

Bonneagar Iompair Éireann
Transport Infrastructure Ireland

TII Publications

GE PE DN CC OP AM RE

The Management of Sub-standard Road Structures

AM-STR-06039

June 2014

AM

Asset Management &
Maintenance

Standards

About TII

Transport Infrastructure Ireland (TII) is responsible for managing and improving the country's national road and light rail networks.

About TII Publications

TII maintains an online suite of technical publications, which is managed through the TII Publications website. The contents of TII Publications is clearly split into 'Standards' and 'Technical' documentation. All documentation for implementation on TII schemes is collectively referred to as TII Publications (Standards), and all other documentation within the system is collectively referred to as TII Publications (Technical). This system replaces the NRA Design Manual for Roads and Bridges (NRA DMRB) and the NRA Manual of Contract Documents for Road Works (NRA MCDRW).

Document Attributes

Each document within TII Publications has a range of attributes associated with it, which allows for efficient access and retrieval of the document from the website. These attributes are also contained on the inside cover of each current document, for reference. For migration of documents from the NRA and RPA to the new system, each current document was assigned with new outer front and rear covers. Apart from the covers, and inside cover pages, the documents contain the same information as previously within the NRA or RPA systems, including historical references such as those contained within NRA DMRB and NRA MCDRW.

Document Attributes

| | | | |
|-------------------------------|---|-----------------------------|------------------|
| TII Publication Title | <i>The Management of Sub-standard Road Structures</i> | | |
| TII Publication Number | AM-STR-06039 | | |
| Activity | <i>Asset Management & Maintenance (AM)</i> | Document Set | <i>Standards</i> |
| Stream | <i>Structures (STR)</i> | Publication Date | <i>June 2014</i> |
| Document Number | <i>06039</i> | Historical Reference | <i>NRA BD 79</i> |

NRA DMRB and MCDRW References

For all documents that existed within the NRA DMRB or the NRA MCDRW prior to the launch of TII Publications, the NRA document reference used previously is listed above under 'historical reference'. The TII Publication Number also shown above now supersedes this historical reference. All historical references within this document are deemed to be replaced by the TII Publication Number. For the equivalent TII Publication Number for all other historical references contained within this document, please refer to the TII Publications website.

The Management of Sub-standard Road Structures

June 2014

St. Martin's House, Waterloo Road, Dublin 4. Tel:+353 1 660 2511 Fax +353 1 668 0009
Email : info@nra.ie Web : www.nra.ie

Summary:

This Standard sets out the procedures for managing road structures that have been found to be sub-standard.

**VOLUME 3 HIGHWAY
STRUCTURES: INSPECTION AND
MAINTENANCE**

SECTION 4 ASSESSMENT

PART 14

NRA BD 79/14

**THE MANAGEMENT OF SUB-
STANDARD ROAD STRUCTURES**

Contents

Chapter

1. Introduction
2. Management Processes
3. Immediate Risk Structures
4. Low Risk Provisionally Sub-standard Structures
5. Interim Measures
6. Review of Interim Measures
7. Prioritisation for Strengthening or Replacement
8. Removal of Interim Measures
9. References
10. Enquiries

Appendix A - Management Processes

Appendix B - Assessment Stages

Appendix C - Reliability Based Methods of Assessment

Appendix D - Monitoring of Sub-standard Structures

Appendix E - Sub-standard Structure Summary

Appendix F - Interim Measures Feasibility Assessment for Bridges

Appendix G - Interim Measures Feasibility Assessment for Retaining Walls

Appendix H - Proposal for Interim Measures

Appendix I - Monitoring Specification

Appendix J - Review of Interim Measures

Appendix K - Immediate Risk Structure: Emergency Action Record of Agreement/Incident Log

Appendix L - Interim Measures Removal

1. INTRODUCTION

General

- 1.1 The purpose of this Standard is to provide the requirements for the management of road structures that have either been assessed to be sub-standard according to the requirements of NRA BD 21 ‘The Assessment of Road Bridges and Structures’ (NRA Design Manual for Road and Bridges) or are deemed to be sub-standard by inspection under the Eirspan Bridge management system or by other methods. Since assessments are typically based on theoretical calculations and the identification of sub-standard structures without completed assessments are typically based on engineering judgement, 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 is intended for use by the Bridge Owner. Its application to a particular structure should be confirmed with the National Roads Authority (NRA).

