VOLUME 3 HIGHWAY STRUCTURES: INSPECTION AND MAINTENANCE

SECTION 4 ASSESSMENT

PART 18

BD 79/06

THE MANAGEMENT OF SUB-STANDARD HIGHWAY STRUCTURES

SUMMARY

This Standard sets out the procedures for managing structures that have been found to be sub-standard following assessment and it supersedes and replaces BA 79/98 (DMRB 3.4.18).

INSTRUCTIONS FOR USE

1. Remove existing contents pages for Volume 3
2. Remove BA 79/98 from Volume 3, Section 4, Part 18, which is superseded by BD 79/06, and archive as appropriate.
3. Insert new contents pages for Volume 4 dated August 2006.
4. Insert BD 79/06 into Volume 3, Section 4, Part 18.
5. Please archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.

THE HIGHWAYS AGENCY

TRANSPORT SCOTLAND

WELSH ASSEMBLY GOVERNMENT
LLYWODRAETH CYNULLIAD CYMRU

THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

The Management of Sub-standard Highway Structures

Summary: This Standard sets out the procedures for managing structures that have been found to be sub-standard following assessment and it supersedes and replaces BA 79/98 (DMRB 3.4.18).

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

VOLUME 3 HIGHWAY STRUCTURES: INSPECTION AND MAINTENANCE

SECTION 4 ASSESSMENT

PART 18

BD 79/06

THE MANAGEMENT OF SUB-STANDARD HIGHWAY STRUCTURES

Contents

1. INTRODUCTION

General

1.1 The purpose of this Standard is to provide the requirements for the management of highway structures that have been assessed to be sub-standard according to the requirements of BD 21 (DMRB 3.4.3). Since assessments are typically based on theoretical calculations, such structures do not necessarily pose an immediate and unacceptable risk to safety. This Standard provides guidance on appropriate interim measures that may be used to manage the risks associated with Sub-standard and Provisionally Sub-standard Structures.

1.2 This Standard replaces the Advice Note BA 79/98 "The Management of Sub-standard Highway Structures". The guidance in BA 79/98 has been extended and combined with the interim measures that were previously in BD 21 (DMRB 3.4.3), forming the basis of this Standard.

1.3 This Standard is primarily intended for use by the Overseeing Organisations, although it is recommended that it should also be used by other highway (or roads) authorities and structure owners. Its application to a particular structure should be confirmed with the relevant Technical Approval Authority (TAA).

1.4 This Standard has been prepared through a Technical Project Board, which included representatives from the following organisations:

Highways Agency
Transport Scotland
Welsh Assembly Government
Northern Ireland Roads Service
County Surveyors' Society
Network Rail
London Underground
British Waterways
Transport for London
Maintaining Agents
Local Authorities

Scope

1.5 This Standard covers the safe management of Sub-standard Structures (see definition in Clause 1.8), including highway bridges, retaining walls and other highway structures. In particular the Standard provides requirements and guidance on the use of interim measures during or following the assessment process.

In addition, where agreed with the TAA, the principles of the Standard may also be useful and relevant for the management of:

(i) structures with sub-standard elements that are not directly affected by carriageway or verge loading, including sub-standard parapets;

(ii) Sub-standard Structures that do not carry a highway;

(iii) structures that have been assessed using Standards other than BD 21 (DMRB 3.4.3) (e.g. BD 86 (DMRB 3.4.19), BD 37 (DMRB 1.3.14)) and found to have insufficient capacity.

Implementation

1.6 This Standard must be used forthwith for highway structures that are in the process of being assessed or those that have been assessed to be sub-standard. Notwithstanding any other requirements for Sub-standard Structures set out in the DMRB the requirements of this Standard must take precedence.

Mandatory Requirements

1.7 Sections of this Standard that are mandatory requirements of the Overseeing Organisations are contained within boxes. The remainder of the document contains advice and enlargement, which is recommended for consideration.

Definitions

1.8 The following definitions apply in this Standard:

Immediate Risk Structures: Structures that are considered to represent an immediate and unacceptable risk to the public. Guidance on identifying Immediate Risk Structures is included in Chapter 4.

Load Mitigation Interim Measures: Interim measures that reduce the **effects** of the loading on the structure to an acceptable level, either by reducing the magnitude of the loading or by altering the response of the structure. These include weight restrictions, lane restrictions, propping, use of a temporary structure and closure.

Low Risk Provisionally Sub-standard Structures: Provisionally Sub-standard Structures that are considered to be low risk and therefore not requiring any interim measures while the assessment is in progress. Guidance on identifying Low Risk Provisionally Sub-standard Structures is included in Chapter 4.

Monitoring: For the purposes of this Standard, monitoring is defined as the *periodic* or *continuous observation* and *recording* of *information* pertaining to structural behaviour, in order to detect *deterioration* or distress should it occur, to determine the extent, severity and rate of deterioration, and to determine whether a critical limit state or other criteria are at risk of being reached, where:

Periodic refers to observations carried out at discrete times with intervals between them measured, in general, in weeks or months;

Continuous refers to an observation that continues without break in which a continuous record is made or maxima and minima are recorded, or to one that takes place at sufficiently small intervals to be considered continuous;

Observations are most commonly obtained by visual inspection but they may also include measurement made using transducers, strain gauges, probes or other instruments;

Recording refers to writing down or mapping information from visual observations, measurements or test data, photography, or the automatic storage of information on charts, printers, magnetic media or other similar;

Information may be qualitative, such as the presence of staining or other defects, or quantitative, such as the dimensions, locations and patterns of cracks, profile of span, strain or deflection, or readings obtained from non-destructive testing methods;

Deterioration refers to a decline in condition, integrity or performance arising from any cause (including an aggressive environment, loading, and impact), for example, corrosion-induced spalling, load-induced cracking or changes evidenced by strain/displacement measurement.

Monitoring-appropriate Structures: Structures that are considered to be appropriate for monitoring as an interim measure. Guidance on identifying Monitoring-appropriate Structures is included in Clauses 5.7-5.10.

Monitoring Interim Measures: Interim measures in the form of monitoring alone or monitoring with other measures.

Overseeing Organisation: The highway authority responsible for motorways and other trunk roads or designated roads in England, Scotland, Wales, or Northern Ireland.

Provisionally Sub-standard Structures: If a structure is assessed to have sub-standard load capacity at any stage during the assessment process and it is considered appropriate to progress the assessment further, it is to be considered as a Provisionally Sub-standard Structure.

Risk: An evaluation of the likelihood and consequences of a hazard (including consideration of the likelihood that the hazard may be prevented in response to the detection of early warning signs).

Sub-standard Structures: Structures found to be sub-standard in terms of meeting the carriageway and verge loading requirements given in BD 21 (DMRB 3.4.3), and retaining walls that have been found to be sub-standard according to the principles in BD 21 (DMRB 3.4.3), after carrying out as rigorous an assessment as considered appropriate by the TAA, or, in Northern Ireland, by the Overseeing Organisation. For some retaining walls and some forms of sub-structure, assessments may be based upon engineering judgement without the use of calculations.

2. ASSESSMENT

General

2.1 Assessment of an existing structure should be carried out in stages of increasing complexity, with the object of efficiently determining its adequacy. Early stages may contain conservative means of determining load effects. Provided that a structure is shown to be adequate at these stages, then no further analysis would be required. However, if a structure is found to be inadequate at an early stage then assessment work should continue, and later stages should seek to remove any conservatism in the assessment calculations.

Levels of Assessment

2.2 The progression of the assessment process may be described by levels of assessment as described in Clauses 2.4 to 2.12. However, intermediate levels of assessments may be omitted in agreement with the TAA, and it may also be appropriate to undertake some Level 3 Assessment techniques prior to fully exhausting all Level 2 Assessment methods. For example, it can often be cost-effective to undertake material testing to determine worst credible properties before undertaking refined analysis.

2.3 Each additional level of assessment may involve considerable time and cost. The TAA should consider these implications, together with the Structure Owner (if applicable), and approve the progress of the assessment through the various levels (however, in Northern Ireland, only Category 3 Structures are generally subject to Technical Approval; for the purposes of Chapter 2, approval of the progress of assessments through the various levels should generally be carried out in Northern Ireland by the Overseeing Organisation). All such deliberations and the conclusions should be carefully recorded (see Clause 3.11).

Level 1 Assessment

2.4 Level 1 is the simplest level of assessment, giving a conservative estimate of load capacity. At this stage, only simple analysis methods are necessary. The material properties and characteristic strengths should generally be as specified in BD 21 (DMRB 3.4.3), although where as-built construction information regarding material properties and strengths is available this may be used, provided that it is documented in the Approval in Principle (AIP) as appropriate.

Level 2 Assessment

2.5 Level 2 Assessment involves the use of more refined analysis and better structural idealisation. More refined analysis may include grillage or finite element analyses whenever it is considered that these may result in higher assessed capacities. Non-linear and plastic methods of analysis may also be used, for example, yield-line analysis or orthotropic grillage analysis (see Clause 4.4.3 of BD 44 (DMRB 3.4.14)).

2.6 Level 2 also includes the determination of characteristic strengths for materials based on existing available data. This may be in the form of existing mill test certificates or recent tests on another similar structure (for example, see Clause H.4.1 of BD 56/96 Annex A (DMRB 3.4.8)). If new tests are to be carried out on the structure being assessed then this should be considered as a Level 3 Assessment.

Level 3 Assessment

2.7 Level 1 and Level 2 Assessments make use of Assessment Live loadings from BD 21 (DMRB 3.4.3) for short span bridges and from BD 50 (DMRB 3.4.2) for long span bridges but without the use of Bridge Specific Assessment Live Loading (BSALL). Level 3 Assessment includes the option to use BSALL.

