actions required in case of an assessment failure include progressive assessment with increasing levels of refinement, identification of low-risk Sub-Standard bridges that can remain in service provisionally, load testing, monitoring and strengthening
- Several Assessment Levels are proposed starting with simple conservative methods and progressing to more refined methods when a higher assessed load capacity is required. An intermediate Level requires in-situ material properties to be determined. The final Level entails the direct application of reliability methods. An optional base Level caters for bridges that have not been individually assessed.

Suggestions for achieving these recommendations are discussed in the Guidelines, principally in the Methodology section.

IMPLEMENTATION

Bridge assessment is an on-going process. It is not suggested that BRIME partner countries interrupt their current assessment programmes and abandon the methods and procedures they are currently using. It is proposed, however, that they consider what can be done to improve their current practices and how best to move towards a compliant assessment programme suitable for a full Bridge Management System. To do this requires a number of policy decisions to be considered, for example the adoption of Limit State methods if these are not currently used, and the systematic assessment of all bridges

DELIVERABLE D10: GUIDELINES FOR ASSESSING LOAD CARRYING CAPACITY

1 INTRODUCTION

This report is an output of Workpackage 2, which is concerned with methods of assessing the load carrying capacity of existing bridges. It is the fourth of four reports. The main body of work on bridge assessment carried out for Workpackage 2 is contained in the previous reports numbered D1, D5 and D6 (see Section 9, References). This report is presented in the form of Guidelines for assessment describing the framework and principles recommended by the partners. Detailed technical descriptions of the processes are contained in the previous reports and not repeated here.

All countries carry out bridge assessments but their methods and procedures differ. In general terms, the process is well known, and many of the principles and objectives identified in this report are self-evident. The Guidelines have been compiled using the best practices and procedures found in the BRIME partner countries. They are written in the form of proposals recommended to the relevant Technical Authorities in the countries concerned. They are not intended to be a manual for use by engineers to assess bridges.

At opposite extremes, bridge assessment can be a stand-alone process for a single bridge or an integral part of a bridge management system. The requirements are very similar, but differences arise from the greater need for uniformity, efficiency and information recording when a system is applied to a network of roads and bridges.

The main report describes the principal features of the proposed Guidelines. Appendix 1 contains background material and a discussion of some of the proposals the Guidelines.

2 TERMINOLOGY

For the purpose of the Guidelines, the following terminology is used. The descriptions given are not intended to be precise definitions.

Assessment
In the field of structural engineering, assessment has come to mean a set of activities used to determine the safe load-carrying capacity of an existing structure. This is the description adopted here. For a bridge, the main live load/action arises from traffic, and safety is determined with respect to a prescribed traffic-loading model, in combination with other loads/actions as appropriate.

Load carrying capacity
The traffic load that can be carried in combination with other loads/actions where appropriate. A full assessment may examine many aspects of structural adequacy, for example resistance to impact on supports, or scour. These may separately prevent the use of the bridge by traffic.

Assessment Level
One of a number of levels of increasing refinement that can be applied successively in the assessment of a bridge, normally when the lower levels are insufficient.

Reliability Level
In reliability theory nomenclature, there are three recognised levels designated Levels I to III. In Level I, appropriate levels of structural reliability are provided by the specification of partial factors related to the characteristic values of basic variables. Level III refers to the method that delivers a probability of failure or Reliability Index[1] based on a probabilistic analysis using a full distributional approach. Level II is an approach that checks safety at selected points on the failure boundary.

Assessment Live Loading
A traffic-loading model used for bridge assessment, which may be less onerous than design loading, for example when the latter contains an element for future developments. In the most cases, it is likely to cater for current high-density traffic covering all standard vehicles that can freely use the highways. It may ignore special "abnormal" vehicles that are restricted in their use of the highways, their movements being subject to regulation or control.

Reduced Live Loading
A reduced traffic-loading model to cater for the assessment of bridges that are to be restricted in use to selected vehicle types or maximum Gross Vehicle Weights by roadside signing.

Bridge-Specific Live Loading
A traffic-loading model devised for a specific bridge using measured site-specific data – e.g. weigh in motion or traffic flow.

Assessment loading
Primarily intended to refer to the traffic-loading model used for assessment, because it is here that there is most scope for reductions from the design values. However, when used without the addition of the term "Live" it may be assumed to include other loads/actions that need to be taken into account in assessment.

Sub-Standard
A bridge is Sub-Standard when it has failed an assessment. The exact definition of the term will depend on national practice. In the most cases, it is likely to mean unsuitable for carrying Assessment Loading, in the combinations adopted, ignoring special "abnormal" vehicles. It could mean, possibly, Sub-Standard for a combination of loads that excludes primary traffic load.

[1] See Reports D5 and D6 for further discussion.

Capacity Index
A ratio quantifying the extent of the deficiency or reserve of strength in a member (or whole structure). Typical examples are the ratio of member resistance to load effect for the chosen combination of loads, or member live load resistance to live load effect. Safety factors are included.

Condition Index
A number used to quantify the condition of a bridge or member essentially to prioritise maintenance, generally using a descriptively defined scale depending on the severity of any deficiencies.

Condition Factor
A factor of value unity or below used as to reduce the assessed capacity when calculations of the effect of condition are not provided – generally subjective.

Monitoring
The process of observing a Sub-Standard bridge in a manner sufficient to detect any change in performance that could affect its safe operation.

Technical Authority
The authority responsible for technical standards for the bridge or bridge stock in question. It is recognised that many countries do not have a single authority responsible for the management of all bridges, but there will often be a national authority responsible for standards on public roads, including those relating to assessment. Legal responsibility may reside with a local or national highway authority, which may be different from the Technical Authority. The term Technical Authority is used in the Guidelines for simplicity.

Universal Assessment
This refers to the principle of assessing or providing a proxy for an assessment for all bridges within the bridge stock. The intention is to use the Capacity Index to prioritise short-term remedial action to restore safety and, by tracking and predicting it, to provide long-term expenditure planning within a Bridge Management System. The decision to adopt this principle rests with the Technical Authority.

Bridge Management System
Unless stated otherwise, this refers to a comprehensive computer based system that prioritises expenditure on bridge management, for example using reliability-based optimising techniques where available. It is expected to use mechanisms for predicting future expenditure using the Condition Index and, if required by the Technical Authority, the Capacity Index. The abbreviation BMS is used.

3 OBJECTIVES

There are objectives relating to bridge assessment and others to the Guidelines as proposed in this report.

3.1 Objectives of assessment

Some objectives relate to bridge assessment as a process and some to assessment in the context of bridge management. Principal objectives are:

- To investigate safety when this has become open to question. Further objectives arise when the assessment finds the bridge Sub-Standard, for example assessing Reduced Loading, other traffic restrictions or strengthening.

- To minimise disruption and cost resulting from bridge assessments. The Technical Authority should seek to minimise over-conservatism consistent with safety and provide short-term solutions for Sub-Standard bridges (such as Monitoring) that avoid traffic restrictions wherever possible.

- To maximise the usefulness of assessment results within bridge management. This requires the results to be archived and accessible in a standard form suitable for future updating. Reliable predictions should be provided of future changes in capacity for planning purposes.

- To aid optimisation and prioritisation when a BMS is to be used. There is a need to specify a comprehensive and unambiguous assessment framework and standards that can be applied uniformly over the bridge stock so that the optimisation process is not adversely affected by inconsistencies or inadequacies in the data.

Superimposed on these objectives is the need to maintain the whole bridge stock in a safe and serviceable condition economically and without unnecessary disruption to traffic on the network. The evaluation of corrective solutions to deficiencies and impending deficiencies, and their costs, is therefore an important facet of the assessment process.

The Technical Authority must decide if it requires a value of assessed capacity for all bridges, and if so whether this must be a formal assessment in all cases or may include a deemed to satisfy option. It must also decide whether the assessed capacity is to be a major factor in the prioritisation of the funding for bridge management. These are principles rather than objectives (see Section 4, Principles).

It could be an objective for the Technical Authority to seek to employ these principles in the future if it is impractical in the short term.

3.2 Objectives of assessment within bridge management

Within the process of bridge management, assessment has objectives at two levels:

Specific to managing a particular, single bridge (project level).
Relating to the bridge stock as a whole (network level).

Specific objectives for an assessment framework are therefore:

- To calculate the carrying capacity of individual bridges, the extent of any surplus or deficiency (e.g. Capacity Factor), and identify Sub-Standard bridges with their Reduced Loading capacity where required - (*project level*).

- To provide options for addressing safety, maintenance and strengthening issues when a bridge has capacity deficiencies, including costs – (*project level).*

- To identify bridges that are likely to become Sub-Standard in the foreseeable future – (*project level).*

- To provide data that will in aggregate, provide a network view of the state of the bridge stock (Sub-Standard bridges, their number, type, location, age etc) – (*network level).*

- To provide data of a form and consistency suitable for the BMS to use to lead to efficient management of the network of bridges – (*network level*).

3.3 Objectives of the Guidelines

The Guidelines are the end product of Workpackage 2, in that they present an overview of bridge assessment as perceived by the partners during the review.

Specific objectives of the Guidelines are:

- To propose a framework for national or area procedures, and standards, for bridge assessment.

- To suggest how partner countries can improve their assessment methods for national use – e.g. more efficient and not over-conservative.

- To provide a discussion of the options for bridge assessment within a BMS.

- To identify areas for further development.

- To provide sufficient flexibility for Technical Authorities to use with due regard for current procedures and future preferences.

- To provide an understanding of bridge assessment within the BRIME project so that it can be accommodated within a Bridge Management System.

Bridges need attention when they become unserviceable or unsafe. Expenditure planning deals with current problems on a basis of priority and future expenditure by predicting future problems.

The weight given to assessed capacity (current, and future predictions) in relation to condition in the prioritisation of expenditure on bridge management is an important consideration. It is affected by the variability inherent in assessment calculations, and whether they are uniformly conservative and not over-conservative.

It was not the intention in this report to pre-empt conclusions about the use of assessment information in a bridge management system, although some options are given. That was a task of Workpackage 7.

4 PRINCIPLES

The main principles or propositions contained in the Guidelines are as given below.

- The proposed Guidelines are intended to be part of a Bridge Management System but bridge assessment can be used independently.
- Initially it is acceptable to assess bridges only when the need arises – for instance when there is deterioration or a change of loading - but the Guidelines are written assuming that all bridges will eventually be assessed (Universal Assessment) and data entered into the BMS for prioritising maintenance and strengthening work
- Bridge assessment should be carried out using loading and structural standards devised for the purpose and not design standards, as these will generally be too conservative. Countries currently using design standards should aim to improve their methods.
- Assessments should be carried out using Limit State principles with partial safety factors and characteristic values according to Level I [2] reliability methods, and progress towards Level III methods where this is economic. Countries using other methods should aim towards adopting this form of assessment.
- Load testing is acceptable in support of assessment by calculation, but is expected to be the exception.
- Several Assessment Levels [2] are proposed starting with simple conservative methods and progressing to more refined methods when a higher assessed load capacity is required. An optional base level caters for bridges that have not been individually assessed.
- Bridges that have not passed assessment to an acceptable capacity when all practical Assessment Levels have been tried are classed as Sub-Standard or provisionally Sub-Standard when assessment in still in progress. Some bridges of this class may remain in service if they present a low risk, subject to Monitoring.