Scope

- 1.3 This Standard covers the management of Sub-standard Structures (see definition in Clause 1.7), including road bridges and other road structures subject to normal traffic loading. In particular the Standard provides requirements and guidance on the use of interim measures.
- 1.4 The principles and procedures of this Standard may also be useful and relevant for:
 - (i) the management of structures with sub-standard non-primary load carrying elements (e.g. sub-standard parapets, bridge supports at risk from collision);
 - (ii) the management of Sub-standard Structures that do not carry a road;
 - (iii) the management of structures that have been assessed using Standards other than NRA BD 21 (e.g. NRA BD 86 ‘The Assessment of Road Bridges and Structures for the Effects of Abnormal and Exceptional Abnormal Load Vehicles Using SV and SOV Load Models’) or NRA BD 37 ‘Loads for Highway Bridges,’ and found to have insufficient capacity.

However, in these cases, the structure will not be considered to be within the scope of this Standard.

Implementation

- 1.5 This Standard shall be used on all projects for the assessment and maintenance of motorway and National Primary and Secondary roads.

Identification of Sub-standard, Immediate Risk and Provisionally Sub-standard Structures

- 1.6 The identification of Sub-standard, Immediate Risk and Provisionally Sub-standard Structures is not restricted to the assessment process. Structures may be identified by other methods including, but not restricted to, inspections (in accordance with the NRA Eirspan Bridge Management System, NRA BD 97 ‘Assessment of Scour and Other Hydraulic Actions at Road Structures’) and monitoring trigger levels being reached. For some retaining walls and some forms of sub-structure, assessments may be based upon engineering judgement without the use of calculations.

Definitions

- 1.7 The following definitions apply in this Standard:

Immediate Risk Structures: Structures that are considered to represent an immediate and unacceptable safety risk to the public. Guidance on identifying Immediate Risk Structures is included in Chapter 3.

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 5.9 – 5.11.

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

Provisionally Sub-standard Structures: If a structure is deemed to be sub-standard without an assessment (e.g. scour, impact damage, deterioration) or assessed to have sub-standard load capacity at any stage during the assessment process, it is to be treated as a Provisionally Sub-standard Structure regardless of whether it is considered appropriate to progress the assessment further.

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 loading requirements given in NRA BD 21, or by other means (e.g. scour, impact damage, deterioration) and retaining walls that have been found to be sub-standard either according to the principles in NRA BD 21, or by other means after carrying out an appropriate assessment. A structure where only the verge under accidental wheel loading is sub-standard is generally not included but this should be confirmed with the National Roads Authority. The definition does not apply to structures with sub-standard non-primary load carrying elements that are not directly affected by traffic loading (e.g. sub-standard parapets, bridge supports at risk from collision).

Lead Structural Assessment Engineer: Chartered Engineer with recognised University degree to Level 8 or equivalent with a minimum of 10 years post graduate experience in the assessment of bridge structures. Must have experience as a Team Leader in both conservative and refined assessment of relevant masonry, concrete and steel bridge structures using contemporary methods and software packages.

Structural Assessment Engineer: Engineer with recognised University degree to Level 8 or equivalent with a minimum of 7 years post graduate experience in the design or assessment of bridge structures. Must have experience in design or assessment of relevant masonry, concrete and steel bridge structures using contemporary methods and software packages.

2. MANAGEMENT PROCESS

Key Processes

- 2.1 Appendix A contains flowcharts summarising key processes for the identification and management of Provisionally Sub-standard Structures and Sub-standard Structures with a table summarising documentation of management processes.
- 2.2 Sub-standard and Provisionally Sub-standard Structures shall be managed by assessing the risks to public safety associated with their continued use and imposing appropriate interim measures when necessary.
- 2.3 Load Mitigation Interim Measures shall be urgently imposed on Immediate Risk Structures in accordance with Clause 3.1.