2.8 For short span bridges (loaded length less than 50m), it is generally not considered cost effective to develop BSALL. BD 21 (DMRB 3.4.3) already takes account of varying traffic flows and surface irregularities. However, there may be particular situations, for example, when heavy vehicles cannot reach the structure because of width restrictions or tight bends, where it may be appropriate to accept a lower assessment loading for short span bridges on minor roads, when agreed with the TAA.

2.9 For long span bridges, where the 40 Tonne assessment fails by a small margin, the use of BSALL may be beneficial. Reference should be made to BD 50 (DMRB 3.4.2).

2.10 Level 3 Assessment may make use of both material testing to determine characteristic strength or yield stress, and also Worst Credible Strength or Worst Credible Yield Stress. Reference should be made to BD 44 (DMRB 3.4.14) and BA 44 (DMRB 3.4.15) for the Worst Credible Strength and to Appendix H of BD 56 for Worst Credible Yield Stress procedures.

Reliability-based Methods of Assessment

2.11 Following assessments at Level 1 to 3, reliability-based methods of assessment may be used with the agreement of the TAA. Such methods require specialist knowledge and expertise and are only likely to be worthwhile and possible in exceptional cases. Verification by an independent organisation should generally be carried out.

2.12 Some guidance on reliability-based methods of assessment is included in Appendix B.

Technical Approval and Certificates

2.13 Requirements for Technical Approval relating to assessment of structures are given in BD 2 (DMRB 1.1). It is essential that there is dialogue between the Assessment Team and the TAA when the scope and complexities of assessment develop, particularly where this requires increasing input of subjective judgement.

2.14 The adoption of Departures from Standards may be useful (when appropriately justified) for the assessment of particular structures. Applications for Departures from Standards should be made in accordance with BD 2 (DMRB 1.1).

2.15 Amendments to an AIP shall be required for each subsequent level of assessment proposed and must be included as an addendum to the original AIP.

3. MANAGEMENT PROCESSES

Key Processes

3.1 Sub-standard and Provisionally Sub-standard Structures must be managed by assessing the risks to public safety associated with their continued use and imposing appropriate interim measures when necessary.

3.2 Load Mitigation Interim Measures must be urgently imposed on Immediate Risk Structures in accordance with Clause 4.1.

3.3 Appendix A contains a flowchart summarising key processes for the management of Provisionally Sub-standard Structures and Sub-standard Structures and a table summarising documentation of management processes.

Use of Interim Measures During Assessment

3.4 If, at any stage during an assessment or whilst monitoring, a structure is found to be a Provisionally Sub-standard Structure, the use of interim measures must be considered and recorded.

3.5 Load Mitigation Interim Measures should be imposed on any Provisionally Sub-standard Structure unless any of the following criteria apply:

(i) it can be shown to be a Low Risk Provisionally Sub-standard Structure (see Clauses 4.5 and 4.6), in which case it may not be necessary to impose any interim measures, provided that such a decision is agreed with the TAA and the Structure Owner; or

(ii) it is not an Immediate Risk Structure, and it is considered probable that further assessment could raise the assessed capacity to an acceptable level, and it is possible to proceed with this assessment without delay. In this case it may not be necessary to impose any interim measures, provided that such a decision is agreed with the TAA and the Structure Owner; or

(iii) it can be shown to be a Monitoring Appropriate Structure (see Chapter 5). In this case the interim measures should be either Monitoring Interim Measures or Load Mitigation Interim Measures.

Use of Interim Measures on Completion of Assessment

3.6 If on completion of the assessment process a structure is found to be a Sub-standard Structure, interim measures must be used pending strengthening or replacement of the structure.

3.7 Prior to strengthening or replacement, all Sub-standard Structures should be considered as representing a risk to the public until appropriate interim measures such as those recommended below have been applied. The purpose of these interim measures is to reduce the risks to levels that are acceptable until strengthening or replacement of the structure is carried out.

3.8 Load Mitigation Interim Measures must be imposed on any Sub-standard Structure, unless the imposition of Load Mitigation Interim Measures is likely to cause excessive disruption to traffic or incur disproportionate costs, and it can be shown to be a Monitoring Appropriate Structure (see Chapter 5), in which case either Monitoring Interim Measures or Load Mitigation Interim Measures must be imposed.

3.9 Where an appreciable delay is likely between the completion of an assessment and the implementation of the selected Load Mitigation Interim Measure, consideration must be given to the management of the risk in the intervening period, for example by the use of monitoring on a short-term basis (if appropriate).

3.10 Sub-standard Structures should be prioritised for strengthening or replacement. Some guidance on this process is given in Chapter 6.

Document Management

3.11 For each Provisionally Sub-standard and Sub-standard Structure, an auditable record must be maintained to enable the management of the structure to be clearly documented. This record must include details of the decisions taken at each stage of the assessment process, and evidence of the approval and implementation of any interim measures. It should also contain documentation of the regular review of the management of the structure.

3.12 The record should include the following:

(i) Documentation of the progress of the assessment and the history of the management of the structure. The Sub-standard Structure Summary form given in Appendix D may be used to summarise the progress of the assessment process and any interim measures that have been proposed or implemented.

(ii) Risk assessments.

(iii) Assessment of the feasibility, cost and appropriateness of options for Interim Measures. The forms in Appendices E and F may be used to record the feasibility of options for interim measures and to identify Immediate Risk Structures, Low Risk Provisionally Sub-standard Structures, and Monitoring-Appropriate Structures.

(iv) Record of the decision not to carry out interim measures, if appropriate, including a record of the agreement of the TAA and the Structure Owner.

(v) Proposals for interim measures. The form in Appendix G may be used to propose recommendations for interim measures. The proposal should include an assessment of the feasibility of different interim measures (see Appendices E and F) and details of proposed actions, including the Monitoring Specification (see Appendix H), if appropriate.

(vi) Approval of interim measures. Documentation of the approval from all required authorities to proceed with the recommended interim measures or details of alternative actions should be provided, for example by including a copy of the form in Appendix G signed by all relevant responsible parties.

(vii) Record of implementation of interim measures, if appropriate.

(viii) Monitoring records/reports, for structures that are being monitored.

(ix) Records of the regular review of interim measures, including the regular review of the management of Provisionally Sub-standard Structures for which no interim measures are in place.

(x) Record of removal of interim measures, if appropriate.

(xi) Record of strengthening or replacement, if appropriate.

Roles and Responsibilities

3.13 The process for proposing and approving Load Mitigation and Monitoring Interim Measures must involve the following parties:

(i) Principal: A senior representative of the Assessment Team having authority to sign on its behalf. Responsible for proposals for interim measures made by the Assessing Organisation.

(ii) Technical Approval Authority: Responsible for appraising the proposed interim measures.

(iii) Highway (or Roads) Authority: Needed to give agreement for Load Mitigation and Monitoring Interim Measures where these will affect the traffic on the highway or roads network.

(iv) Structure Owner: Responsible for approving interim measures and instructing implementation of the interim measures. The signatory for the Structure Owner must be suitably authorised to make decisions regarding the allocation of funding and management of risks.

(v) Other relevant parties: Required to approve, endorse or instruct interim measures as necessary, for example, where the responsibility for the implementation and the cost of interim measures is shared between parties.

4. IMMEDIATE RISK STRUCTURES AND LOW RISK PROVISIONALLY SUB-STANDARD STRUCTURES

Immediate Risk Structures

4.1 The Assessment Team must inform the TAA without delay if, during the course of or following the conclusion of the assessment of a structure, an immediate and unacceptable risk to public safety is identified. Once confirmed and agreed with the TAA, appropriate Load Mitigation Interim Measures (or, for elements that do not support a carriageway, appropriate interim measures as described in Clauses 5.16-5.17) must be implemented as a matter of urgency on any Immediate Risk Structure. A temporary emergency closure must be considered where there is likely to be a delay in implementing the Load Mitigation Interim Measures and the risk of keeping the structure open in the interim period is considered to be unacceptable.

4.2 The identification of Immediate Risk Structures requires some judgement and will be dependent upon specific circumstances. In assessing immediate risk to public safety, relevant factors such as the consequence of failure, nature of the structural weakness, any corresponding signs of distress, the possibility of hidden distress, condition data, the sensitivity of the structure to the applied loading, the recent load history of the structure and the level of assessment completed should be taken into account. The past performance of the structure under unrestricted loading can often provide valuable evidence in assessing whether an immediate risk is posed.

4.3 Any of the following may be taken to be indicative of an Immediate Risk Structure:

(i) Any structure that is unable to sustain nominal loading (i.e. the loading according to BD 21 (DMRB 3.4.3) but without any partial load factors applied) according to any plastic upper bound method of assessment (such as a yield-line mechanism analysis).

(ii) Any structure that, when the capacity is calculated across the full width of the structure and compared with the load effects assuming that the loads are fully distributed across the full width of the structure, has a corresponding live load capacity factor C (as defined in BD 21 (DMRB 3.4.3)) that is less than $K/1.5$, where K is the required Load Reduction Factor appropriate to the traffic on the structure, as defined in BD 21 (DMRB 3.4.3).

(iii) Any structure with significant signs of distress associated with either a non-ductile failure mode or the formation of a failure mechanism.

4.4 Other structures that may need to be considered as Immediate Risk Structures include structures with:

(i) primary carriageway elements that have been assessed to have zero live load capacity;

(ii) carriageway elements for which the assessed capacity would be insufficient for the required assessment live loading even when all partial safety factors (including all γ_{fL}, γ_m, and γ_{f3}) are set to unity.