[2] For the difference between Assessment Levels and Level of Reliability Method, see Section 2, Terminology.

- Deterioration is taken into account in determining the current assessed capacity. Initially it is expected that the effect and timing of future deterioration will also be estimated during the assessment process, before data are entered into the BMS database. In due course, it could be done internally by the system algorithms.

- National Technical Authorities should initially specify their own assessment methods and standards rather than to attempt to combine to develop European standards. It would take too long and may result in many bridges being classed as Sub-Standard. This principle could be reconsidered later.

The calculation of costs is an essential part of managing bridges, including the long-term and short-term requirements for dealing with Sub-Standard bridges. Although this requirement is included as a part of the framework described in the Guidelines, the methodology for cost calculation was not within the scope of Workpackage 2.

5 METHODOLOGY

5.1 Framework

The responsible Technical Authority should establish a framework for assessment to be used by engineers and managers within its jurisdiction. It is suggested that documentation should cover the following:

- Primary documents to define and implement the assessment policy of the Technical Authority, and specify the methods and standards to be used.

- Assessment standards equivalent to design standards for all common structure types tailored to the requirements of assessment, avoiding over-conservatism, and prescriptive methods and details.

- Assessment live loading including a standard loading model to be used in the general case, bridge specific loading, and reduced levels of loading when weight restrictions are to be imposed.

- Methods of determining deterioration and its effect on current and future assessed load carrying capacities.

- Actions required in case of an assessment failure including progressive assessment with increasing levels of refinement, identification of low-risk Sub-Standard bridges that can remain in service provisionally, Monitoring and strengthening.

- The requirements for recording assessment conclusions and interaction with the management system, costing, funding etc.

Experience in the BRIME partner countries shows that it is impractical to launch a complete assessment package at the outset. Interim rules will allow the process to commence (or continue) in a systematic way, and improvements can be made as more information about the bridge stock and its apparent deficiencies becomes available. The main proviso is that avoidable repetition of bridge assessments should be carefully excluded where possible.

5.2 Primary documentation

A standard or other document is needed to implement the assessment policy of the Technical Authority. It should define the bridges and the circumstances for which assessments are required. There could, for example, be a programme for assessing particular bridge types and/or construction periods with associated priority rankings.

All together, the primary documentation should provide the technical and administrative requirements for inspecting and assessing existing current and outmoded bridge types including selection and prioritisation. Reference should be made to standards that provide for loading, structural analysis, resistance evaluation and arrangements for departing from these standards where a need arises. It should also contain or refer to provisions for managing Sub-Standard bridges in the short term and long term.

5.3 Assessment loading

The principal load case is dead load in combination with traffic live loading, and this is the main consideration given here. Other traffic loads may include braking and centrifugal forces. In some circumstances, loads and effects from temperature and wind may be required. For the basic gravity traffic loading the following points should be considered:

- It is likely that design loading will be used until the Technical Authority has developed Assessment Loading.

- A model for Assessment Loading suitable for general application is required that will cater for high traffic flows, overloading and dynamic amplification as currently observed.

- Initially, the model for Assessment Loading is likely to be similar to the model for design loading but with reductions in magnitude were possible. Later, a model similar to the Eurocode version could be adopted.

- Methodology should be provided for determining reduced Bridge-Specific loading for long-span bridges, based on weigh-in-motion measurements, for which congestion loading is likely to govern.

- Short-span Bridge-Specific loading can show a reduction with respect to the general Assessment Loading model when traffic flows and dynamic amplification are low. It is possible for the Technical Authority to produce this for typical cases using traffic data and reliability methods.

- If the Technical Authority is prepared to accept bridges with restrictions on permitted Gross Vehicle Weights, Reduced Loading models are required for each class of restriction.

5.4 Assessment standards

5.4.1 Derivation from design standards

Bridge assessment can be carried out with design standards because the underlying structural process is similar. A load model is applied to a structural model to produce load effects in members, which must not exceed the corresponding member resistances when the defined safety factors are applied. The Technical Authority may develop a strategy for assessment based on the following:

- The first stage is to use design standards where assessments are needed before assessment standards have been developed.

- The Technical Authority should decide the procedures it will permit, and the checks it requires, for allowing the assessor to interpret the design standard and make adjustments where necessary to avoid unnecessary assessment failures.

- It is presumed that Technical Authorities will each develop their own assessment standards based on their current design standards or on European standards if they can accommodate the discrepancies that may arise.

- For older types of bridge and detail, it may be necessary to consult previous design standards. These should be reviewed using modern methods and up-to-date knowledge, and not accepted unreservedly.

- The development of assessment standards should include consideration of the similarities and differences between design and assessment (See 5.4.3).

This approach does not accommodate Level III reliability methods, which are not currently used in design, but may be appropriate for assessment. Before this approach can be adopted widely, the Technical Authority needs to provide the basis for this type of assessment. It may decide to restrict it to particular cases carried out by specialists and individually reviewed by the Technical Authority at the highest level.

5.4.2 Load effects

In most cases, load effects are calculated by elastic analysis as in design. The only point to note is that a simple assessment can be carried out using a strip method or simple load distribution. There may be sufficient reserves of strength in the structure for these conservative methods to give an assessment pass, particularly where the assessment live loading is less than design loading.

If these methods do not produce an assessment pass, it will be necessary to use more refined methods such as grillage or finite element analysis.

Generally, load effects are calculated from an elastic analysis, which results in a lower bound equilibrium solution. The use of non-linear analysis and upper bound methods, generally not used in design, may be allowed for assessment providing implementation documentation can be provided to the satisfaction of the Technical Authority. Reference can be made to the literature for guidance, and developments are expected in the near future[3].

5.4.3 Resistance calculations

In changing from design standards to assessment standards the following points should be considered:

- Opportunities should be sought to relax the design rules based on more up to date information and research.

- It is advantageous to use the same format for the assessment rules as used in the corresponding design standard. Mistakes can be reduced and the engineer can identify differences more easily.

- Where possible, methods and formulas that in design produce the required size of a component or constituent part knowing the required resistance should be re-formulated to give the resistance knowing the size.

- Minimum and maximum provisions (e.g. reinforcement area, lap length) should be relaxed or removed provided its effect on resistance can be calculated explicitly. This type of requirement is reasonable for design, and may simplify the design process. However, if applied in assessment, a compliance failure can lead to a zero resistance rather than a reduced resistance.

- Non-compliances that relate to ease of construction, robustness or durability are likely to be inappropriate for assessment provided the as-built structure appears to be satisfactory: e.g. cover or bar spacing in reinforced concrete. However, where strength can be affected, for example reduction in bond stress with limited cover, due allowance should be made in calculations.

- Some design codes limit the strength of materials or nominal resistances to specific tabulated values and give safety factors implicitly. It may be better to give the underlying formulas so that alternative figures can be used. If possible, the range should be extended to values that can be justified by research in the literature.

- Provide methods for calculating capacities using measured imperfections, and non-standard detailing, sizes, sections, elements, connections and assemblies that do not comply with design assumptions.

[3] In the UK.

- Where a code provision is believed to be very conservative, new testing combined with a review of the technical literature may lead to a less conservative method of assessment.

- It is sometimes justifiable to adopt a more complex method of resistance calculation for assessment than for design. The balance between complexity and higher resistance is different in assessment.

- Safety factors: although it may not be the intention to reduce the safety of bridges in assessment, a review of safety factors may be appropriate in the assessment standard. This may be treated as a separate issue from Assessment Level 4 provisions (as described in 5.6.4).

Resistance calculations in the presence of deterioration are discussed in 5.5.

5.4.4 In-situ material properties

Values are required for in-situ material properties including density, modulus and various strength parameters (e.g. ultimate stress, maximum working stress, yield stress). For assessment they can be provided for as follows:

- Values quoted in the assessment standard as typical of the period and construction type – generally, minimum values will be appropriate.

- From drawings and contract documents from the bridge being assessed.

- From construction records relating to the bridge being assessed.

- From samples taken from the bridge and tested.

- From site testing – non-destructive or semi-destructive testing.

Obtaining values from samples or site testing can be very effective in increasing the values of material strength and hence the assessed capacity. However, care is necessary in collecting and interpreting the data so as not to affect the inherent reliability of the conclusion. This can lead to the need for a large sample size.

5.4.5 Load testing

Load testing has a part to play in bridge assessment but there is no consensus on how it should be applied. Possible options are:

- To give confidence in the performance of the structure under normal working loads.

- To provide information at working load levels that can be used to revise the structural model for further assessment calculations.

- To provide a direct indication of a lower-bound capacity by application of the assessment load with all load factors included (sometimes known as Proof testing).

- To provide information that can be used for designing a Monitoring regime.

It is presumed that the assessment process has been devised by the Technical Authority to deliver a capacity that prevents the Ultimate Limit State being achieved in service (or ensures that its probability of occurrence is acceptably small).

The first option is not intended to address the ULS assessment directly. The second option depends on using the revised model in a way that is consistent with this aim. It would be expected to provide a lower bound ultimate load based on the measured data and data from ULS tests relating to similar structures.

5.5 Deterioration

5.5.1 Reduction in capacity

Taking account of deterioration and damage is probably the least well-developed aspect of the assessment process. Tools available are:

- Use of a reduction factor (Condition Factor) applied to the calculated capacity of a bridge or component based on engineering judgement.

- Recalculation of the capacity using measured cross-sectional areas: e.g. a reduced section of member, reduced reinforcement area.

- Recalculation based on the loss of connection: e.g. loss of bond in reinforcement, loss of shear connection in composite sections, loss of strength at joints in bolted/welded connections.

- Revised models for resistance of sections suffering from deficiencies or deterioration: e.g. low strength or loss of integrity of concrete, imperfections in steel construction.

Further points that should be noted are:

- Inspection records need to include relevant factors for assessment such as amount of section loss, or potential loss of connection (shear connectors, bond etc).

- Resistance formulas devised for design have been established for intact members and non-deteriorated materials. It cannot be assumed that the same models apply to deteriorated cases.

- It is necessary to estimate the carrying capacity of a structure in the future when further deterioration may have taken place (to an assumed state or at an assumed rate).

- The effect of deterioration on capacity and models to predict future deterioration are the subjects of Workpackages 3 and 4 (Reports D11 and D8). Further research is required.

- It is considered that reliability assessment has a role to play in the assessment of deteriorated structures because the material strength distribution and model uncertainties can be accommodated.

5.5.2 Inspection for assessment

Inspection is an integral part of bridge management. Deterioration can be expressed as a Condition Index for prioritisation of maintenance but this may not be enough for the assessment of load carrying capacity. There is a need to obtain inspection data about condition that will lead to an estimate of the capacity if this is likely to be reduced from the as-built condition.

The use of a subjective assessment Condition Factor for accounting for deterioration or poor condition is to be avoided where possible unless it is based on reliable experimental evidence.