Use of Interim Measures for Structures Deemed Provisionally Sub-standard

- 2.4 If, at any stage during an assessment, whilst monitoring or by any other means, a structure is found to be a Provisionally Sub-standard Structure (see Clause 1.7), the use of interim measures shall be considered and recorded.
- 2.5 Load Mitigation Interim Measures shall 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 4.1 and 4.2), in which case it may not be necessary to impose any interim measures, provided that such a decision is agreed with the National Roads Authority and/or Road Authority where relevant; 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 National Roads Authority and/or Road Authority where relevant; or
 - (iii) it can be shown to be a Monitoring Appropriate Structure (see Clauses 5.9 – 5.11). In this case one of the following must be applied:
 - (a) Monitoring Interim Measures;
 - (b) Monitoring in combination with Load Mitigation Interim Measures.

Use of Interim Measures on Completion of Assessment

- 2.6 If on completion of the assessment process a structure is found to be a Sub-standard Structure, interim measures shall be used pending strengthening or replacement of the structure.
- 2.7 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.

-
- 2.8 Load Mitigation Interim Measures shall be imposed on any Sub-standard Structure, unless agreed with the National Roads Authority and/or Road Authority where relevant that 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 Clauses 5.9 – 5.11), in which case Monitoring Interim Measures alone or with Load Mitigation Interim Measures shall be imposed.
 - 2.9 Where an appreciable delay is likely between the completion of an assessment and the implementation of the selected Load Mitigation Interim Measure, the risk shall be managed in the intervening period, for example by the use of monitoring on a short-term basis (if appropriate).
 - 2.10 Sub-standard Structures should be prioritised for strengthening or replacement. Guidance is given in Chapter 7.

Document and Records Management

- 2.11 The following document control guidelines could be used in the management of Provisionally Sub-standard and Sub-standard Structures.
- 2.12 The records could 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 E should 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 F and G should 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 National Roads Authority and/or Road Authority where relevant.
 - (v) Proposals for interim measures. The form in Appendix H should be used to propose recommendations for interim measures. The proposal should include an assessment of the feasibility of different interim measures (see Appendices F and G) and details of proposed actions, including the Monitoring Specification (see Appendix I), 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 H signed by all relevant responsible parties.
 - (vii) Record of implementation of interim measures.
 - (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.
 - (xi) Record of strengthening or replacement.

2.13 These records shall be uploaded on to the National Roads Authority management information system.

Roles and Responsibilities

2.14 The process for proposing and approving Load Mitigation and Monitoring Interim Measures typically involves the following:

- (i) **Lead Structural Assessment Engineer:** A senior representative of the Assessment Team or the organisation responsible for the maintenance of the structure having authority to sign on its behalf. Responsible for proposals for interim measures made by the Assessing Organisation.
- (ii) **National Road Authority:** Needed to give agreement for Load Mitigation and Monitoring Interim Measures where these will affect the traffic on the National road network.
- (iii) **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.

3. IMMEDIATE RISK STRUCTURES

Immediate Risk Structures

- 3.1 The Assessment Team or the organisation responsible for the maintenance of the structure shall inform the National Roads Authority 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. The Assessment Team or the organisation responsible for the maintenance of the structure shall develop and propose to the National Roads Authority, appropriate Load Mitigation Interim Measures and determine if the structure is required to be closed to the public. Once confirmed and agreed with the National Roads Authority, appropriate Load Mitigation Interim Measures (or, for elements that do not support a carriageway, appropriate interim measures as described in Clauses 5.24 – 5.25) shall be implemented as a matter of urgency on any Immediate Risk Structure and/or where the safety risk to the public is deemed unacceptable. A temporary emergency closure shall 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.
- 3.2 The identification of Immediate Risk Structures is not restricted to the assessment process. Structures may be identified as Immediate Risk Structures by other methods.
- 3.3 The identification of Immediate Risk Structures requires engineering 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.
- 3.4 Where an emergency interim measure is required to make safe an Immediate Risk Structure, the agreement between the relevant parties should be recorded using the form in Appendix K.