Low Risk Provisionally Sub-standard Structures

4.5 Certain Provisionally Sub-standard Structures may be assessed to be of sufficiently low risk that it is not considered necessary to impose any interim measures during the assessment process. This decision should be based on an assessment of the risks associated with the continued use of the structure without imposing any interim measures. The proposal to manage the structure without imposing interim measures, including any supporting information and the arrangements for the regular review of the management of the structure, should be recorded, together with the agreement of the TAA and the Structure Owner (as described in Clauses 3.11-3.12).

4.6 Either of the following may be taken to be indicative of Low Risk Provisionally Sub-standard Structures:

(i) Structures whose only provisionally substandard elements are non-carriageway elements that are only predicted to fail under accidental loading. However, in some cases the erection of a partially effective barrier protecting the non-carriageway part may be a necessary interim measure before the structure could be considered as low risk.

(ii) Structures in sound condition for which all of the following conditions apply:

(a) the failure is likely to be gradual over time progressing from local signs of distress, e.g. cracking or local failure at a connection, to more extensive failure before reaching the point where total collapse is precipitated;

(b) the consequences of failure are low; and

(c) the live load capacity factor C (as defined in BD 21 (DMRB 3.4.3)) is greater than $K/1.5$, where K is the required Load Reduction Factor appropriate to the traffic on the structure as defined in BD 21 (DMRB 3.4.3).

5. INTERIM MEASURES

Load Mitigation Interim Measures

5.1 The purpose of Load Mitigation Interim Measures is to reduce the carriageway loads, or the effects of the loads, so that they are safely within the capacity of the structure.

5.2 Load Mitigation Interim Measures must comprise one or more of the following actions:

(i) Vehicle weight restrictions, calculated in accordance with BD 21 (DMRB 3.4.3).

(ii) Lane restrictions, calculated in accordance with BD 21 (DMRB 3.4.3).

(iii) Propping of the structure.

(iv) Use of a temporary structure.

(v) Closure of the structure.

5.3 It is possible that further deterioration of the structure might occur, even with Load Mitigation Interim Measures in place. In such a situation, the appropriateness of the interim measures must be reviewed and, where the deterioration could affect the adequacy of the Load Mitigation Interim Measures, Monitoring Interim Measures must be used in combination with Load Mitigation Interim Measures.

5.4 Where an existing weight restriction has been in place for some time, and where periodic reviews confirm that the restriction is effective and of benefit, the Structure Owner may consider continuation of the measure as a long-term arrangement, with the agreement of the Highway (or Roads) Authority.

Monitoring Interim Measures

5.5 Monitoring Interim Measures must only be carried out on Monitoring-appropriate Structures.

5.6 Monitoring Interim Measures must comprise either:

(i) monitoring alone; or

(ii) monitoring with other measures, such as propping or partial restriction of traffic loading.

5.7 Sub-standard structures that satisfy all the criteria given in (i), (ii) and (iii) below, may be considered to be Monitoring-appropriate Structures, subject to TAA approval:

(i) Structures where no sign of significant distress is observed and hidden distress, deterioration or weakness is unlikely to be present, or structures where distress is observed that does not appear to be recent or significant and detrimental to the safety of the structure.

(ii) Structures where failure is likely to be gradual over time progressing from local signs of distress, e.g. cracking or local failure at a connection, to more extensive failure before reaching the point where total collapse is precipitated (in contrast to structures whose mode of failure and collapse under traffic load will be sudden and brittle). Furthermore, it must be possible to predict the mode(s) of failure under traffic load with reasonable certainty.

(iii) Structures and situations for which monitoring will be meaningful and effective (further guidance is given in Appendix C).

5.8 Bridges of small span (generally less than 5 metres) that are in sound condition and where the consequences of failure are low may also be considered to be Monitoring-appropriate Structures, subject to TAA approval.

5.9 Types of Sub-standard Structure that are likely to be Monitoring-appropriate include:

(i) Reinforced concrete slab bridges or composite steel and concrete slab bridges with theoretical longitudinal or transverse flexural inadequacy, especially where adequate continuity exists over the supports.

(ii) Structures in which the structural inadequacy is in an element or connection whose failure would not precipitate sudden collapse and whose failure can be observed by monitoring. The inadequacies may be in flexure, shear or anchorage. The crucial feature is that the structure will retain a substantial proportion of its load carrying capacity following element/connection failure until the failure is detected and safeguarding measures are implemented.

(iii) Structures in which deterioration is gradually progressing and for which monitoring may be used to measure the progression of the deterioration.

5.10 Sub-standard Structures that are not normally Monitoring-appropriate include bridges that are substandard by virtue of tension, shear, anchorage or buckling inadequacies where failure in tension, shear, anchorage or buckling would precipitate collapse of the structure.

5.11 Managing Sub-standard Structures through monitoring, with or without other measures, is a complex process and requires in depth knowledge of the techniques and the potential problems. This must be undertaken rigorously and appropriate professional engineering expertise and advice must be used throughout.

5.12 Guidance on monitoring is provided in Appendix C.

5.13 If Monitoring Interim Measures are used, the monitoring regime must be documented in a Monitoring Specification. The Monitoring Specification must include:

(i) a summary of the assessment findings and other background information relating to the appropriateness of the proposed monitoring;

(ii) a detailed plan of the monitoring regime, including the definition of all parameters to be monitored, directly related to the predicted mode(s) of failure, and the degree of accuracy required;

(iii) the frequency of the monitoring;

(iv) definition of trigger levels;

(v) details of any actions to be taken if trigger levels are exceeded;

(vi) requirements for the recording and reporting of monitoring activities;

(vii) a plan for the review of the monitoring regime.

5.14 The format in Appendix H may be used for the Monitoring Specification.

5.15 Monitoring by itself does not prevent damage from occurring. The longer monitoring is continued, the greater is the probability of damage, particularly for bridges on heavily trafficked routes. A planned maximum duration for the monitoring, not exceeding three years, must be specified in the Monitoring Specification, during which the structure should be strengthened or replaced, or Load Mitigation Interim Measures imposed, or, at the end of which, the continued application of monitoring must be formally reviewed.

Interim Measures for Non-carriageway Parts of Structures

5.16 Some of the methods of Load Mitigation Interim Measures as described in Clause 5.2 may be appropriate interim measures for non-carriageway parts of structures, e.g. propping of bridge cantilevers. However, it may be more suitable to install a ‘partially’ effective barrier such as a safety fence subject to defined vehicle loading checks, which may be considered as a long-term solution (refer to Annex J of BD 21 (DMRB 3.4.3)). This applies to both deck cantilevers as well as non-carriageway parts of beam and slab decks.

5.17 Other forms of barrier which act as a partially effective barrier and which reduce the level of risk to one acceptable to the TAA may be deemed to be an appropriate interim measure.

6. PRIORITISATION FOR STRENGTHENING

6.1 The strengthening or replacement of all Sub-standard Structures is likely to take a number of years. The work will therefore need to be prioritised, whilst ensuring the safety of the structures by maintaining appropriate interim measures. Value Management techniques may be useful for the prioritisation of strengthening works (reference may be made to Section 5.11 of "Management of Highway Structures – a Code of Practice").

6.2 Prioritisation of strengthening work should take account of:

(i) the relative risks of the structures to public safety, taking account of the effectiveness of the interim measures (which may include monitoring only); reserves of strength; causes, severity, extent and rate of deterioration; etc;

(ii) the specified maximum intended duration for Monitoring Interim Measures (see Clause 5.15);

(iii) the traffic delay costs which are caused by the implementation of interim measures and which will be eliminated when the strengthening is complete;

(iv) other social, environmental and economic consequences caused by interim measures to business and community in addition to those related to the traffic delay costs and which will be eliminated when the strengthening is complete;

(v) the risks and other issues associated with alternative routes (including winter conditions and other route related considerations);

(vi) the cost-effectiveness of the strengthening, taking account of the ratio of costs and benefits;

(vii) other benefits which will result from the work such as improvements to sight lines and parapets, general repairs and preventative maintenance; and

(viii) strategic development of the highway network.

7. REFERENCES

7.1 Design Manual For Roads and Bridges

Volume 1: Section 1: Approval Procedures

BD 2 Technical Approval of Highway Structures (DMRB 1.1)

Volume 1: Section 3: General Design

BD 37 Loads For Highway Bridges (DMRB 1.3.14)

Volume 3: Section 1: Inspection

BD 63 Inspection of Highway Structures (DMRB 3.1.4)

BA 63 Inspection of Highway Structures (DMRB 3.1.5)

BA 86 Advice Notes on the Non-Destructive Testing of Highway Structures (DMRB 3.1.7)

Volume 3: Section 3: Repair

BA 35 Inspection and Repair of Concrete Highway Structures (DMRB 3.3)

BA 43 Strengthening, Repair and Monitoring of Post-tensioned Concrete Bridge Decks (DMRB 3.3.2)

Volume 3: Section 4: Assessment

BA 16 The Assessment of Highway Bridges and Structures (DMRB 3.4.4)

BD 21 The Assessment of Highway Bridges and Structures (DMRB 3.4.3)

BD 34 Technical Requirements for Assessment and Strengthening Programme for Highway Structures: Stage 1 - Older Short Span Bridges and Retaining Structures (DMRB 3.4)

BA 44 The Assessment of Concrete Highway Bridges and Structures (DMRB 3.4.15)

BD 44 The Assessment of Concrete Highway Bridges and Structures (DMRB 3.4.14)

BD 46 Technical Requirements for Assessment and Strengthening Programme for Highway Structures: Stage 2 - Modern Short Span Bridges (DMRB 3.4.1)

BD 50 Technical Requirements for the Assessment and Strengthening Programme for Highway Structures: Stage 3 - Long Span Bridges (DMRB 3.4.2)

BA 54 Load Testing for Bridge Assessment (DMRB 3.4.8)

BD 56 The Assessment of Steel Highway Bridges and Structures (DMRB 3.4.11)

BD 61 The Assessment of Composite Highway Bridges and Structures (DMRB 3.4.16)

BD 86 The Assessment of Highway Bridges and Structures For The Effects of Special Types General Order (STGO) and Special Order (SO) Vehicles (DMRB 3.4.19)

7.2 BSI Publications

BS 1881: Part 201: Guide to the Use of Non-Destructive Methods of Testing Hardened Concrete.