If the variability of resistance arising from a deteriorated structure is different from its variability in the original intact condition, the use of normal characteristic values and partial safety factors may not be sufficient. This calls for either a Level 5 assessment, a Level 4 (see 5.6) assessment in which differences in partial factors have been calibrated by reliability methods, or a cautious conservative approach.

5.6 Assessment Levels

5.6.1 Overview

It is proposed that assessments are initially carried out using simple methods but more refined methods are used if the required capacity is higher than the assessed capacity. Five Assessment Levels are proposed, with a sixth, Level 0, as an option (a proxy for assessment) that some Technical Authorities may wish to consider. This is illustrated in diagrammatic form in Figure 1.

5.6.2 Level 0

Level 0 describes a state in which a structure is accepted into the management system without a formal assessment. Placing it into this category implies that records have been consulted that permit this level to be assigned, and its condition is not giving cause for concern.

5.6.3 Levels 1 and 2

These two levels entail carrying out a formal assessment using available records of the bridge to determine dimensions, structural details and material properties. It is highly desirable to use standards for loading and structural analysis that have been developed specifically for assessment.

The difference between the two levels is that Level 1 uses simple methods of structural analysis to determine load effects and Level 2 uses more refined methods.

Unless there are recent inspection results that confirm the construction and condition of the bridge, the site will have to be visited to supplement inspection records.

5.6.4 Levels 3 and 4

These levels make use of tests or surveys to obtain current bridge-specific data - Level 3 - and allow adjustments to the standard safety factors - Level 4. In Level 4, normal semi-probabilistic methods are used but with revised partial factors to account for bridge specific information. Preferably, the changes in partial factors will be obtained from reliability assessments of typical bridges of the type and specific conditions and tabulated in the assessment standard. Level 4 stops short of a full reliability assessment based on statistical data for loading, material resistances and loading models – which requires Level 5.

5.6.5 Level 5

Level 5 is a full reliability analysis using Reliability Level III methods. Although this is sufficiently well developed for practical application, there is a need to base the rules on a standard and rational footing. Important matters to settle are model uncertainties, the target reliability and factors affecting these quantities.

5.6.6 Reasons for levels of assessment

There are several reasons for proposing a formal set of Assessment Levels.

- Bridges without a capacity problem can be assessed quickly and cheaply.
- Bridges with a potential capacity problem can be assessed in a standard manner with increasing refinement.
- Contracts or instructions to assess a bridge can be defined in scope.
- A BMS can contain a record of the assessed Capacity Index, and the Assessment Level used to obtain it. This may be helpful in predicting priorities for bridge repairs, as the Capacity Index will depend on Assessment Level – in general, higher levels producing higher assessed capacities.

5.7 Management of Sub-Standard bridges

A Sub-Standard bridge is one that cannot be shown able to carry normal traffic loading with the desired level of safety[4]. During the assessment process, before all

[4] See Section 2, Terminology - the precise definition is the responsibility of the Technical Authority.

reasonable Assessment Levels have been tried, it may be thought of as provisionally Sub-Standard.

Measures for dealing with the bridge can be interim (temporary), or long-term. In the long term, unless the bridge is appropriate for Reduced Loading or closure, it must be replaced or modified to bring it within standard. Interim measures can range from closure or propping to “do nothing at present” where this is judged adequately safe. The deciding factors include the following:

- The history and condition of the bridge.
- The Assessment Level – if a low Assessment Level reveals a potential weakness and higher levels are in hand.
- The extent and severity of the deficiency.
- The nature of the deficiency - ductile failure with warning, or otherwise.
- The overall risk - nature of danger to bridge users and obstacle crossed.
- Whether or not the bridge is suitable for Monitoring in service.

Immediate action is required if the assessment shows a bridge to be seriously below capacity, and there is a significant risk of collapse unless it is subjected to traffic restrictions. If the overall risk is low, the bridge may remain in service for a limited period while long-term measures are considered. This includes the delay while bridge is assessed at a higher level, or a temporary period of unrestricted service while a planned route change is completed.

Some Technical Authorities may find it acceptable to install monitoring equipment to extend the period of unrestricted service. The essential requirement is that the risk is managed to an acceptable level.

5.8 Recording assessment results

Bridge assessment conclusions at the project level will be summarised in the assessment calculations, preferably in a standard format for ease of archiving and data retrieval. If the bridge is Sub-Standard, the calculations will generally include interim proposals for managing the bridge.

For use at the network level, a database is required to manage the data. This may be a part of a full BMS, in which case it is the subject of Workpackage 7 (Report D13). Some suggestions on what should be included follow:

- Whether the bridge currently has sufficient capacity for full normal traffic loading or is Sub-Standard.
- The overall rating of the bridge in terms of a Capacity Index and/or a permissible reduced gross vehicle weight.

- The Capacity Index for all critical or near critical members, load effects and modes of failure.
- The Assessment Level.
- An estimate of the effect of deterioration in the future – possibly at predetermined intervals.
- If the bridge is Sub-Standard, how the bridge is being managed in the short-term and proposals for managing it in the long-term.

5.9 Re-assessment

The assessed capacity will not be correct indefinitely. Consequently, the Technical Authority must consider the need for re-assessment at some time in the future.

Policy options are to re-assess at pre-determined intervals or when a change to condition, loading etc has occurred that could reduce the capacity significantly. If deterioration is the critical factor, this should be kept under review and revised at each periodic inspection.

There is also a possibility that a re-assessment could lead to a higher capacity if a higher Assessment Level is adopted or if the assessment rules have changed since the previous assessment was carried out. This can have implications for the prioritisation module for a BMS.

6 IMPLEMENTATION

Implementation of an assessment programme or standards and a full BMS are not necessarily inseparable. Either could be implemented without the other. The Technical Authority must decide its policy with respect to providing Assessment Loading, Universal Assessment, and transitional arrangements.

Bridge assessment is an on-going process. It is not suggested that BRIME partner countries interrupt their current assessment programmes and abandon the methods and procedures they are currently using. It is proposed, however, that they consider what can be done to improve their current practices and how best to move towards a compliant assessment programme suitable for a full BMS

An important matter to consider is the move towards semi-probabilistic methods (Level I reliability) and full reliability (Level III) methods in assessment. Another is the implementation of a Universal Assessment programme for the BMS.

7 QUESTIONS FOR CONSIDERATION

A number of issues are raised in the Guidelines that the Technical Authority needs to consider in deciding the framework they intend to adopt for assessment and a Bridge Management System. The following are included:

- Is it necessary to provide the assessed capacities for all bridges (Universal Assessment)?
- Is the policy to assess bridges using the design standards, or acceptable to use less conservative methods where these are sufficient for safety?
- Is the policy to have a formal, multi-level assessment progression?
- Is the policy to have procedures for allowing departures from standard?
- Is the policy to adopt Level I limit state calculations for the assessment of all bridges optionally up-rated to Level III where appropriate?
- In the use of reliability methods for assessment, is it appropriate to establish a universal reliability index for all bridges, or should it be dependent on structure type, load effect, span etc – obstacle crossed?
- Is the same reliability required for old/existing bridges as for new ones?
- Is it acceptable to allow deteriorated bridges to remain in service using a reduced capacity if that is sufficient for current loading? The alternative is to restore a structure irrespective of the capacity remaining.
- Is there a role for higher levels of assessment in establishing a surplus capacity in bridges to allow for future deterioration as distinct from raising the assessed capacity to the minimum requirement?
- Is there a role for load testing in assessment?
- Should the predicted reduction in capacity from future deterioration be accounted for inside or outside the BMS in the first instance or in the longer term?
- Will a comprehensive BMS with deterioration and predictive optimised prioritisation be available in the short term to the satisfaction of the Technical Authority? Should plans be developed in the assumption that it will?

8 CONCLUSIONS

- The Guidelines are recommended to Technical Authorities for applying or developing bridge assessment methods in their area of jurisdiction, whether or not a comprehensive optimised prioritising bridge management system is in place.
- The primary objective of bridge assessment is to ensure that bridges are operated safely within their carrying capacity. It follows that for effective bridge management this should be accomplished efficiently in terms of the cost of bridgeworks and the maintenance of public utility.
- Suggestions are made for developing assessment standards and Assessment Loading using design standards and loading as the starting points.
- It is proposed that bridges should be assessed using versions of national design codes and loading adapted for assessment. In the longer term, it may be possible to move towards European standards but although this should be possible for loading, structural standards will present problems.
- Level I reliability methods with limit states and partial factors should be used in assessment, or the Technical Authority should move towards this position if it is not currently the case.
- Assessment should be carried out using simple methods initially but with the option to use increasingly refined methods as necessary. The final optional stage of refinement is the direct application of Level III reliability methods.
- The introduction of an assessment programme and revised assessment methods can usefully be staged to take account of the evolution of the methods and an increasing knowledge of the load carrying characteristics of the bridge stock.
- A clear policy is needed for dealing with theoretically Sub-Standard bridges that are still serviceable.
- It is reasonable to assess all bridges that are not known to comply with current standards – starting with those that are likely to have least capacity – and allow this to take precedence in prioritising bridge management. The alternative is to allow the observed condition from inspection to govern but this may reduce reliability against failure.[5] The weight given to these two factors in a bridge management system is a matter for Workpackage 7 to recommend (Report D13).

[5] The counter argument is that methods of assessment at the ULS are too conservative (because structural models are not known well enough) and the relationship between assessed capacity and true ultimate load varies between bridge types. This argument extends to the proposition that it is more effective to maintain the bridges in good condition and act only if structural distress begins.

- A basic bridge management system should include as a minimum a record of the safe capacity of the bridge in the form of a Capacity Index. Arguably, it should also contain several values of the index relating to other near-critical parts of the structure. Where progressive assessment is adopted, the bridge management system should also contain the relevant Assessment Levels.

- Deterioration, current or future can be reflected in values of the Capacity Index derived by the engineer independently of the bridge management system. Later, if a suitable bridge management system is available, it could be accounted for by software within the system.

- For use within a bridge management system, bridge assessment methods should be regulated over the network so that they can be applied uniformly and hence facilitate the processes of prioritisation and optimisation of expenditure on bridge management. It would seem that a high level of detail is required in the system database to compensate for a potential loss of judgement applied at the project level.

- It is a matter for individual Technical Authorities to decide the methodology and procedures to adopt for assessment and its use in the bridge management process. Some of the policy decisions that have to be considered are indicated in the "open questions" section of this report, the most significant being the adoption of Universal Assessment, with or without Assessment Level 0. The Guidelines are written on the assumption that eventually this principle will be widely adopted.

9 REFERENCES

The following list contains the BRIME Deliverables quoted in the Guidelines. Additional references are given in Appendix 1.

Deliverable D1

Kaschner R, Cremona C and D W Cullington (1999). *Review of Current Procedures for Assessing Load Carrying Capacity,* BRIME PL97-2220.

Deliverable D5

Cremona C, Kaschner R, Haardt P, Daly A F and D Cullington (2000). *Development of Models (Load and Strength)*, BRIME PL97-2220.

Deliverable D6

Cremona C, Godart B, Kaschner R, Haardt P and S Fjeldheim (2000). *Experimental Assessment Methods and Use of Reliability Techniques*, BRIME PL97-2220.