4. LOW RISK PROVISIONALLY SUB-STANDARD STRUCTURES

Low Risk Provisionally Sub-standard Structures

- 4.1 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. 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 National Roads Authority and/or Road Authority (as described in paragraphs 2.11 – 2.13).
- 4.2 Either of the following may be taken to be indicative of Low Risk Provisionally Sub-standard Structures:
- (i) Structures whose only provisionally sub-standard elements are non-carriageway elements that are only predicted to fail under accidental loading. However, in some cases the erection of an appropriate safety 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.

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 within the capacity of the structure.
- 5.2 Load Mitigation Interim Measures should comprise one or more of the following actions:
 - (i) Vehicle weight restrictions, calculated in accordance with NRA BD 21.
 - (ii) Lane restrictions, calculated in accordance with NRA BD 21.
 - (iii) Propping of the structure.
 - (iv) Use of a temporary structure.
 - (v) Closure of the structure to all users or classes of vehicles.
- 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 shall be reviewed and, where the deterioration could affect the adequacy of the Load Mitigation Interim Measures, Monitoring Interim Measures shall be used in combination with Load Mitigation Interim Measures.
- 5.4 The planned maximum duration for Load Mitigation Interim Measures should not exceed two years, during which the structure should be strengthened or replaced, or, at the end of which, the continued application of Load Mitigation Interim Measures should be formally reviewed (as described in Clauses 6.1 – 6.3).

Existing Weight Restrictions

- 5.5 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 Road Authority.
- 5.6 Periodic reviews of weight restrictions (as described in Clauses 6.1 – 6.3) should be carried out at intervals not exceeding two years, subject to condition, use and deterioration, or until such time that formal approval to maintain the weight limit as a permanent measure is granted by the Road Authority. The form in Appendix L can be used as a mechanism for accepting the weight limit as a permanent measure.

Monitoring Interim Measures

- 5.7 Monitoring Interim Measures shall only be carried out on Monitoring-appropriate Structures.
- 5.8 Monitoring Interim Measures should comprise either:
 - (i) monitoring alone; or
 - (ii) monitoring with other measures, such as propping or partial restriction of traffic loading.

5.9 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 National Roads Authority 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 D).

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

5.11 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.

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

5.13 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 shall be undertaken rigorously and appropriate professional engineering expertise and advice shall be used throughout.

5.14 In order to design an effective monitoring and reporting system, it is necessary to understand the likely failure mechanism of the structure.

5.15 Guidance on monitoring is provided in Appendix D.

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

- (i) a summary of the assessment findings and other background information relating to the appropriateness of the proposed monitoring;
- (ii) a protocol for monitoring, reporting and the escalation of decision making;

- (iii) an emergency response and communication plan, where appropriate and agreed with the National Roads Authority and where sudden deterioration could lead to a structure being classified as an Immediate Risk Structure;
- (iv) 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;
- (v) the frequency of the monitoring;
- (vi) definition of trigger levels;
- (vii) details of any actions to be taken if trigger levels are exceeded;
- (viii) requirements for the recording and reporting of monitoring activities;
- (ix) a plan for the review of the monitoring regime.

5.17 The format in Appendix I should be used for the Monitoring Specification.

5.18 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 two years, shall 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 shall be formally reviewed (as described in Clauses 6.1 – 6.3).

5.19 If Monitoring Interim Measures are to be removed whilst the structure remains Sub-standard, the form in Appendix L should be submitted together with the form in Appendix H detailing the alternative Interim Measures to be put in its place.

Certification of Interim Measures

5.20 The necessity or otherwise of any certification in addition to that described in this Standard should be agreed with the National Roads Authority.

Interim Measures for Non-carriageway Parts of Structures

5.21 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 an appropriate safety barrier subject to defined vehicle loading checks, which may be considered as a long-term solution (refer to Annex I of NRA BD 21). This applies to both deck cantilevers as well as non-carriageway parts of beam and slab decks.

5.22 Other forms of barrier which reduce the level of risk to one acceptable to the National Roads Authority may be deemed to be an appropriate interim measure.