BS 1881: Part 206: Recommendations for the Determination of Strain in Concrete.

7.3 Other Publications

Concrete Society “Non-structural Cracking of Concrete - 1992”.

Appraisal of existing structures, 1996. Institution of Structural Engineers, 11 Upper Belgrave Street, London SW1X 8BH.

Moore J F A (Ed) 1992. Monitoring building structures. Blackie.

Moss, R M and S L Matthews, 1995. In-service structural monitoring, a state-of-the-art review. The Structural Engineer, Vol 73, No.2/17 January 1995.

Monitoring of large structures and assessment of their safety. Colloquium, Bergamo 1987, IABSE report Vol 56.

Management of Bridges (Gestion des ponts), Anglo-French Liaison Report, Highways Agency, TRL, SETRA, LCPC. Thomas Telford, 2005. (http://www.roadscodes.org)

Management of Highway Structures – A Code of Practice, Roads Liaison Group. The Stationery Office, 2005.

Technical Guide 2. Testing and Monitoring the Durability of Concrete Structures. Concrete Bridge Development Group. April 2002.

8. ENQUIRIES

All technical enquiries or comments on this Standard should be sent in writing as appropriate to:

Chief Highway Engineer
The Highways Agency
123 Buckingham Palace Road
London
SW1W 9HA

G CLARKE
Chief Highway Engineer

Chief Road Engineer
Transport Scotland
Victoria Quay
Edinburgh
EH6 6QQ

J HOWISON
Chief Road Engineer

Chief Highway Engineer
Transport Wales
Welsh Assembly Government
Cathays Parks
Cardiff
CF10 3NQ

M J A PARKER
Chief Highway Engineer
Transport Wales

Director of Engineering
The Department for Regional Development
Roads Service
Clarence Court
10-18 Adelaide Street
Belfast BT2 8GB

G W ALLISTER
Director of Engineering

APPENDIX A MANAGEMENT PROCESSES

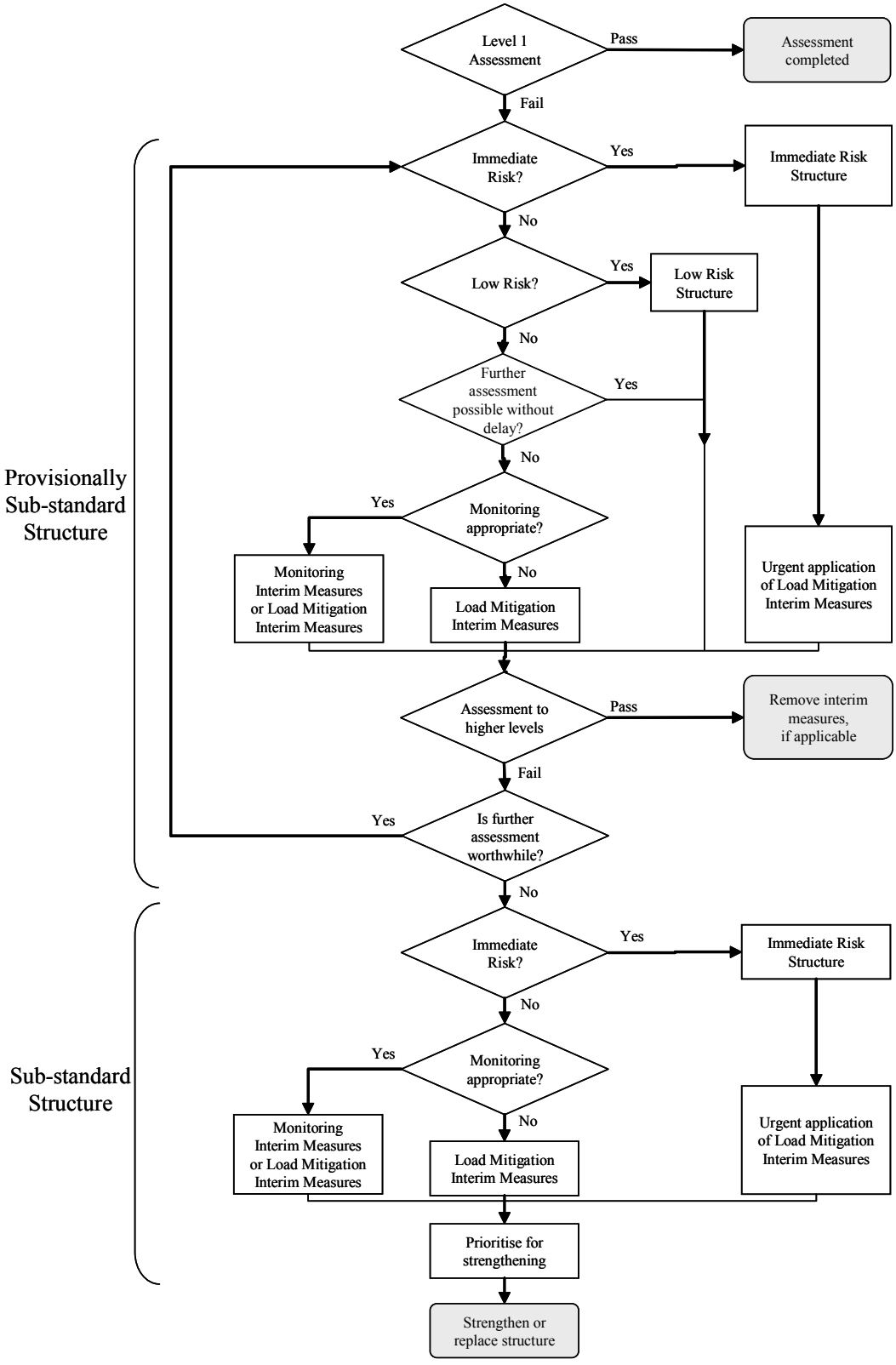

Figure A.1 – Management Processes Flowchart

Process	Recommended Approach for Reporting	Reference
Identification of Immediate Risk Structure	Interim Measures Feasibility Assessment	Bridges: Appendix E to Section 3 Retaining Walls: Appendix F to Section 5
Identification of Low Risk Provisionally Sub-standard Structure	Interim Measures Feasibility Assessment	Bridges: Appendix E to Section 3 Retaining Walls: Appendix F to Section 5
Identification of Monitoring-appropriate Structure	Interim Measures Feasibility Assessment	Bridges: Appendix E to Section 4 Retaining Walls: Appendix F to Section 6
Interim measures for non-Monitoring-appropriate Structures	Interim Measures Feasibility Assessment Interim Measures Proposal Form	Bridges: Appendix E to Section 5 Retaining Walls: Appendix F to Section 7 Appendix G
Interim measures for Monitoring-appropriate Structures	Interim Measures Feasibility Assessment Interim Measures Proposal Form Monitoring Specification	Bridges: Appendix E to Section 6 Retaining Walls: Appendix F to Section 8 Appendix G Appendix H

Table A.1: Documentation of Management Processes

APPENDIX B RELIABILITY-BASED METHODS OF ASSESSMENT

B.1 Codes and Standards for Bridge Assessment employ partial safety factors to ensure an appropriate level of safety for bridges. These factors guard against extreme variations in design parameters (e.g. material properties, extreme loads, etc.) that could occur during service. In order to ensure that the design rules are simple for routine use, the format and values of the partial factors are chosen to cater for a wide range of structure/component types and failure modes. As a result, the theoretical probability of failure of structures is not equal in all cases.

B.2 Level 1 to 3 Assessments, as described in Chapter 2, are based on code-implicit levels of safety, incorporated in the nominal values of loads and resistance parameters and the corresponding partial safety factors. These assessment techniques are sometimes referred to as deterministic methods. As an extension to these levels of assessment, reliability-based methods may be used, with the agreement of the TAA .

B.3 Reliability-based methods are concerned with assessing directly whether the probability of failure of a structure is acceptably low. Reliability based methods may, therefore, be of benefit in cases where, for a specific structure or element of a structure, the code-specified partial factors lead to a particularly conservative probability of failure, compared with that required of similar structures or elements.

B.4 Reliability-based assessments require specialist knowledge and expertise and are only likely to be worthwhile and possible in exceptional cases. If reliability based assessments are proposed, the TAA shall be consulted in respect of the methods and criteria to be used. Particular care is required because the results are very sensitive to the statistical parameters and the methods of structural analysis used. In establishing the criteria to be used in an assessment, it may be appropriate to take the consequences of failure into account.

B.5 The procedures for reliability and deterministic analyses are illustrated in Figures B.1 and B.2. In a reliability analysis, the input parameters are described using probability density functions (pdfs) and the output is a probabilistic assessment of the likelihood that the structure will satisfy a certain limit state. In contrast, a deterministic analysis uses a set of discrete inputs based upon characteristic or nominal values of loading, material or geometric properties together with their associated partial factors. The output from a deterministic analysis identifies the margin by which a limit state is satisfied (or failed).