Deliverable D8

Blankvoll A, Fluge F, Larsen C K, Markey I, Raharinaivo A, Bevc L, Capuder M and I Peruš (2001). Bridge Management and Condition Monitoring. BRIME PL97-2220.

Deliverable D11

Daly A. F (2000). *Modelling of Deterioration in Bridges*, BRIME PL97-2220.

Deliverable D13

Godart B and P R Vassie (2001). *Bridge Management Systems: Extended review of Existing BMS and Outline Framework for a European System.* BRIME PL97-2220.

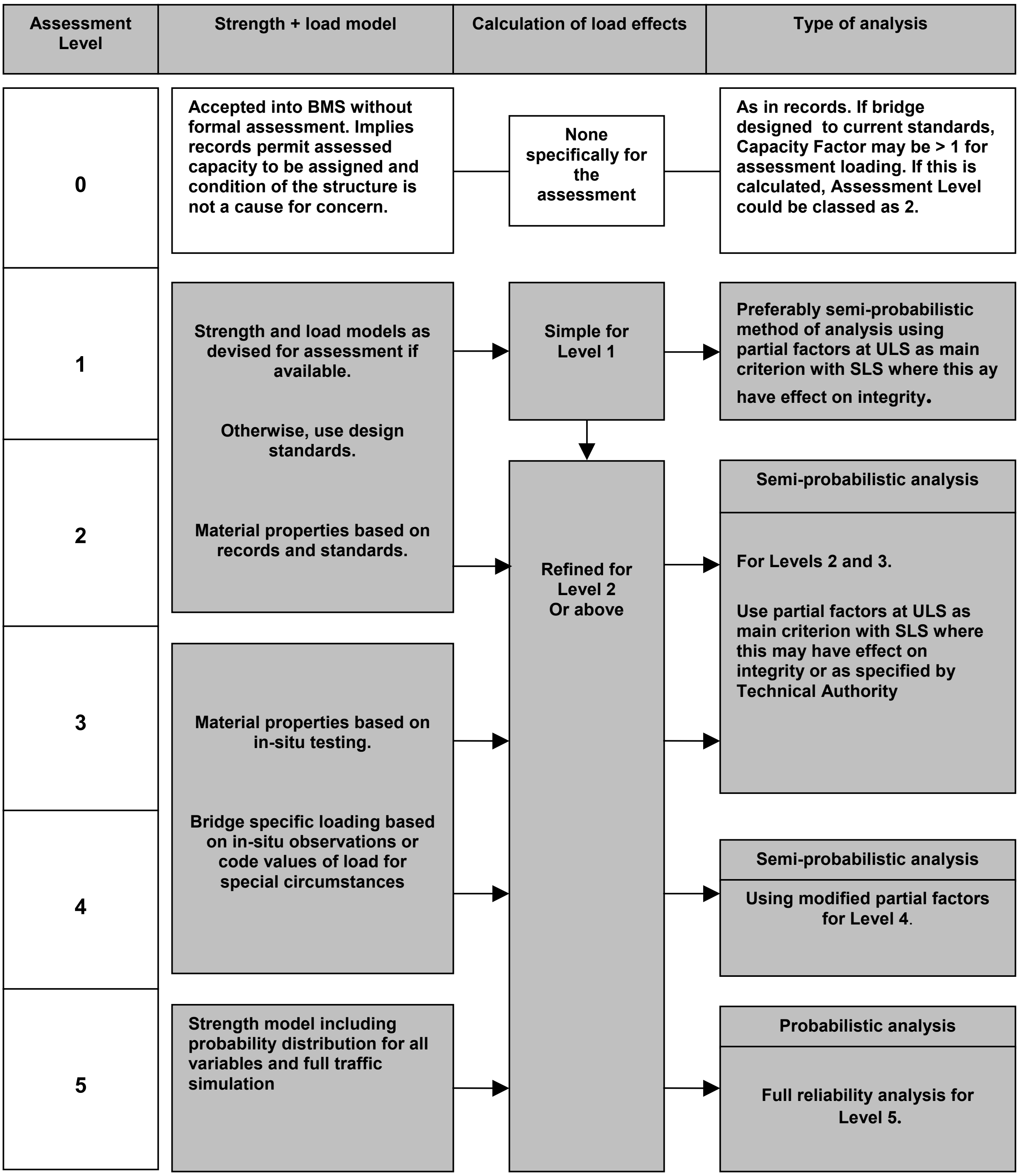

Figure 1: Load models and calculation principles

APPENDIX 1: BACKGROUND

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1 INTRODUCTION

The appendix provides a discussion of the Guidelines section by section and some general background material, some of which is speculative. This has been done to separate the discussion from the Guidelines in order to retain the maximum clarity of the Guidelines without losing the detail contained in the appendix. A common numbering system is used in the Guidelines and appendix for ease of cross-referencing.

Report D1 contains a review of current procedures for assessing the load carrying capacity of bridges primarily within the BRIME partner countries. It contains the reasons given for needing assessments and a description of the basic structural methodologies employed viz. allowable stress and partial factor methods. Direct application of reliability analysis is a recent development also described. References are given to documents used for assessment in the BRIME countries.

Differences between the bridge stocks of the countries include the distribution of ages of bridges and the predominant types. It should be noted that the stocks given in D1 are for the main national networks.

Reports D5 and D6 describe advanced methods that can be used in assessment and the development of assessment procedures.

Report D5 describes models for strength and traffic loading and the fundamental theories underlying the processes of establishing the models. For strength modelling, examples are given of material properties and their variation. For load modelling, distribution densities are given for vehicle gross vehicle weight and the derivation of load models. The German, French and UK distributions are shown to be similar.

Report D6 gives details of experimental techniques that can be used to determine the state of a bridge: i.e. the behaviour, material properties and defects present in structures being assessed. It also describes the concepts that underlie structural reliability theory: how this can be employed in assessment and its advantages and disadvantages with respect to the partial factor Limit State and allowable stress methods.

Bridge assessment is needed in all countries because over a period of time changes occur to live loading, structural design and bridge condition all of which affect the perceived ability of bridges to perform adequately in the present environment. Significant changes have occurred over the last 50 years, a period when a great many bridges have been constructed in Europe using a variety of structural and loading standards.

Bridge assessment is an essential part of any comprehensive, bridge management system. Methods of bridge assessment, procedures and states of play vary widely between countries, and it is important to consider how best to address the issues Europe-wide.

It has been reported previously by Workpackage 2 (in Report D1) that there is a wide disparity in assessment procedures and methods currently used in the BRIME countries. Some use design standards with few additional provisions. The Guidelines presented here are based on a review of procedures already in use or under development within the BRIME countries. They draw extensively on the UK experience because bridge assessment has been a major interest there since the 1960's and has developed considerably since 1984 (Chatterjee, 1985). It is recognised, however, that the assessment framework and methodology in the UK relates to the national situation, and it has therefore been necessary to consider the broader implications for other partners. It should be noted that although many bridges have been assessed in the UK, the assessment methods in use and the role of assessment in bridge management is still evolving. It is the nature of the issues that have been addressed rather than the solutions adopted that merit consideration by other countries.

The Guidelines are not intended to be a manual for use by engineers to assess bridges. They are written in the form of policy proposals recommended to the relevant Technical Authorities in the BRIME countries. It is assumed that in most countries there will be a Technical Authority (see Guidelines Section 2, Terminology) ultimately responsible for providing the regulations under which bridges are assessed (and also designed and managed). In implementing the Guidelines, they will be responsible for specifying methods, or providing standards, for all aspects of assessment including loading, calculations for member resistance and subsequent actions.

2 TERMINOLOGY

The terminology given in the Guidelines is not intended for use with other reports in the BRIME series.

The term Universal Assessment is related to an important issue for bridge assessment within a BMS. The description given in the Guidelines refers to a proxy for assessment. This means assigning an assessed capacity without specific assessment calculations. It can be invoked for bridges newly designed, or bridges of a period of construction and/or type that are known to be adequate, or some other category at the discretion of the Technical Authority.

Assessment loading differs from design loading where design loading is considered inappropriately high for assessment. It is presumed that there is more scope to reduce loads for assessment for traffic loads than for other loads. These other loads include, for example, indirect actions such as thermal effects, secondary traffic loads such as arise from braking or impact, wind, earthquake or settlement. The values of these other loads/actions may possibly be revised for assessment if the design values are shown to be too onerous for assessment.

In design, it is necessary to consider the effect of a number of loads (actions) and to do this in various combinations. For assessment, the Technical Authority, with knowledge of its bridge stock and design methods may limit the combinations to be adopted in assessment unless there appear to be reasons to do otherwise on a bridge specific basis. This will reduce the work to achieve Universal Assessment, provided the Technical Authority is content to adopt it in this limited form. In some countries, bridges may mainly be governed by the combination of dead, superimposed and traffic loads.

Determination of the safe Load Carrying Capacity is the main purpose of an assessment unless there is a concern about other loads or actions. When the governing load combination includes little or no associated primary traffic loading, the bridge may be considered Sub Standard for use by traffic irrespective of the provisions of Reduced Live Loading. For example, if the supporting structure is susceptible to impact loads and fails to meet the required standard, action will be needed to remedy the situation. The Technical Authority will need to address its priorities in upgrading its bridge stock to account for deficiencies of this type, when present. It should be noted that the purpose of the Guidelines is related to assessment of the Load Carrying Capacity. Thus, for example, the only loading that has been reviewed is the traffic loading.

It is important to distinguish between Assessment Levels (0 to 5) and Reliability Levels (I to III). The former have been devised to allow the engineer to classify the degree of refinement used for the assessment of a particular bridge. The later (Reliability Levels) are an integral part of reliability theory and are defined discussed and applied in numerous specialist publications on the subject. In an overwhelming number of instances, a Level I or semi-probabilistic approach will be used for bridge assessment (as it is in currently in many limit-state design codes): i.e. in Levels 1 to 4. The partial factors used with the characteristic strengths will either be determined from a reliability analysis or selected to deliver a predetermined result based on past practice or experience. In Assessment Level 4, the basic partial factors may be altered for the specific bridge being assessed. The use of Level III is proposed for Assessment Level 5. Level II can be used to determine discrete values of partial factors for use in Level I codes.

3 OBJECTIVES

3.1 Objectives of assessment

Bridge assessment is the process of determining the capacity of a bridge to fulfil its primary function – to carry the specified highway loading - and the extent of any deficiencies or reserves of strength it possesses. It is generally carried out by calculation using normal, structural analysis techniques, although testing may be used to supplement the available information.

Assessment can be carried out for several combinations of loading. Dead load and superimposed load are present, and most combinations include some traffic loading. In many cases the dead plus superimposed plus traffic loading case is expected to govern (particularly at the Ultimate Limit State). In other cases, another load may enter the critical combination. Provided the bridge has a calculable capacity to carry traffic loading on its superstructure, a Capacity Factor for traffic load can be deduced for the combination, and the lowest value for all such combinations will govern.