5.23 A planned maximum duration for interim measures for non-carriageway parts of structures should be specified during which the structure should be strengthened or replaced, or, at the end of which, the continued application of interim measures should be formally reviewed.

6. REVIEW OF INTERIM MEASURES

Load Mitigation Interim Measures, Monitoring Interim Measures and/or Interim Measures for Non-carriageway Parts of Structures

- 6.1 Load Mitigation Interim Measures, Monitoring Interim Measures and/or Interim Measures for Non-carriageway Parts of Structures should be formally reviewed at intervals not exceeding two years if the structure has not been strengthened or replaced. Additional formal reviews should also be undertaken if there is a change in the condition or use of the structure.
- 6.2 Formal agreement of the continued application of Load Mitigation Interim Measures, Monitoring Interim Measures and/or Interim Measures for Non-carriageway Parts of Structures should be recorded using the form in Appendix J.

7. PRIORITISATION FOR STRENGTHENING OR REPLACEMENT

- 7.1 The strengthening or replacement of a Sub-standard Structure typically takes several years. The work will therefore need to be prioritised, whilst ensuring public safety and preventing loss of use of the structures by maintaining appropriate interim measures. Value Management techniques may be useful for the prioritisation of strengthening works.
- 7.2 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 and consequences;
 - (ii) the specified maximum intended duration for Monitoring Interim Measures (see Clause 5.18);
 - (iii) the traffic delay costs which are caused by the implementation of interim measures and which will be eliminated when the strengthening or replacement 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 whole life cost-effectiveness of the strengthening, taking account of the ratio of costs and benefits and the residual life of the structure;
 - (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.

8. REMOVAL OF INTERIM MEASURES

- 8.1 The removal of Interim Measures requires formal confirmation that a structure is no longer Sub-standard and that it is safe to remove Load Mitigation Interim Measures, Monitoring Interim Measures and/or Interim Measures for Non-carriageway Parts of Structures.
- 8.2 Formal agreement of the removal of Load Mitigation Interim Measures, Monitoring Interim Measures and/or Interim Measures for Non- carriageway Parts of Structures shall be recorded using the form in Appendix L.
- 8.3 A copy of the completed form shall be forwarded for approval to the NRA.

9. REFERENCES

9.1 National Roads Authority's Design Manual For Roads and Bridges

| | |
|-----------|---|
| NRA BD 2 | Technical Approval of Highway Structures |
| NRA BA 86 | Advice Notes on the Non-Destructive Testing of Road Structures |
| NRA BA 35 | Inspection and Repair of Concrete Road Structures |
| NRA BA 16 | The Assessment of Road Bridges and Structures |
| NRA BD 21 | The Assessment of Road Bridges and Structures |
| NRA BD 37 | Loads For Highway Bridges |
| NRA BA 43 | Strengthening, Repair and Monitoring of Post-tensioned Concrete Bridge Decks |
| NRA BA 44 | The Assessment of Concrete Road Bridges and Structures |
| NRA BD 44 | The Assessment of Concrete Road Bridges and Structures |
| NRA BA 54 | Load Testing for Bridge Assessment |
| NRA BD 56 | The Assessment of Steel Road Bridges and Structures |
| NRA BD 86 | The Assessment of Road Bridges and Structures for the Effects of Abnormal and Exceptional Abnormal Load Vehicles using SV and SOV Load Models |
| NRA BD 97 | Assessment of Scour and Other Hydraulic Actions at Road Structures |

9.2 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.

9.3 Other Publications

Concrete Society 'Non-structural Cracks in Concrete – 2010'.

Appraisal of existing structures, 2010. 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.