B.6 The methods used for analysing the effects of loads and evaluating resistances, to establish whether a limit state is reached, are essentially the same in both deterministic and reliability-based methods. For example, in one method for undertaking a reliability analysis, called the Monte-Carlo method, many separate analyses are undertaken sampling input parameters from each input distribution in proportion to their likelihood. For each sampled set of inputs an analysis is undertaken in much the same manner as a deterministic analysis, with the output probability distribution constructed from the results of these many separate analyses. Because of the added numerical complexity of reliability-based methods, in some cases in a reliability analysis it can be impractical to use some of the more sophisticated analysis methods suitable for deterministic assessments.

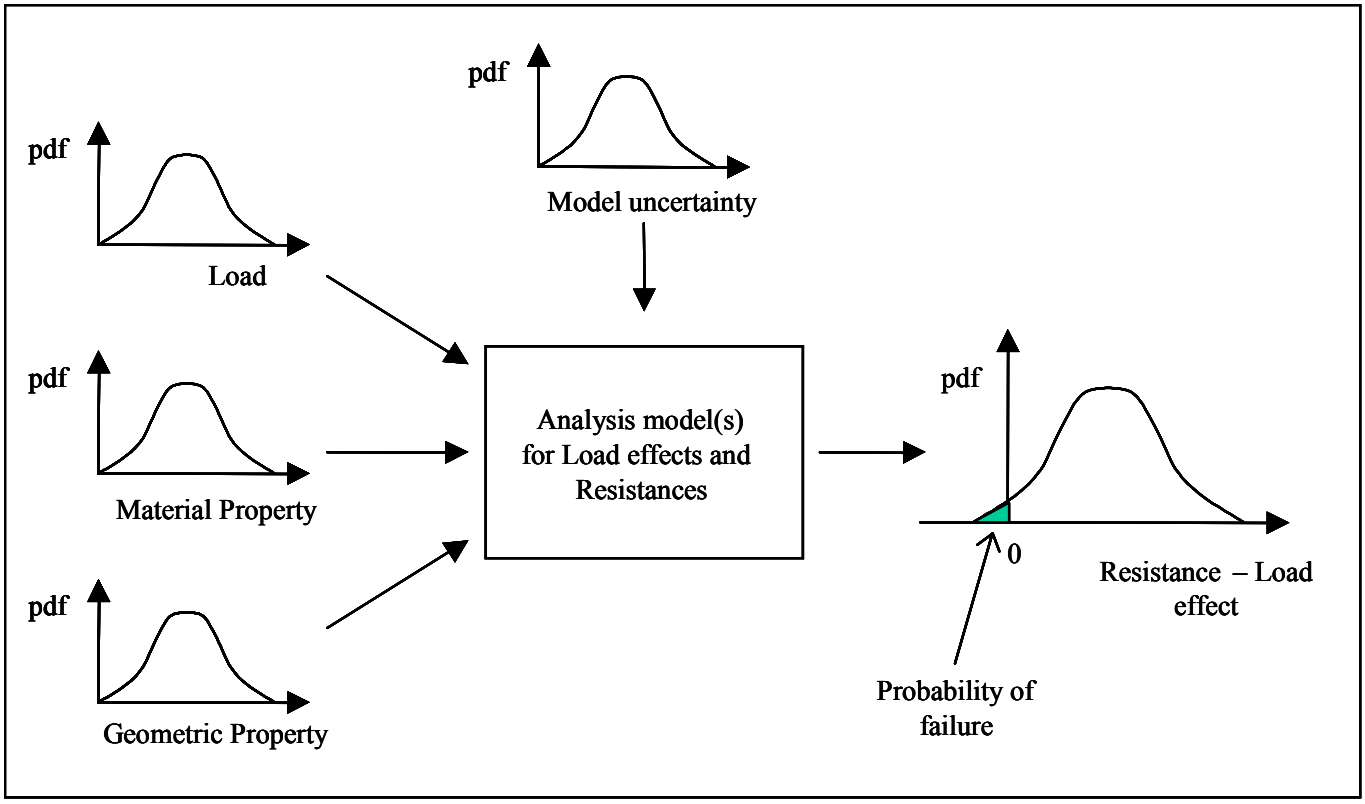

Figure B.1: Illustration of Reliability Analysis Procedure

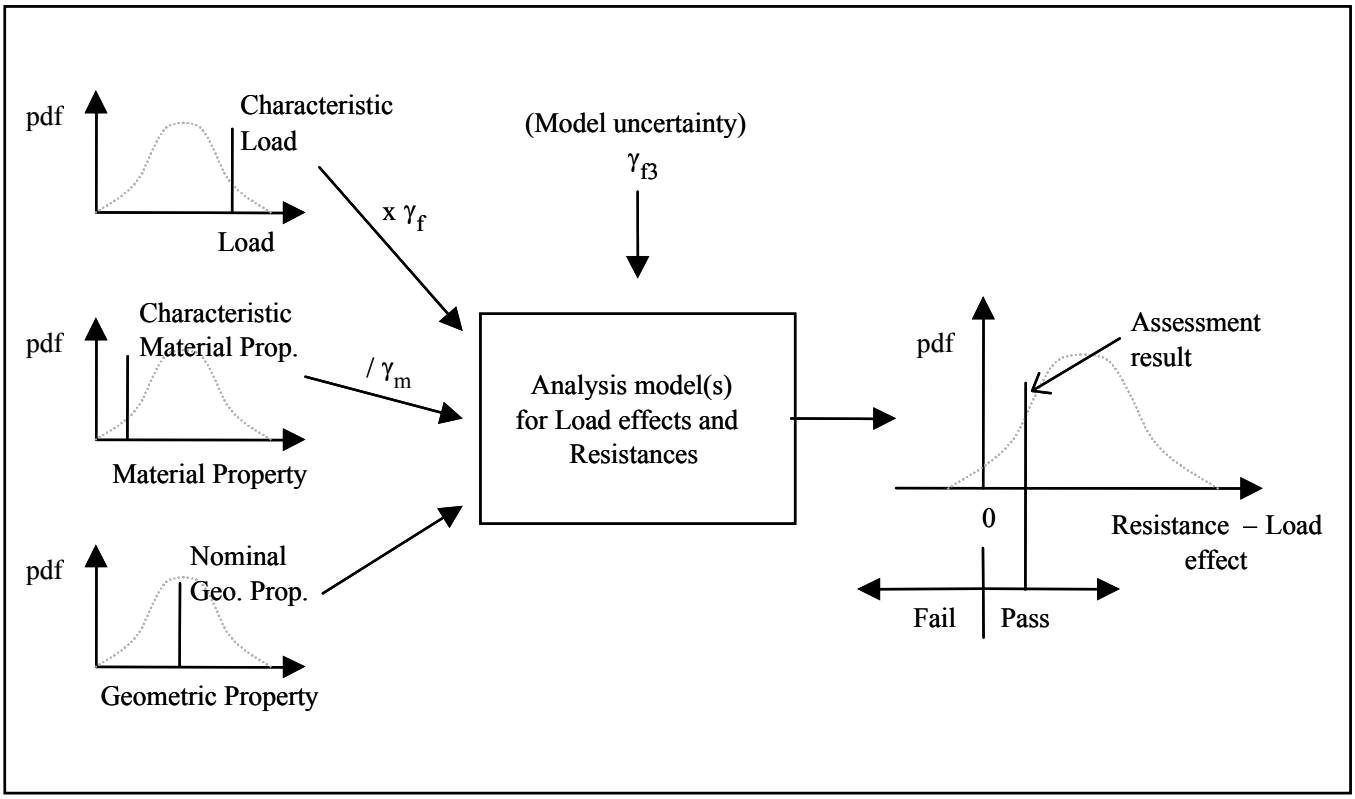

Figure B.2: Illustration of Deterministic Analysis Procedure

APPENDIX C MONITORING OF SUB-STANDARD STRUCTURES

C1. General

C1.1 This Appendix gives advice on the application of monitoring. It describes different classes of monitoring for structures found to be Monitoring-appropriate in the assessment process and provides guidance on their use.

C1.2 The class of monitoring should be selected to suit the circumstances of the particular structure and its assessed inadequacy in order to provide the level of additional assurance required. At the lowest level monitoring may be limited to visual inspection and recording information.

C1.3 All highway structures are, as a minimum, subjected to basic visual inspections (General Inspections) and more detailed inspections (Principal Inspections) generally at intervals described in BD 63 (DMRB 3.1.5) (but see also "Management of Highway Structures – A Code of Practice" Clauses 6.4.28 and 6.4.29).

C1.4 Once in operation, any unexpected or potentially critical change in the condition of the structure or its loading revealed by the monitoring should be examined urgently and reported to the Structure Owner to determine the next course of action.

C1.5 The extent of monitoring will depend on the type of structure, its condition, current circumstances, Load Mitigation Interim Measures proposed and the assessed structural inadequacies. The monitoring should be continued until the structure has been strengthened or replaced, or Load Mitigation Interim Measures have been implemented. In some cases it may be appropriate to monitor in conjunction with Load Mitigation Interim Measures.

C1.6 Where weight restrictions on a bridge have been implemented, consideration should be given to the likely extent of compliance, level of policing and need for systematic monitoring.

C1.7 Types of inadequacy that may be inherent in a Sub-standard Structure include the following:

(i) The assessment calculations indicate that the load carrying capacity is inadequate because the original design loading was lower than that now required, and/or other principles and criteria used in the original design were less onerous than those now adopted for assessment.

(ii) There was an error in design or construction that has resulted in a specific potential weakness, without which the carrying capacity would be adequate.

(iii) There has been deterioration or damage since construction sufficient to reduce the assessed capacity, without which the structure would have been adequate. Deterioration may be continuing, thereby reducing the capacity still further.

(iv) Ad hoc/rule of thumb construction was used. The structure was not formally designed for any traffic loading.