When a bridge is Sub-Standard for a particular combination because of a significant fundamental weakness not related to traffic loading, the governing bridge Capacity Factor may not relate to traffic loading. If the weakness is decisive, its importance to the management process will be profound. In this case, it is suggested that the Capacity Factors be recorded for traffic loading and non-traffic loading combinations. If the weakness is corrected or monitored, the carrying capacity of the bridge is readily available. Indeed, it is a necessary part of the management process to determine the carrying capacity if the deficiency is corrected.

An example of this is the capacity of the supports to resist impact loading from vehicles on the carriageway beneath the bridge. If the supports are significantly deficient, the bridge may be closed to traffic while remedial measures are taken. These could be the erection of a barrier between the carriageway and the support(s) in question and their subsequent strengthening if desired.

Presuming that all such deficiencies are catered for in an acceptable way, and the bridge may consequently remain open to traffic, the governing Capacity Factor will generally relate to traffic load. When a bridge is operating to a reduced performance, or at a lower reliability than desired, its importance to the network should be adequately reflected in the prioritisation process – inside or outside a BMS. This applies whether or not the critical Capacity Factor is related to traffic load capacity.

- Structural safety

The primary concern in assessment is to ensure that failure does not occur in a component of the structure or the structure itself: i.e. it is carried out for the Ultimate Limit State. It may nevertheless be necessary to consider the serviceability performance where the structural effects of loading may be a serviceability failure that could lead to a reduction in the ultimate load.

Safety can become open to question for a variety of reasons, some specific to the bridge and some relating to the bridge type, age etc. Examples are deterioration or damage, a change in local or general loading, and changes to design standards with time. In an ageing bridge stock, some bridges are likely to be of obsolescent types that do not comply with present codes and have not recently been assessed.

It is a matter for the Technical Authority to specify the assessment principles to be used in the management of its bridge stock. This may be to move towards the adoption of Universal Assessment for bridge management. If so, a transition is required from an “assess as necessary ” approach, which is common in BRIME countries. Techniques for targeting this process include

- A year by year review of changes to design and loading standards, to establish when the standards in force were less onerous and may have resulted in low carrying capacities.
- A similar review of changes to design and loading standards unrelated to traffic– for example deficiencies in earthquake or impact resistance.
- The assessment of a random sample of bridges representative of the overall stock.
- A review of the effects of deterioration on the bridge stock as part of the random sample of bridges or as a separate exercise based on inspection results.

The results can be used to prioritise bridge types and construction periods and stage the implementation of assessments for the network.

- Minimising disruption and cost

Design standards can afford to be more conservative than assessment standards because the consequences for a new structure are limited to a marginal increase in the strength and cost. In assessment, the result is a bridge being classified as Sub-Standard with substantial associated costs and disruption. Measures for handling this situation include:

- Reducing Assessment Loading
- Relaxing design standards
- Providing a procedure for departing from standards where this is appropriate.
- Providing ways of dealing with Sub-Standard bridges other than immediate traffic restrictions.

This does not imply that there should be a deliberate policy to reduce general levels of safety for assessment below those adopted for new bridges[6]. The exception to this is where design standards are intended to allow for future trends and this is not considered appropriate for assessment (although it would have to be considered at a later date if the predicted trends take place). Otherwise, the aim in assessment is to avoid the over-provision of strength in particular designs, details or specific bridges.

- Maximising usefulness for bridge management

The archive should ideally contain the assessment calculations for future reference. Where this is not possible, a summary should include the standards used, assumptions made, level of assessment refinement, the extent of deterioration and how this was accounted for, and the Capacity Index for all main components and load effects. Key facts can be selected and entered into a database.

- Optimisation for bridge management systems

[6] This is a policy matter. It is possible to adopt lower requirements for bridges with a short intended life. In the USA it is permitted to allow bridges to operate at a higher load rating than is consistent with design safety factors on the understanding that deterioration may occur (AASHTO, 2000).

It is evident that if bridge assessments are carried out variably between bridge types, or between authorities or regions within the country, prioritisation will be affected and bridge management budgets may be spent on the wrong bridges.

3.2 Objectives of assessment within bridge management

- Project Level – single bridge

At the simplest level, bridge assessment produces one of two results, a pass or fail. A bridge passes its assessment when it is shown capable of carrying all combinations of the Assessment Loading without distress[7]. It fails its assessment when this is not the case, and it can then be described as Sub-Standard. In deterministic terms, a Sub-Standard bridge is one that cannot be shown to have sufficient reserves of strength to accommodate pessimistic assumptions about loading, material properties and member resistance. In reliability terms, a Sub-Standard bridge has a probability of failure that exceeds the accepted target value.

The result of the assessment in the case of a Sub-Standard bridge will be a Capacity Factor, or more likely, several Capacity Factors for the important load effects and locations within the structure. An overall permitted Reduced Load may also be required. It will assist the process of determining the Reduced Load if the assessment standard provides values for Reduced Load as a function of Capacity Factors and any other geometrical or structural parameters that affect it.

Single bridges can be managed at the project level. If safety appears to be compromised there is an expectation that remedial action would follow, which may be urgent repair or closure in the short term. Funds are sought to remedy the situation from the available budget. At the project level, either funds are provided or traffic restrictions imposed. If the deficiency is of a minor nature, a delay may be permitted while actions are considered and funding sought.

It is important to note that the absence of visible distress in a bridge does not imply that it is necessarily sufficiently safe (i.e. that its safety meets the criteria established for assessment). This is because the margin between distress and failure, say, cracking and collapse, varies depending on the type of structure, the load effect concerned, ductility and other similar factors. What it shows is that the current actual loading in practice is not producing a serviceability problem. However, the fact that it has not failed in service provides a certain amount of information about its reliability against collapse.

Determining the required level of safety is largely a theoretical process because collapses under live loading without the contribution of undiscovered weaknesses or freak events are virtually non-existent. This is generally accepted as the desired condition – bridges should not be allowed to collapse in service under live loading.

[7] The meaning of distress depends on the method of assessment and type of loading. For instance, for assessment at the Ultimate Limit State, distress means that the component or structure has reached its theoretical, factored ultimate capacity ULS loading.

The tendency is to rely on past experience with structures that do not collapse to judge the required level of safety. This policy is conservative, but limits what can be achieved in future assessments or future safety policy

- Network Level – whole stock

When a bridge is Sub-Standard, it does not necessarily imply that it is unsafe for normal traffic and will collapse if it remains in service. It does imply, however, that if a network contains a large number of Sub-Standard bridges the overall risk of a collapse somewhere is unacceptably high[8]. Some bridges will have a lower assessed capacity or a higher probability of failure than others according to calculation, but if a collapse occurs it will not necessarily be one with the lowest capacity. Reasons include the actual loading that occurs, undiscovered weaknesses, freak events and natural disasters, and the fact that assessments are based on probability concepts.

- Specific objectives for assessment framework

    - The extent of surplus or deficiency has to be recorded (e.g. as Capacity Factors). This will allow prioritisation to be carried out if there is a deficiency, and future management needs to be accounted for if there is a current surplus and a likelihood of deterioration. This also implies that all significant load effects and locations within the structure require Capacity Factors to be recorded so that deterioration can be accounted for wherever it occurs.

    - Costed options are required when a bridge is substandard. The assessment process normally extends into an evaluation of temporary solutions for any deficiencies that the assessment reveals – such as traffic restrictions, propping or closure. Later it may lead to the evaluation of longer-term solutions including rehabilitation and strengthening schemes. This is a process related to assessment, and may use many of the same techniques, but in a sense it is not assessment. It may usefully be considered within the Guidelines, although an evaluation of strengthening techniques is not within the scope of the BRIME project

    - At the basic level, identification of bridges that are currently satisfactory but are likely to become Sub-Standard in the near future may be a matter of judgement using inspection records. A comment to this effect may be entered into the BMS database with an estimated time-scale. Alternatively, it may entail calculation of the rate and effect of deterioration that can be done outside the BMS.

    - Aggregating bridge project-level data will provide a network-level view particularly for the interim period during which implementation of Universal Assessment is in progress.

[8] Although this statement itself contains uncertainty because of the difficulty of calculating it in absolute terms

- An effective bridge-management system requires the bridge assessment process to be managed in a consistent way so that network expenditure on maintenance is optimised. Although the underlying assessment principles remain the same in both cases, there is a need to consider differences in application.

3.3 Objectives of Guidelines

It is important to acknowledge the need for flexibility for individual Technical Authorities to adopt their own methodologies in the light of their own bridge stocks and national priorities, while recognising the trends in other countries.

The assessment of a bridge can change with time if it deteriorates, experiences a change in designated loading, or is repaired or strengthened. These factors have to be accounted for in bridge management: i.e. in planning the expenditure on bridge repairs, strengthening and replacement to maintain and operate the network efficiently. This is the case whether or not a formal, optimised management system is in use.

The reliance placed on assessed capacity (current, and future predictions) in the prioritisation of expenditure on bridge management is an important issue. If safe load carrying capacity can be assessed accurately with a high degree of confidence, the conclusions relating to bridge management are valid: it can be argued that safety should take precedence over condition (Frangopol and Das, 1999). However, if the available assessment methods are perceived to deliver an over-conservative capacity and in addition, this is variable between bridge types, assessed capacity is less reliable as a factor for prioritisation. This observation applies particularly to capacity in the presence of deterioration and predictions for its effect in future, which introduce additional variables into the process.

The use of reliability methods for prioritisation in bridge management systems may address this issue, but in the meantime, it may be a reason why some countries have not embarked on Universal Assessment. The alternative is to assess a bridge when safety becomes an issue and otherwise use bridge condition to prioritise expenditure on management. Where parts of the bridge stock are old, not assessed and in poor condition safety is an issue.

At the project level, universal bridge assessment is not the only option if the Technical Authority is prepared to allow non-assessed bridges to remain in service (see Section 4, “Principles”). At the network level, using an optimised prioritised BMS, it is less logical to have some bridges assessed and some not assessed. This could upset the prioritising process. One suggestion is to accept the assessed capacity as sufficient but with a low associated confidence (see also Level 0 in 5.6).

4 PRINCIPLES

The principles stated in the Guidelines are expanded in Section 5 of the main report.

- Guidelines

The aim is to establish assessment procedures that are progressive, effective, not over-conservative or unnecessarily disruptive in dealing with Sub-Standard bridges.

- Universal Assessment

The key principle proposed is to adopt or move towards adoption of Universal Assessment as part of the BMS. The alternative is to select bridges for assessment for a variety of reasons specific to the bridge in question - reasons generally related to the condition of the bridge or an intended change of use. For the purposes of setting up a bridge management system, there is a strong case for assessing the current capacity of all bridges, although this requires investment by the bridge owner. The assessed capacity is one of a number of inputs that can be considered central to the operation of a comprehensive prioritising bridge management[9] system.

The main reasons for carrying out assessments that can be regarded as policy related are as follows:

- Assessments are initiated on a bridge by bridge basis only when there has been a change such as structural deterioration or loading.
- Assessments are carried out to check the capacity of all bridges or a particular group of bridges, for example older bridges affected by changes in design or loading standards, or bridges on a heavy load route.
- Assessments carried out specifically for the purposes of an optimised, bridge management system.