C1.8 Two or more of these types of inadequacy may be present in combination. For structures falling within the scope of C1.7 (ii) or (iii), the primary objective will normally be to monitor the deficient part of the structure or the development of deterioration. For structures falling within the scope of C1.7 (i), the assessment calculations provide the basis for identifying the critical areas for monitoring.

C1.9 Any of the inadequacies described in C1.7 may be present in a structure without visible signs of structural distress. Cracking with associated corrosion may be present where it is hidden from visual inspection, e.g. in the webs of contiguously placed beams, under the surfacing in hogging regions, at half joints or hinges. Such possibilities together with information on other forms of deterioration should be taken into account when planning a monitoring scheme.

C1.10 It is important to consider the reasons for the absence of predicted live load distress for all sub-standard structures particularly for those within the scope of C1.7 (i). The possibilities of deterioration in performance should also be considered and how this can be identified by monitoring. In some circumstances evidence of deterioration may be found in an area other than the one assessed as inadequate. For example, an inadequacy in mid-span flexure, relieved in practice by moment restraint at supports, may first be indicated by the onset of movement at the supports rather than distress at mid-span.

C1.11 An essential starting point in considering whether to implement a monitoring regime for a structure is the criteria for Monitoring-appropriate Structures given in Chapter 5. Other key issues to be considered are its specific purpose, what events, distress or deterioration may possibly occur, the ability to observe them and the consequences should they not be detected, the accuracy and relevance of the observations and the costs and disruption incurred in obtaining data.

C1.12 The presence of structural distress is an important criteria requiring careful consideration. Where distress in a structure appears to be recent, significant or to have resulted from live load effects, monitoring in service may not be appropriate without other measures being implemented. Other types of distress, particularly distress of a minor nature, are unlikely to invalidate monitoring provided their significance and effects can be accounted for.

C1.13 Potential modes of collapse, in particular, progression from local failure and ductility, will be strongly influenced by the structural form, especially the extent of redundancy and the presence of alternative load paths. When relying on alternative load paths as part of the justification for the implementation of a monitoring regime, there should be no weak links in the redundant path.

C1.14 When attempting to foresee possible modes of failure it should be borne in mind that the C factor (see BD 21 DMRB 3.4.3) for each inadequacy may not give a definitive indication of the collapse mode, or the load effect that will first show signs of distress. Alternatives should be reviewed to ensure that a sudden mode of failure has not been overlooked.

C1.15 When the above considerations lead to doubt about the effectiveness of a monitoring regime, monitoring should not normally be relied upon alone without the implementation of Load Mitigation Interim Measures. Where another interim measure is in place, a monitoring regime may be devised to provide assurance that the measure is functioning as required. Thus, for example, if temporary propping is installed, monitoring inspections may be used to check continued integrity of the temporary props and to check for signs of movement, distress or degradation.

C2. Classes of Monitoring

C2.1 A principal objective of all classes of monitoring is the detection of deterioration in structural behaviour or condition, should it occur; it may also be used to confirm structural behaviour under live load. The monitoring regime for a structure should be defined in detail in each specific case. A Monitoring Specification is required as described in Clause 5.13 and Appendix H. The three monitoring classes described below serve as a starting point for more detailed specification. Class 1 is the lowest class of monitoring and Class 3 the highest. Class 2 includes all the Class 1 provisions and Class 3 all the Class 1 and 2 provisions. For all classes of monitoring, if deterioration occurs, the cause, severity and extent should be identified.

Class 1 - Basic Monitoring

C2.2 Class 1 monitoring consists of visual observations and recording. The use of photography is essential. Measurements are not normally undertaken, but the condition of the critical parts of the structure should be noted and compared with previous records. Inspection at touching distance is normally required, although for some structures the use of binoculars may be appropriate, with the agreement of the TAA. Simple operations, such as hammer tapping to check for delamination or loose members, may be included. Recording of traffic flows and composition may also be required.

C2.3 Observations for Class 1 monitoring should be at intervals of weeks or months and should therefore be more frequent than for a structure that meets the requirements of BD 21 (DMRB 3.4.3).

Class 2 - Detailed Monitoring

C2.4 Class 2 monitoring includes the visual observations and photographic provisions of Class 1, supplemented as appropriate by one or more of the following:

(i) Recording of quantitative information which may include: the extent and nature of deterioration, e.g. the locations and dimensions of areas affected, the length, width, depths and spacing of cracks; a level survey repeated periodically; non-destructive testing. Reference may be made to BA 86 (DMRB 3.1.7) and “Technical Guide 2: Guide to testing and monitoring the durability of concrete structures”.

(ii) Measurement of changes in parameters such as displacement or strain at typical or critical positions in cases including those where visual inspection alone is not sufficient to confirm that there is no change in the structural action,

structure condition, or response to traffic loading. Parameters to be monitored may include measurements to detect changes in permanent or transient effects, so monitoring may need to be continuous, instantaneous or maximum/ minimum. (It is emphasised that the use of the word typical here refers to a situation in which, for instance, one typical beam might be monitored from a multi-beam span, or one typical span monitored from a multi-span deck, to act as a check on the progression of any distress. If undue distress is observed the situation should be reviewed, additional monitoring may be necessary or Load Mitigation Interim Measures may be required.)

(iii) Measurement of parameters such as strain or displacement at particular defects, or in areas associated with damage or deterioration, in a bridge otherwise not sub-standard.

(iv) Extended traffic loading survey, as appropriate.

C2.5 The frequency of observations for Class 2 monitoring can differ, depending on the bridge, from periodic visits at intervals of several months, to more frequent visits or to continuous monitoring. Determination of the frequency should take into consideration the most likely modes of failure, its progression and consequences and the ability of the monitoring system to detect warning of progression.

Class 3 - Extensive Monitoring

C2.6 Class 3 monitoring is the highest level of monitoring. It may require frequent or continuous monitoring in one or more of the Class 2 categories where the onset of change is predicted to progress significantly towards failure in a short time. Measurements carried out in typical or critical positions, as appropriate to Class 2 monitoring, may be insufficient and a more extensive coverage of potentially critical points is likely to be required.

C2.7 Class 3 monitoring will often require continuous monitoring using data loggers and, where appropriate, remote monitoring techniques. Automatic alarm systems may be installed, to give warning when a parameter goes outside a pre-determined limit.

C3. Selection of Appropriate Monitoring Class

C3.1 The following discussion, which is not exhaustive, indicates some of the important factors that may need to be considered in defining the monitoring regime for a particular Sub-standard Structure. Some specific guidance is given for flexural and shear inadequacies and for masonry arch structures. In all cases, if deterioration occurs, the level of monitoring should be reviewed.

C3.2 A visual inspection regime (Class 1) will be sufficient in many cases to give an adequate assurance of safety. Structures having a sound structural form with no significant defects or signs of distress but which have been assessed to be sub-standard are typical subjects for this type of monitoring. The predicted mode of failure of the structure and its speed of progression over time are important considerations. Where the mode of failure is such that the structure will gradually show visual signs of increasing distress over a period of (at least) several weeks as traffic continues to use the bridge, then a visual inspection regime may be appropriate.

C3.3 When an evaluation of the structure indicates that additional assurance is required, then measurement using a small number of instruments placed at typical positions may be justified in accordance with a Class 2 monitoring regime. This might be appropriate when, for example, there would be an advantage in detecting any increase in maximum strain under live load or in the dead load condition. A Class 2 regime might also be appropriate when it is desired to increase the intervals between visual inspections. The use of instrumentation may also be needed where access for regular visual inspection of critical elements is not practical.

C3.4 The higher classes of monitoring should be considered when the predicted mode of failure and its speed of progression towards bridge collapse might be quite rapid once visual signs are present. When visual signs are likely to occur only when progression towards collapse is well advanced, monitoring should allow detection as soon as possible. Depending on the likely timescales involved, a high frequency of visual inspection, or intermittent or continuous monitoring (Class 2 or Class 3), using instrumentation in addition to visual inspection should be considered, for example, where the structure has a defect or advanced degradation in a critical element, or the critical element is sound but under-strength, and failure under high traffic load would lead to sudden collapse. In these circumstances the adoption of monitoring alone should be considered with particular caution, the need being to ensure the monitoring system will provide adequate forewarning of collapse.

C3.5 Class 3 monitoring will normally be required on a structure where it is necessary to allow a higher level

of loading than that given in the assessment Standards to continue, although the inadequacies of the structure are substantial and its strengthening or replacement is given a high priority. It may have a combination of defects. A decision to increase the level of monitoring from Class 2 to Class 3 may be influenced by the perceived consequences of failure.

Sub-standard Bridges with Flexural Inadequacies

C3.6 Examples of flexural inadequacy where monitoring requirements may usually be met are:

(i) Bridges where the theoretical structural inadequacy is in an element or connection, or type of load effect, where its failure can be observed by monitoring if it should fail, and where the failure will not cause sudden collapse of the bridge span.

(ii) Bridges where there is a theoretical flexural inadequacy that may lead, under repeated or increasingly heavy load, to progressively increasing permanent or transient deflection or strain.

An inadequacy in transverse flexure in a reinforced concrete slab bridge places the bridge in the first of these two categories: i.e. longitudinal cracking might occur initially, but collapse would not be expected to follow until longitudinal failure took place with accompanying transverse cracking. For an inadequacy in longitudinal flexure at mid span, the bridge might fall into the second category.