The first two reasons have current safety as the prime motive. For the third reason, it is the longer-term safety of the network and efficient use of funds that overlay safety considerations.

If the policy of the bridge owner or country is to assess bridges only for the first reason, it follows that other bridges are deemed satisfactory by virtue of their original design and/or satisfactory performance in service.

The extent to which the principle of Universal Assessment is adopted in management systems used in BRIME partner countries will depend on national priorities or preferences, and progress with implementation. It also depends on the age of the bridge stock and the presence or absence of changes to standards that may affect the theoretical carrying capacity.

[9] A basic bridge management system may consist simply of records of bridge details, including assessments, which assist the bridge owner to allocate resources in the immediate future. A prioritising system may use reliability methods to optimise network decisions including long term predictions of deterioration and its effect on assessed capacity.

Currently in BRIME partner countries, bridges are managed without the formal, analytical assessment of all bridges in the national bridge stocks. Furthermore, there are significant differences national practices. One major difference is the practice of assessing bridges that are visually[10] in a sound condition, and are not intended for a change of use or abnormal load but are simply old. In this context, old means of an age where the original design calculations are not available or where methods of design and constructions have changed, and reliance cannot be placed on the assessed capacity. Examples include masonry arch bridges, troughing decks and early steel and cast iron bridges - and any older type of bridge where responsibility for management has changed hands and design/construction records have gone astray (Cullington and Beales, 1995)
.
Fatigue is an example of changes occurring to design and calculation methods. The identification of fatigue-prone structures and details can be used to target inspections and may lead to assessment when carrying capacity can be affected by progressive cracking. Uncertainties present in fatigue calculations are increased when knowledge of the loading history is scant or non-existent.

- Development of assessment standards

Bridge design and construction are not static and have not been static over a period when most of the national road networks have been constructed. During this period:

- Methods of analysis have improved, so that some older designs may be shown to have reserves of strength that will help them carry modern loads.
- Some old bridge types have gone out of favour and modern methods of analysing their behaviour have not been developed
- There have been changes to design codes that may increase or decrease the capacity of a given component, member or structure.
- Some older bridges have details that are no longer permitted because they are considered inadequate or poor practice. Consequently, the assessed capacity will be low.

Reference to a change of design method includes a change from working stress design to Limit State design, which generally uses different partial safety factors for dead and live loads. Calibration may produce partial factors that deliver average designs for new bridges that are equivalent to previous working stress designs. Nevertheless, some existing bridges will change their relative strength compared with the average when assessed at the Limit State.

The need for standards devised specifically for assessment lies in the need to avoid spending money unnecessarily on existing bridges which are performing well and

[10] When a bridge is visually in a sound condition, it does not necessarily preclude the presence of hidden deterioration. A comprehensive inspection regime may reveal deterioration by non-destructive or semi-destructive methods. In those circumstances, an assessment may follow the inspection when the deterioration is judged to be structurally significant.

have adequate safety but would not conform to current design standards. This is discussed in more detail in Section 5.

- Limit state assessment and reliability methods

The use of Limit State and partial factor principles is recommended because this is used in European standards and is generally recognised as more logical than earlier methods. Level III methods may have significant advantages for particular bridges where reliability can be shown adequate based on bridge specific factors.

- Load testing

The use of load testing varies between countries. It is also controversial when used in the context of assessments at the Ultimate Limit State. It is expected to be used in exceptional circumstances because of the cost of testing, uncertainties in the use of results and the fact that number of bridges that are likely to be suitable is low.

- Progressive assessment levels

It is recommended that the assessment process is approached in a systematic progressive way, starting with simple methods and progressing to more complex methods as the need arises. The need will arise when the simple assessment leads to the conclusion that the bridge is Sub-Standard. (or in the case of a fully developed optimising management system, that deterioration expected in the foreseeable future will lead to it becoming substandard).

There are many ways of defining a progressive system. One example is given in 5.6.

- Deterioration

This is dealt with in Workpackages 3 and 4 (Reports D11 and D8) which give an account of methods that can be used to estimate the effect of deterioration on resistance and the future rate of deterioration. If there is deterioration present at the time of the assessment, it is expected that this will be taken into account in calculating the carrying capacity. If the assessor can estimate the rate of loss of capacity in the future, this should be done in a standard way for the bridge in question. This could be the length of time the assessment is expected to remain valid or before the bridge becomes Sub-Standard or drops to a lower Reduced Live Loading level.

As methods of dealing with deterioration and its rate of progression develop, it may be possible to provide the assessor with an “expert system” in the assessment package that provide assistance with this task. For use within a BMS, the accuracy of predictions such as these is central to the process of optimisation.

Data entered into the BMS can initially be current capacity and the expected capacity at dates in the future based on the past and present condition, type of structure and environment. It will depend on whether deterioration is expected to occur in the critical regions for the assessed capacity. Deterioration in the critical regions will have an immediate effect on the Capacity Factor, whereas deterioration elsewhere may not be significant in capacity terms, or may only become significant after a long period if not corrected.

It is expected that a BMS will make provision for predicting the condition of the bridge stock overall by the use of past history and theoretical methods of extrapolation (preferably using reliability concepts). If it is to take over this role for individual bridges, it must take account of the current capacity of all regions that might become critical eventually, and relate to them the expected deterioration rates.

- National assessment standards

It is suggested that Technical Authorities should initially specify their own assessment methods because these can be based on their own design methods and bridge stocks. Any European assessment standard, particularly for those clauses dealing with member resistance, would need to account for a great many variations in design details. The alternative would be for it to cover only very general methods and permit the individual Technical Authorities to specify the detail in their areas of jurisdiction. Neither is very satisfactory. In the short term, bridge assessment would be delayed while agreement was reached. It may be possible to develop European documents for assessment in the longer term as bridge stocks converge in type and design methods. Standards for assessment loading may converge over a shorter period than standards for resistance.

It is recognised that even if the recommendations are accepted, it will take time to implement them. National differences found in practices and procedures in the BRIME partners mean that countries are starting from different positions. Final targets may also be governed by national preferences. Nevertheless, contributors to this Workpackage take the view that harmonisation along these lines is a desirable objective.

5 METHODOLOGY

5.1 Framework

The items it is suggested the framework should cover are expanded in later sub-sections of Section 5, and further discussion here is therefore limited.

The primary objective of a bridge assessment is to establish whether the bridge in question can remain in service without restriction or whether it is substandard in some way and further action is required. This is true regardless of whether a formal, bridge management system is in operation. When a bridge is assessed to be Sub-Standard, procedures are required to address the matter.

One reason for assessment has been given as carried out specifically for the purposes of an optimised, bridge management system. This category can be subdivided into two classes depending on the type of bridge management system being adopted. This could be either

- A fully developed system in which deterioration rates are predicted at the individual bridge level and aggregated to form a prediction of the likely behaviour of the network overall and in given localities. Such a system is likely to include the costs of traffic delays and accidents, and the cost of the assessment process itself. The prioritisation of bridge maintenance will be optimised using reliability techniques.

- A more simple system, perhaps an interim solution, in which more reliance is placed on past recorded behaviour. The principle objective would be to provide rapid access to data on individual bridges so the engineer can make informed judgements about maintenance requirements.

5.2 Primary documentation

The responsible Technical Authority needs to establish a framework for assessment to be used by engineers and managers within its jurisdiction. If the starting point is to use design standards and loading it is unlikely that an assessment orientated framework can be developed in a short time-scale. This will mean that in the interim period, unnecessary (and undesirable) assessment failures will occur if a programme of universal assessment is initiated straight away. However, it is not necessary to wait until the whole set of procedures is fully documented. Provided a framework is agreed, selected assessments can begin and further documentation introduced progressively. An assessment failure can be treated as provisional provided safety is not an immediate concern for the bridge in question. Repetition of an assessment will be limited to updating the previous assessment provided adequate records are archived.

It is widely appreciated that there should be scope for the engineer to be more flexible when assessing a bridge than when designing one. This is because the bridge being assessed may not comply with design standards, or with the current assessment standards, but still be adequate for further unrestricted service for reasons that are specific to the bridge. However, permitting flexibility carries disadvantages for the bridge owner and the assessor. The bridge owner may receive inconsistent assessments, some of which are over-conservative, and others non-conservative. The assessor who uses his judgement to pass a bridge when it does not comply precisely with the standards is liable to be at professional risk if the bridge subsequently suffers from problems.

For this reason, there needs to be a clear policy that the engineer and the bridge owner can follow. It should set the rules and methodology for assessing the bridge in question and formally approve departures from normal standards (assessment or design) where these are necessary and acceptable to all parties. This does not absolve the parties from blame if there is a difficulty, but it regulates the assessment process in a useful way.

5.3 Assessment Loading

- Use of design loading

Unless or until the Technical Authority has introduced assessment live loading, it is expected that design loading will be used for assessment. However, it should be a priority to develop assessment live loading. This is particularly important where national design requirements provide a significant element in the loading for future development in vehicle/axle weights or traffic density: i.e. where current traffic loading is substantially less than the design requirement.

- Development of assessment loading

A previous report [11] describes the use of statistical methods to develop assessment loading from traffic data. This can be used to provide a general loading model for all bridge on the network.

- Bridge Specific loading

Where an individual bridge is of sufficient importance, and the cost of strengthening is high, it may be economic to provide a bridge-specific, assessment live load using statistical methods with traffic flow and weigh-in-motion data collected from the site. Generally, this will apply to long-span structures.

There is also a precedent for providing a form of bridge specific loading for short span bridges based on traffic counting to establish static load levels and road surface roughness for dynamic amplification. The data for this were provided by measurements on typical sites (Cooper, 1997; Highways Agency et al 1997).

- Reduced loading models

If the Technical Authority is prepared to accept bridges with restrictions on particular classes of vehicle or Gross Vehicle Weights, Reduced Loading models are required for each class of restriction. The restrictions are normally applied by signing at the bridge site. Without rigorous enforcement, these limits are likely to be violated, but they remain an accepted method of reducing the likelihood of overloading. One simple signing method specifies only the gross vehicle weight. This requires a load model for each weight of vehicle that provides automatically for all vehicles of lower weight. A more complicated signing method provides maximum vehicle weights separately for all classes of vehicle (typically three generic types). Assessment is carried out for each class of vehicle and the maximum load determined for each case.

It may be possible and preferable on some bridges to avoid vehicle weight restrictions and instead restrict the number of operational lanes by means of physical barriers.

5.4 Assessment standards

For any bridge owner or country that has not adopted standards for bridge assessment, the first step is to use design standards.

Differences in methodology adopted in different countries relate to the procedures for providing a safe and serviceable design. For example, safety factors can be applied to material stresses, to the loading or to both. The designated loading depends on the assumed frequency of occurrence this in turn affects the safety factors. A single structural-adequacy check can be made combining serviceability and ultimate

[11] Deliverable D5

conditions (e.g. working stress), or these can be separated with different factors or formulas applied to load and resistance.