C3.7 It should not be assumed automatically that any flexural inadequacy is suitable for Class 1 monitoring. Moreover, a combination of circumstances might prevent such a bridge being classified as Monitoring-appropriate. For concrete structures, difficulties arise where the tension fibre cannot be observed, such as the top surface of a built-in slab, portal or box culvert. This could lead to a requirement for a higher level of monitoring, say Class 2, with for example, strain gauges attached in typical positions to detect any reduction in flexural stiffness that could indicate cracking on the concealed surface, or alternatively instrumentation could be placed on the concealed surface. However, for concrete structures, provided there is sufficient ductility and cracking would be expected to occur on the visible face before failure, a Class 1 monitoring regime would be sufficient.

C3.8 For some concrete structures, there may be the potential for a more sudden type of flexural failure with less displacement and cracking, for example, older prestressed structures that contain little reinforcing steel or structures with inadequate laps or anchorages. The margin between the cracking moment and the ultimate moment should also be considered since it indicates the potential for warning signs to be observed. In rare cases the ultimate moment could be less than the cracking moment.

C3.9 Similar issues in steel or composite bridges require a distinction to be made between tension or compression failure in flexure, whether or not the section is compact or if buckling is likely, or whether the resistance would change suddenly as a result of the failure at an interface. Imperfections are likely to have an effect on the appraisal, as is the practicality of measuring out-of-plane displacements.

C3.10 Wide bridges that carry several lanes are statistically less likely to fail suddenly and catastrophically in flexure under traffic loading than a single lane bridge for which one vehicle could cause a loading event of significantly greater magnitude than the bridge had previously experienced. For wide bridges the maximum loading is more likely to build up gradually over time if local traffic conditions change, and failure generally has to occur over the full width if collapse is to take place.

C3.11 Narrow, statically determinate bridges with a global flexural inadequacy under single vehicle or axle loading will not normally satisfy the requirement for gradual progression of distress which can be monitored by visual inspection alone at intervals of several weeks. For such structures a higher level of monitoring may be appropriate including frequent visual inspection or instrumentation to detect progression of distress.

C3.12 Where spans are continuous and thus redundancies are present, a collapse mechanism may begin to form long before collapse becomes imminent. Inadequacies in torsion are more significant when the torsional resistance is required for equilibrium purposes.

Sub-standard Bridges with Shear Inadequacies

C3.13 Bridges with shear inadequacies are not generally suitable for monitoring. Monitoring may however be considered where the bridge is wide. For concrete bridges it should be considered only where either:

(i) visible flexural cracking would precede shear distress and act as an early warning; or

(ii) inclined cracks would occur on surfaces that can be observed.

For monitoring to be appropriate, there must be an adequate margin between first cracking and maximum shear capacity, which may be determined by consideration of the degree of theoretical inadequacy, a comparison between the code provision and the test results from which it is derived, and other factors such as redundancy, width of structure, susceptibility to loading by a single vehicle and the dead load/live load ratio.

C3.14 Narrow concrete bridges with shear inadequacies are not suitable for monitoring when C for shear is less than 0.55K, and not when it is less than 0.66K (see BD 21 (DMRB 3.4.3) and Clause 4.6(ii)(c)) unless inclined cracks would be visible and sufficient shear reinforcement is present to provide a significant capacity margin above the inclined cracking load. Bridges with sub-standard shear details, such as inadequate anchorage, are not generally suitable for monitoring.

Sub-standard Masonry Arch Bridges

C3.15 Masonry arch bridges are suitable for monitoring only when it is considered that there is a significant margin of strength above the assessed capacity and adequate signs of distress will arise under high vehicle load sufficient to forewarn of vulnerability to collapse. The following factors should be considered in establishing whether monitoring is appropriate and if it is, the necessary level of monitoring:

(i) The presence and effect of strengthening features that have not been accounted for in the assessment such as internal walls, robust spandrel/wing walls.

(ii) The load history of the structure, if known, particularly if the structure has previously carried heavy loads.

(iii) The type of arch ring and its influence on observable deterioration. For example: for dressed stone masonry would defects be visible; for a multi-ring bridge is hidden ring separation present; for rubble masonry is deterioration obscured?

(iv) The arch ring shape and its potential for sudden collapse, considering, for example, whether it is circular or elliptical, its span-to-rise ratio, and the effect of haunching.

(v) The condition of the foundations and the potential for movement to produce sudden failure; could a saddle have increased the eccentricity of thrust?

(vi) There may be an additional risk when defects have been subjected to cosmetic repairs that conceal faults, for example the detachment of a spandrel wall or arch ring separation.

(vii) The type and nature of existing defects, which may indicate the potential for sudden collapse.

(viii) The modes of deterioration, considering how the progression of such deterioration may be effectively monitored.

APPENDIX D SUB-STANDARD STRUCTURE SUMMARY

D1.1 The form set out below provides a model for recording the progress of the assessment process in accordance with Clauses 2.14 and 2.15. A sample completed form is included to illustrate its application.

Structure Name:
Structure Ref. No.:

Assessment/ Review	Stage:	**Level 1 Assessment**				
	Date: Report reference: Assessed capacity: Sub-standard status:					
Interim Measures Feasibility Assessment	Date:					
	Is the structure an Immediate Risk Structure or a Low Risk Provisionally Sub-standard Structure?					
	Is the structure monitoring-appropriate?					
Interim Measures Proposal	Date:					
	Recommendations:					
Interim Measures Approval	Date:					
	Approval/Rejection:					
Actions	Implementation date: Details/ref: Provisional finish date for monitoring: Removal date:					
Additional Notes						

Sample Sub-standard Structure Status Summary Sheet

Structure Name: Green Lane Underpass
Structure Ref. No.: 43216

Assessment/Review Stage:	Level 1 Assessment	Level 2 Assessment	Level 3 Assessment	Interim Measures Review	Strengthening Feasibility
Date:	01/05/06	01/08/06	01/12/06	01/11/08	01/01/10
Report reference:	43216/AR1	43216/AR2	43216/AR3	43216/MR8	43216/SFR1
Assessed capacity:	18 tonnes	26 tonnes	26 tonnes	26 tonnes	26 tonnes
Sub-standard status:	Provisionally Sub-standard	Provisionally Sub-standard	Sub-standard	Sub-standard	Sub-standard, pending strengthening
Interim Measures Feasibility Assessment Date:	08/05/06	08/08/06	08/12/06	01/11/08	N/A
Is the structure an Immediate Risk Structure or a Low Risk Provisionally Sub-standard Structure?	Low Risk Provisionally Sub-standard Structure	Low Risk Provisionally Sub-standard Structure	No	No	N/1
Is the structure monitoring-appropriate?	Monitoring-appropriate Structure	Monitoring-appropriate Structure	Monitoring-appropriate Structure	Monitoring-appropriate Structure	N/A N/A
Interim Measures Proposal Date:	08/05/06	08/08/06	12/12/06	01/11/08	01/01/10
Recommendations:	No interim measures proposed	No interim measures proposed	Load Mitigation IM: Weight restriction 26 tonnes, or Monitoring IM: see Monitoring Spec. 43216/MS1	Weight restriction 26 tonnes, with continued monitoring	Strengthen structure with FRP
Interim Measures Approval Date:	22/05/06	22/08/06	05/01/07	15/11/08	N/A
Approval/Rejection:	TAA approval of lack of IM	TAA approval of lack of IM	Monitoring IM approved	Weight restriction and monitoring approved	N/A
Actions Implementation date:	22/05/06	22/08/06	01/02/07	01/12/08	June 2010
Details/ref:	No IM imposed. Assessment to progress to Level 2	No IM imposed. Assessment to progress to Level 3	See Monitoring Spec and Monitoring Reports 43216/MR1-43216/MR8	Restriction sign, purchase order no: PO43216-1. Monitoring reports 43216/MR9-13. Prioritise for strengthening	Structure strengthened; see design drawings 43216/FRP/DR101-102, and spec. 43216/FRP/SP1
Provisional finish date for monitoring:	N/A	N/A	01/02/10	N/A	N/A
Removal date:	N/A	N/A	30/06/10	30/06/10	N/A
Additional Notes	Low Risk Provisionally Sub-standard Structure: no IMs required. Considered likely that a refined structural model could improve assessment capacity.	Low Risk Provisionally Sub-standard Structure: no IMs required. Considered appropriate to progress to Level 3 assessment.	Monitoring details given in monitoring specification. Planned duration of monitoring 3 years.	Monitoring trigger levels exceeded - weight restriction introduced, in combination with continued monitoring. Strengthening prioritised.	Structure strengthened for full design loading. Structure no longer sub-standard.

APPENDIX E INTERIM MEASURES FEASIBILITY ASSESSMENT FOR BRIDGES

1. GENERAL DETAILS

1.1 Structure name and assessment reference:

Structure Ref No:

(Form 277 or equivalent information to be attached)

1.2 Location, route and county/area:

1.3 Assessing Organisation:

Assessed by:

Checked by:

Assessment date:

1.4 Structure type, form, span, skew:

1.5 Obstacle crossed and facility carried:

1.6 Estimated cost of permanent strengthening/replacement works:

2. ASSESSMENT PROGRESS

2.1 Level of assessment reached:

2.2 Assessed capacity:

2.3 Date of assessment:

2.4 Assessment Report reference:

2.5 Provisionally Sub-standard or Sub-standard?

2.6 Description of anticipated mode of failure, including its progressions from local overstress to global collapse mechanism:

2.7 Description of distress (if present):

3. CONSIDERATION OF RISK POSED BY STRUCTURE IN CURRENT STATE

3.1 Discussion

[Section to include discussion of likelihood and consequence of collapse, likelihood of warning signs, degree of safety implied by latest assessed capacity.]

3.2 Is the structure an Immediate Risk Structure?

3.3 Is the structure a Low Risk Provisionally Sub-standard Structure?

4. APPROPRIATENESS OF MONITORING

4.1 Discussion

[Section to include discussion of:

- distress;
- redundancy, ductility, predictability;
- risk (likelihood and consequence);
- effectiveness and meaningfulness of monitoring.]

4.2 Is the structure monitoring-appropriate?

5. OPTIONS FOR LOAD MITIGATION INTERIM MEASURES

5.1 Option Title

[For each option, the following issues should be considered:

- operational and cost implications;
- other implications.]

6. OPTIONS FOR MONITORING INTERIM MEASURES

6.1 Option Title

[If the structure is monitoring-appropriate, for each option, the following issues should be considered:

- description of monitoring regime;
- effectiveness of monitoring regime with reference to anticipated failure mode;
- risk of collapse;
- risk of damage at loads lower than the collapse load;
- operational and cost implications;
- other implications.]

7. RECOMMENDED OPTIONS FOR INTERIM MEASURES

7.1 Recommended Load Mitigation Interim Measures:

7.2 Recommended Monitoring Interim Measures:

APPENDIX F INTERIM MEASURES FEASIBILITY ASSESSMENT FOR RETAINING WALLS

1. GENERAL DETAILS

1.1 Structure name and assessment reference:

Structure Ref No:

(Form 277 or equivalent information to be attached)

1.2 Location, route and county/area:

1.3 Assessing Organisation:

Assessed by:

Checked by:

Assessment date:

1.4 Estimated cost of permanent strengthening/replacement works:

2. DEFORMATION DESCRIPTION:

2.1 Bulging:

2.2 Tilting:

2.3 Sliding:

3. EXTENT OF DEFORMATION:

3.1 Height and width of deformation:

Maximum retaining height of wall: m

Average retained height of wall: m

3.2 Deviation from line vertical:

4. HISTORY:

4.1 General Inspection or Principle Inspection references to deformation:

5. CONSIDERATION OF RISK POSED BY STRUCTURE IN CURRENT STATE

5.1 Discussion

[Section to include discussion of likelihood and consequence of collapse, likelihood of warning signs, degree of safety implied by latest assessed capacity.]

5.2 Is the structure an Immediate Risk Structure?

5.3 Is the structure a Low Risk Provisionally Sub-standard Structure?

6. APPROPRIATENESS OF MONITORING

6.1 Discussion

[Section to include discussion of:

- distress;
- redundancy, ductility, predictability;
- risk (likelihood and consequence);
- effectiveness and meaningfulness of monitoring.]

6.2 Is the structure monitoring-appropriate?

7. OPTIONS FOR LOAD MITIGATION INTERIM MEASURES

7.1 Option Title

[For each option, the following issues should be considered:

- operational and cost implications;
- other implications.]

8. OPTIONS FOR MONITORING INTERIM MEASURES

8.1 Option Title

[If the Structure is monitoring-appropriate, for each option, the following issues should be considered:

- the history of deformation;
- the percentage of total loading effects attributable to live loading;
- the sensitivity of the wall to variation in magnitude and position of vehicle loading;
- description of monitoring regime;
- effectiveness of monitoring regime with reference to anticipated failure mode;
- risk of collapse;
- risk of damage at loads lower than the collapse load;
- operational and cost implications;
- other implications.

9. RECOMMENDED OPTIONS FOR INTERIM MEASURES

9.1 Recommended Load Mitigation Interim Measures:

9.2 Recommended Monitoring Interim Measures:

APPENDIX G PROPOSAL FOR INTERIM MEASURES

1 GENERAL DETAILS

1.1 Structure name and assessment reference:

Structure Ref No:

(Form 277 or equivalent information to be attached)

1.2 Location, route and county/area:

1.3 Assessing Organisation:

Assessed by:

Checked by:

Assessment date:

1.4 Structure type, form, span, skew:

1.5 Obstacle crossed or facility carried:

1.6 Estimated cost of permanent strengthening/replacement works:

2 PROPOSED INTERIM MEASURES

2.1 Summary of assessment progress.

2.2 Summary of feasibility of options for Interim Measures (details attached as an appendix).

2.3 Summary of Recommended Load Mitigation Interim Measures (details attached as an appendix if appropriate).

2.4 Summary of Recommended Monitoring Interim Measures, if appropriate (refer to Monitoring Specification, attached as an appendix).

2.5 Proposal made by:

..... Date:

..... Assessment Team Leader

..... Date:

..... Principal for assessing organisation

3 APPROVAL OF INTERIM MEASURES

3.1 Appraisal of recommended Load Mitigation Interim Measures and Monitoring Interim Measures (if appropriate)

..... Date:

..... TAA[1]

3.2 Acceptance of Load Mitigation Interim Measures (if required[2])

..... Date:

..... Highway (or Roads) Authority (if different from TAA)

3.3 Instruction to implement Interim Measures

Interim Measures to be implemented[3]:

..... Date:

..... Structure Owner

[Additional Signatories[4]]

Notes:

[1] TAA to sign to confirm that recommended Load Mitigation Interim Measures and Monitoring Interim Measures have been appraised and their technical efficacy agreed.

[2] Highway (or Roads) Authority acceptance is only necessary where the accepted interim measures affect the traffic on the highway network.

[3] Structure Owner to instruct which option for interim measures is to be implemented and to sign to endorse action to be taken.

[4] Additional signatories may be required to permit additional relevant parties to approve, endorse or instruct action to be taken, for example, where the responsibility for the implementation and/or the cost of interim measures is shared between parties. Such requirements to be agreed between the relevant parties.

APPENDIX H MONITORING SPECIFICATION

H1.1 As stated in Clause 5.13, the monitoring regime for each Sub-standard Structure to be specified in a clear, unambiguous Monitoring Specification. Except where the monitoring is intended merely to check that Load Mitigation Interim Measures are continuing to function satisfactorily, the specification should include the following:

(1) **Background**

This section should include a summary of the relevant information included in the Interim Measures Feasibility Assessment (see Appendices E and F). In particular, it should include a summary of the following:

(i) **Assessment Findings**. The basis of the assessment inadequacy, stated clearly and concisely. Generic reasons such as "flexure" or "shear" are not sufficient: the location, nature, degree and underlying reasons should be stated, and the live load capacity factor C and the required Load Reduction Factor K for the existing traffic and road surface category given (see BD 21 (DMRB 3.4.3) and Clause 4.6(ii)(c)). When there are several inadequacies, each should be described and an overview given. The level of assessment undertaken should also be stated.

(ii) **Deterioration of Structure.** A review of existing information on the causes, extent and severity of any deterioration together with the expected progession of the deterioration.

(iii) **Service Performance**. An appraisal of the reasons for the observed satisfactory service performance: for example, low load levels, conservative structural model, conservative resistance model, resistance enhancement.

(iv) **Anticipated Failure Mode(s)**. The anticipated mode(s) of failure together with an indication of the likelihood and consequences of such failure.

(2) **Monitoring Plan**

This section should include a detailed statement of the planned monitoring regime. All parameters to be monitored should be related to the predicted mode(s) of failure and progression to that state, together with the required accuracy of observation. Specific reference should be made, where appropriate, to the following:

(i) **Visual Observations**.

(ii) **Measurements**.

(iii) **Photographs**. A description of the location from which photographic records should be taken, and/or a sample photograph.

(iv) **Other Parameters**. A description of any other parameters to be monitored.

(3) **Monitoring Frequency**

This section should include a detailed statement of the frequency of monitoring.

(4) **Monitoring Trigger Levels**

This section should include a description of the ranges of observations which are acceptable and the values, or other features, which constitute trigger or warning levels requiring action. It is sometimes helpful to identify intermediate levels, for example, a red-amber-green system may be used.

(5) **Monitoring Trigger Actions**

This section should include a clear set of procedures to be implemented if trigger or warning levels are reached. These should include contact names and telephone numbers and should be clear as to who has the responsibility for each decision.

(6) **Recording and Reporting**

This section should include clear guidelines on the recording and reporting of monitoring activities, for example including, where appropriate, the use of standardised reporting forms, filing systems and/or electronic databases, and requirements for reporting to the TAA.

(7) **Review of Monitoring Requirements**

This section should include provisions for regular review of the monitoring regime, its planned maximum duration (see Clause 5.15), and also any procedures following observed behaviour of the structure, such as an increased or reduced monitoring frequency.

H1.2 The Monitoring Specification should be developed following a special inspection unless recent inspection records are adequate for the purpose.

APPENDIX I LIST OF AMENDMENTS TO EXISTING DEPARTMENTAL STANDARDS AND ADVICE NOTES

Document Reference	Title	Date of Issue	DMRB Reference	Aspect Amended
BA 87/04	Management of Corrugated Steel Buried Structures	August 2004 with correction in February 2006	3.3.4	Chapter 3, Paragraph 3.3.6 Page 3/6: Delete Text “BA 79” and replace with “BD 79”. Chapter 6, Page 6/2, Delete text “BA 79” and replace with “BD 79”.
BD 21/01	The Assessment of Highway Bridges and Structures	May 2001	3.4.3	Chapter 1, Paragraphs: 1.2(v), 1.3(i) and 1.3(iii) Page 1/1: Delete Text “BA 79” and replace with “BD 79”. Chapter 10, Page 10/2, Delete text “BA79 The Management of Sub-standard Highway Bridges” and replace with “BD 79 The Management of Sub-standard Highway Structures”.
BD 89/03	The Conservation of Highway Structures	November 2003	3.2.4	Chapter 4, Paragraph 4.4 Page 4/1: Delete Text “BA 79” and replace with “BD 79”. Chapter 8, Page 8/1, Delete text “BA79. The Management of Sub-standard Highway Bridges (DMRB 3.4.18)” and replace with “BD 79 The Management of Sub-standard Highway Structures (DMRB 3.4.18)”.