Where the Limit State method is preferred, procedures are required to designate the Limit State to be used in assessment. It is usual to consider the ultimate and serviceability Limit States for design, but there are arguments for limiting assessment to the Ultimate Limit State. This is on the basis that, for many structures, serviceability has already been demonstrated by its period of service since construction. Provided a sub-standard Serviceability Limit State does not lead to progressive damage and finally an ultimate condition, this is not unreasonable. If desired, a serviceability limit state check can be done and any deficiency recorded for attention during subsequent inspections.

Generally, load effects are calculated from an elastic analysis, which results in a lower bound equilibrium solution. Alternatives are non-linear analysis and upper bound solutions. In general, these latter methods require acceptance in principle before being applied in practice.

5.4.1 Derivation from design standards

Understandably, most partner countries use design standards for assessment in the absence of standards specifically aimed at assessment. This puts an onus on the assessor to interpret the design standard and make adjustments where necessary to avoid unintended theoretical deficiencies in capacity. The assessors authority to do that varies between countries – with some having little or no discretion.

It is possible, but almost inconceivable, that any country will strengthen or replace all bridges that do not comply in every respect with the capacity requirements, including detailing, of their current design standards.

The process of developing assessment standards should include consideration of the similarities and differences between design and assessment, such as the following.

Similarities:

- Loading and load combinations are calculated according to the prevailing requirements defined by the Technical Authority responsible.
- Load effects are obtained from the loading by means of structural analysis. The resistance of members and structures is calculated according to codified principles and practices.
- The adequacy of the existing bridge or trial design is assessed by comparing the load effects with the resistances. Safety factors are applied in the calculations, and material properties are selected that relate to the existing structure or design.
- The structure/design is adequate for the designated loading provided the resistances exceed the load effects.
- The extent of the deficiency or surplus capacity can be identified by an assessed Capacity Index (although it is not generally recorded in design, it could prove useful for bridge management in the future).

Differences:

- A trial design can be changed if it proves to be inadequate, unlike an existing structure.
- It is more important in assessment to eradicate over-conservative methods in assessment because of the consequences arising from an assessment failure.
- Structural details and prevailing loading may be known more precisely for a specific existing bridge than for one being designed.
- Structural deterioration or damage needs to be taken into account in assessment unless it is going to be and restored to the as-built condition without delay.

For the second of these differences, it is important to avoid assessing a bridge using design rules with too many prescriptive requirements. It is better to provide methods for assessing the capacity of as many details and situations as possible.

In the case of the third difference, reliance is placed on adjusting the material properties and loading by means of observation on the site/structure in question.

The fourth difference arises because a new structure in the process of being designed does not possess these deficiencies. Methods are required to allow for them in assessment.

For Level III reliability assessments the comparison between resistance and load effects is made indirectly in the sense that the probability of the resistance being less than the load effect is calculated. It is usually expressed as a reliability index. See report D6 for background information.

5.4.2 Load effects

The simple strip-type analysis is applied to uniform slabs and sometimes beam-slab decks where the beam-slab unit governs the width. This provides a quick check on carrying capacity particularly where the loading model consists of uniform distributed lane loads and/or transverse line loads of a lane width or more. Load effects are predominantly in the longitudinal direction.

Where loads or load cases require concentrated loads to be applied to represent wheels, the strip concept is less useful unless transverse effects including lateral distribution are accounted for. The transverse resistance can be low or uncertain in some older types of deck (beam and jack arch or filler beam for example). Assessing the longitudinal capacity of a strip in these circumstances is not wholly sufficient unless supported by test data.

The combination of global and local effects has also given rise to uncertainties, for example in spaced beam and slab decks, when local punching is assumed to govern instead of local flexure. Local and global effects may not be independent.

5.4.3 Resistance calculations

Some likely targets for the relaxation of design rules for assessment are given in the Guidelines[12]. It is helpful to review old design standards to track the changes that have occurred in the country concerned over the years, the effects on details and capacity, and the dates of design and construction that apply in each case.

The review will also provide an opportunity to check the adequacy of older standards so that the validity of outmoded details and structure types can be appraised. It may be necessary to investigate the primary data sources that led to the adoption of the standards and provisions in question. It is appreciated, however, that records may not be good enough for this to be done in every case. In some instances, structural testing in the laboratory may be necessary to produce adequate methods for assessment calculation. These may be bridge specific (Denton et al, 2000) or generic (Cullington and Hill, 2000).

Fatigue failure is an example of the adequacy of old standards being questionable. Fatigue prone details can affect global as well as local failure when, say, a weld failure can propagate to the point that it affects the connection between main members.

5.4.4 In situ materials properties

The assessment process requires material properties, including the density, elastic modulus and strength. Of these, the most significant is the strength, principally for steel and concrete but occasionally for other materials such as masonry.

If there are no records available, an initial assessment can be carried out using minimum values typical of the period of construction. This is a matter for the Technical Authority to decide, and devise appropriate values.

For newer bridges, material strengths will sometimes be available from records, for example for concrete, steel sections, steel reinforcement and pre-stressing tendons. The data may be in the form of minimum strength values or specified characteristic values given on drawings or contract documents. As built drawings are preferred to contract drawings. The Technical Authority should define their policy regarding the use of these data, but with their approval, the initial assessment may be carried out using these values. Actual strengths are more likely to be higher than lower provided the construction contract was carried out competently. Steel strengths may have exceeded the minimum requirement, and for concrete, not only may the strength at the time of construction be higher, further gains can be expected to have arisen from a long period of curing in service

If the construction records are sufficiently well detailed, concrete cube strengths or mill certificates may be available, giving rise to higher strength values. These values

[12] For practice in the UK, further information is provided by Chakrabarti (1999) and in the bibliography given on UK documents in report D1.

may provide useful additional capacity without the need to carry out testing on the structure.

Finally, provision should be made in assessment documents for obtaining material strengths from samples removed from the structure. The method of obtaining the in-situ strength from test results will depend on the requirements in the assessment rules. For example, if the characteristic strength is required, this should be the basis for obtaining the strength from the samples. Sufficient samples should be obtained to deliver a strength value with an equivalent statistical basis as was assumed in the original assessment rules. One technique is to use updating methodology (see Report D5) to improve the characteristic strength starting from an initial assumption of strength based on construction records and using available test results from specimens taken from the structure.

It may be possible to obtain a single value representing the whole structure, or perhaps the whole deck assuming it is uniform. If there are variations, it may not be possible to obtain samples for critical regions for fear of creating a weakness. Secondary tests that cause minimum damage may supplement destructive tests such as coring. Obtaining samples of steel reinforcement is particularly damaging to the structure, because sufficient must be obtained to give a reliable result.

If a reliability analysis is to be carried out (Level III) a frequency distribution of material properties is required. An updating procedure can use any new information to improve the assessment but if the new information is very limited, the outcome will not be improved significantly. This is a specialist matter requiring expert application.

5.4.5 Load testing

Partners should be aware of the divergence of opinion on load testing between countries and within countries. Referring to the four possibilities given in the Guidelines:

- Performance under working loads. Some Technical Authorities may recognise the increase in confidence arising from this type of test, whereas others may discount it as irrelevant.

- Revision of structural model. Some authorities question the concept of using data collected from a structure under low loads to indicate a sufficient capacity at higher loads. The argument is that restraints not normally accounted for in calculations may be present at low loads but reduce or disappear at higher loads. The intention should always be to determine the restraints and make allowance for their reduction or elimination from previous full-scale tests to collapse. This information is rarely available in sufficient detail if at all. However, it should be noted that extrapolation to a specific predicted failure load is not required: only to a safe lower bound.

- Proof testing. This is practised in some countries but regarded with caution elsewhere. There is a risk of collapse and long-term damage. To give a significant increase in capacity, it is probably necessary to continue loading into the non-linear or cracking region. There are other objections in addition to these. It may be worth considering for bridges that would otherwise be demolished.

- For monitoring. This is less controversial provided the authority recognises the practice of monitoring in service as an interim or long-term measure to allow Sub-Standard bridges to remain in service. The test can explain the means by which a bridge is carrying day-to-day loads and indicate where monitoring should be focussed.

A discussion of the underlying principles of a type of proof testing is given in Report D6 and a brief review of types of testing is given in a UK document (Highways Agency et al, 1994). The type of testing described by Denton et al (2000) is a form of bridge-specific load test carried out in the laboratory.

5.5 Deterioration

For further information, refer to output D11 from Work Package 3.

5.5.1 Reduction in capacity

Accounting for a reduction in capacity in the presence of deterioration is difficult, and experimental evidence suggests that the performance of deteriorated members is very variable. Some authorities may prefer to use reliability methods in this situation. This is the province of specialists. Others may prefer to reinstate any structure that has deteriorated to an extent that may affect load carrying capacity. This will depend on the state of the bridge stock in question, and the available funds.

The broad conclusion is that the change in resistance cannot generally be accounted for by use of the normal resistance formulae in which changes are made to the material strengths, although there are occasions when this is reasonable. This requires further study.

Deterioration models that predict the onset of corrosion, for example, have no direct bearing on the assessment process. They relate to the management system and its predictive aspects. Deterioration models that indicate loss of resistance as a function of measurable changes in condition, such as loss of section, distortions, cracking, delamination are useful for an assessment of the current capacity. Only when the condition or resistance is obtained as a function of time will the predictive aspect of the management system be effective.

The extent to which this is a practical objective in the foreseeable future are discussed in the output from Workpackage 3 (Report D11). It is sometimes argued that any deterioration is serious because it indicates that problems have initiated. Furthermore, it is argued that is not possible to make effective comparisons between two structures – one that is barely adequate but not deteriorating and one that has current reserves of strength but is deteriorating. Although it may be difficult, the accomplishment of this comparison is an integral part of the prioritisation process in a fully developed BMS.

A concrete deck that is properly waterproofed and maintained may not deteriorate except at joints: the main problem may lie with the supporting structure that is susceptible to chloride ingress. Where corrosion is affecting the reinforcing steel, the deterioration model is unlikely to be linear with respect to time. It is more likely to be a bilinear function with a level section during which capacity is unaffected and then a rapid decline to a lower level when bond fails. The issue is one of timing the sudden fall in capacity (see output D11). The output from another European funded project deals specifically with the deterioration and loss of strength resulting from reinforcement corrosion (British Cement Association et al, 2001).

The proposal to record Capacity Factors for all significant load effects and locations can be quite onerous. It is suggested so that in a fully operational, prioritising BMS, deterioration can be applied in all relevant locations. A less onerous alternative is to record only those Capacity Factors where there is a strong likelihood of deterioration in the future: or even where deterioration has already started. A more straightforward alternative is to apply engineering judgement to estimate and record the length of time the current assessment is expected to be valid (i.e. not compromised by deterioration) and use this in the prioritisation process.

5.5.2 Inspection for assessment

The BMS requires inspection data to prioritise maintenance. This will be recorded as a Condition Index that is likely to be obtained from a combination of inspection factors. It is expected that the Condition Index will clearly identify those parts of the structure for which there is an expected loss of strength because of the current condition. However, it is unlikely to be able to do this in a definitive way because this requires structural calculations that would be outside the scope of the inspection. Furthermore, the elements reported to be in a poor condition may not be critical in an assessment.

Therefore, for the purposes of assessment, there may be a need for supplementary inspection data to indicate the condition more specifically if loss of carrying capacity is a likely outcome. This is different from the information relating to loss of serviceability. It implies a need to co-ordinate the assessment and inspection processes.

Difficulties arise when an inspection of the visible parts of the bridge is insufficient to determine the condition of hidden parts. It is necessary for the Technical Authority to cover this in its standards for inspection and assessment, and if possible propose details, structural types and locations that may be affected and methods of obtaining the information required. Examples are the deterioration of the tendons in post-tensioned bridges and the corrosion of the webs in shear regions of some older types of girder bridge. A global or local Condition Index is not suitable for these applications.

5.6 Assessment levels

5.6.1 Overview

There is a natural logic in approaching a bridge assessment first at a simple level and progressing to more refined methods when a higher carrying capacity is required. Specifying such a procedure gives it authority within the assessment process and helps to establish uniformity in approach across the bridge stock.

The levels described in the Guidelines are mainly for illustrative purposes and should not be regarded as rigid. Technical Authorities may prefer to specify a different progression of levels that suit their national circumstances better.

There are several advantages in defining a set of levels as discussed in the Guidelines and Appendix 1 in Sections 5.6.6 - primarily that it facilitates communications and recording of data in the BMS.

5.6.2 Level 0

The need for Level 0 will vary with policy on the Universal Assessment of bridges and the progress towards implementation of a fully optimising bridge management system

The primary intention is to apply it to bridges for which the carrying capacity has been checked in a manner other than a formal individual assessment. For example, it could apply to bridges that are deemed satisfactory because a study has been made of similar bridges and found their capacity to be comfortably within the required standards. Depending on national/owner preferences, it could also be applied to bridges for which documentation is incomplete but they are performing well. Preferably, records should be available to indicate that they were designed and constructed to standards that are expected to produce an acceptable capacity.

It could be applied to new bridges that have just been designed and constructed to current standards. Alternatively, this condition could be assigned to Level 1 or 2 as described in the next section.

It is not the intention to assign all bridges that have not been assessed into Level 0. Unless there is some evidence for believing that the assessed capacity is satisfactory, bridges without assessments should be recorded as such – i.e. “not assessed”.

5.6.3 Levels 1 and 2

Level 1

In the case of a Level 1 assessment, only simple methods of analysis are necessary. This can include analysis by strip or simple load-distribution methods. Full safety factors as defined in the assessment standards have to be applied.

Design or as-built drawings and other records are used to determine details and properties, subject to a check on site that the records are consistent with the structure as found. The Technical Authority should specify what is prepared to accept in general terms and they or the highway authority what to accept for a specific bridge. If, for example, the capacity in shear is critical and dependent on the reinforcement being exactly as drawn, an internal investigation may be required. This is likely to lead the assessment into a higher level.

In effect, these methods give a quick check on the capacity that will generally be conservative. If the structure complies with the loading requirements, no more needs to be done, unless the intention is to demonstrate a greater margin of safety (Capacity Factor). This might be the objective when deterioration is likely, or the bridge capacity to carry abnormal loading is of interest. During the transition stage towards Universal Assessment, it will probably be a low priority to investigate additional capacity using a higher assessment level once the required capacity has been demonstrated.

Level 2

In the case of a Level 2 assessment, analysis and structural idealisation will be more refined. This could include grillage analysis or finite element analysis where it is considered these may lead to higher capacities. Non-linear methods and upper bound solutions such as yield line analysis may be used where there are approved procedures for applying them.

A Level 2 assessment may entail the use of construction records to determine the strength of materials in specific critical parts of the structure, where such records exist. This is instead of accepting the characteristic or minimum strength figures recorded in the design documents.

General comment

The single factor most likely to improve the capacities for Levels 1 and 2 assessments is the provision of assessment standards and loading. If these are not available to the owner, design standards can be used as a fallback option. However, it must be recognised that for some owners this will lead to bridges being unnecessarily classified as Sub-Standard because design standards are too conservative.

There is an argument for classifying bridges that have only the current design calculations (i.e. no assessment calculations have been done) as Level 1 or 2 because refined methods were used in the design. It should be noted however, that if the assessment loading is lower than the design loading an adjustment to the Capacity Factor would be appropriate.

5.6.4 Levels 3 and 4

Level 3

Material properties, primarily strength, may be obtained from samples collected from the bridge being assessed. The aim is to obtain enough test results to allow higher strength values to be used with the standard partial factors for material strength as used in Levels 1 and 2. Concrete compressive strength can be obtained from cores cut from the structure. There is a possibility of obtaining values in critical areas of the structure by reducing the number of cores to an acceptable number but increasing the sample by means of less destructive testing. Schmidt hammer, pulse velocity or below-surface pull-off tests all have their advocates and their detractors, particularly where older structures are concerned. Calibration on the bridge using the core strengths where available and testing on the adjacent concrete will provide guidance on their use.

Bridge live loading may be reduced from the standard assessment loading following determination of the traffic conditions found on the bridge. This bridge specific loading is likely to depend on traffic flows and road surface condition. It will be lower than the standard assessment loading when the traffic flow is lower and the surface condition better (less dynamic amplification) than the in standard case. The revised loading could be devised so that it has the same probability of being exceeded as in the standard case, and be used with the standard safety factors for load (subject to a reliability check).

If Universal Assessment is being implemented, assessments up to Level 3 are likely to predominate.

If the Technical Authority permits load testing, then this is an appropriate level to consider it (see 5.4.5)

Level 4

Level 4 allows revised (reduced) values of safety factors to be used. It is grouped with Level 3 assessment because it employs the same methodology with the exception of adjustment to the partial safety factors. The suggestion is for the responsible Technical Authority to authorise a framework of permitted variations to the default values of safety factors for specified circumstances. It is expected that reliability analysis will be carried out on typical bridges to allow these proposed reductions to be made while maintaining the level of reliability.

Factors that have been suggested (Shetty and Chubb, 1999) that may allow reduction of partial factors include:

- Bridge specific information
  - Dimensional survey
  - Strength of materials from samples taken from bridge

- Modifications to live load criteria
  - Transverse members
  - Age of bridge

- Modifications to achieve consistent risk
  - Consequences of failure
  - Warning of failure

The aim is to provide a more consistent level of safety across the bridge stock without the complexity of a Level 5 assessment. At the time of writing, the methodology is under development for the UK situation. A version of the methodology is contained in USA documents (e.g AASHTO, 1989, 2000).

5.6.5 Level 5

The application of reliability methods and models for load and material properties are discussed in outputs D5 and D6.

At the present time the use of this methodology is restricted to specialists. For general application, the Technical Authority has a number of issues for address to ensure consistency over the network, in particular the approach to be used for selecting reliability index. This can range between fixing a single value for all bridges and imposing a variable index according to bridge type, load effect, failure mode etc, based on typical values deduced from bridges currently accepted as satisfactory.

5.6.6 Reasons for levels of assessment

It is not the intention to prescribe inflexible Assessment Levels. Methods of increasing complexity can be introduced in stages as agreed between the assessor and owner or Technical Authority on a bridge specific basis. Not all provisions of a given level need be adopted. Nevertheless, it is helpful to use the levels descriptively as an indication of the degree of refinement adopted.

5.7 Management of Sub-Standard bridges

When a bridge is assessed as Sub-Standard, appropriate action must be taken to ensure public safety is not compromised. The engineer responsible for the assessment can make a recommendation, but the Technical Authority (or highway authority if different) is likely to be ultimately responsible for public safety and therefore has to be party to the final decision. This process and the highway network can be managed more effectively if guidance is given by the Technical Authority.

There is a consensus of opinion that the measures taken should be appropriate to the level of risk and that a Sub-Standard bridge should not automatically be taken out of service immediately.

The issue of the management of Sub-Standard bridges is likely to be most significant in the period during which Universal Assessment is introduced.

Guidance from the Technical Authority could include:

Classification of bridges according to the degree to which they are sub-standard and the level of risk posed by the type of structure, the location and usage.

Actions to take in the short intermediate and long term according to the above classification.

The status, acceptability and technical requirements for monitoring bridges in service with a permitted loading that theoretically exceeds the assessed capacity.

The technical and procedural requirements necessary to register and approve the proposed measures.

Methods for prioritising the strengthening of Sub-Standard bridges.

In the longer term, when a BMS is used for the prioritisation of bridgeworks within the network, separate prioritisation provisions are unlikely to be needed. Before this is available and when Universal Assessment is being phased in, it may be needed if resources (funds and engineering capacity) to carry out all the work are not available in the short term. Factors to consider include:

The relative risks including the effectiveness of interim measures
Traffic delay costs
Social, environmental and economic consequences of the interim measures
Suitability of alternative routes
Cost effectiveness and incidental benefits of the proposed scheme.

A document giving advice for the management of Sub-Standard bridges is available in the UK (Highways Agency et al, 1998) and a discussion of its use is given by Cole (2000).

5.8 Recording assessment results.

Many of the suggested items in the Guidelines are self-explanatory.

The motive for recording the Capacity Index for other than the most critical member is to account for future deterioration. This is also a motive for recording the Assessment Level, as higher levels should give a higher capacity and therefore a greater margin for deterioration. (Whether or not this is a fact should be the subject of a study.) A bridge assessed at Level 1, which is progressing towards a Sub-Standard status, may be less critical than it appears.

5.9 Re-assessment

If it is intended to adopt Universal Assessment, the initial period will cover the assessment of each bridge to an appropriate level. Later, as bridges begin to deteriorate or loading changes, consideration will have to be given to raising the assessment level if it is economic to do so.

If Universal Assessment is not the adopted policy, it is expected that bridges will continue to be assessed as the need arises from load changes or inspection results.

The operation of a BMS that prioritises bridgeworks according to Capacity Index requires this value (or values) to be updated periodically (effectively as a continuous process).

6 IMPLEMENTATION

It remains to be seen how far the BRIME countries, and others in Europe, will adopt the methodology for assessment and bridge management described in the BRIME outputs.

7 QUESTIONS FOR CONSIDERATION

Most of the questions raised are directly related to proposals contained in the Guidelines. It is possible to take decisions on virtually all the questions without reference to the other questions in the list (i.e. they are independent of each other).

8 CONCLUSIONS

These conclusions have been reached by Workpackage 2 participants on the basis that they contain reasonable proposals for recommending to the BRIME partners. There is, however, an understanding of the significance of the changes implied for national practices in some cases, which is why selective or progressive implementation is envisaged. The adoption or otherwise of the principle of Universal Assessment affects the need for a comprehensive set of documents for bridge assessment and related matters such as the management of Sub-Standard bridges. If bridges are only to be assessed as the need arises, there is arguably a less pressing case for developing the documents because bridges can be dealt with on an individual basis. The assessed capacity will have a less significant role in the allocation of maintenance funds in an associated bridge management system.

9 REFERENCES

A list of the BRIME reports referred to in the Guidelines and Appendix 1 is given in the Guidelines. Other references are given in this appendix. A list of relevant UK documents on bridge assessment and related topics is given in Report D1.

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