10. ENQUIRIES

- 10.1 All technical enquiries or comments on this document or any of the documents listed as forming part of the NRA DMRB should be sent by e-mail to infoDMRB@nra.ie, addressed to the following:

“Head of Network Management, Engineering Standards & Research
National Roads Authority
St Martin’s House
Waterloo Road
Dublin 4”



.....
Pat Maher
Head of Network Management,
Engineering Standards & Research

APPENDIX A MANAGEMENT PROCESSES

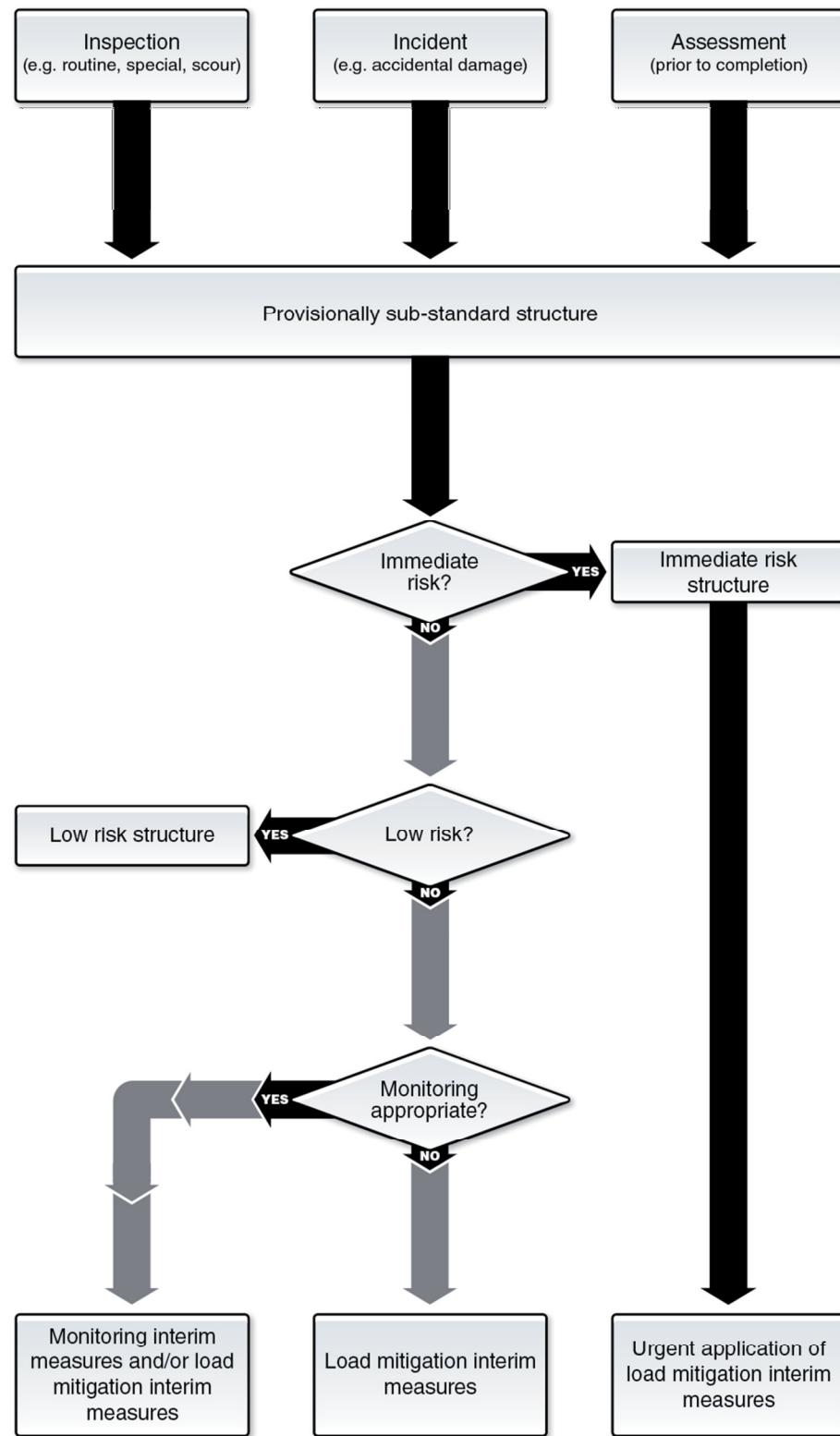


Figure A.1 – Management Processes Flowchart – Phase 1 Provisionally Sub-standard Structures

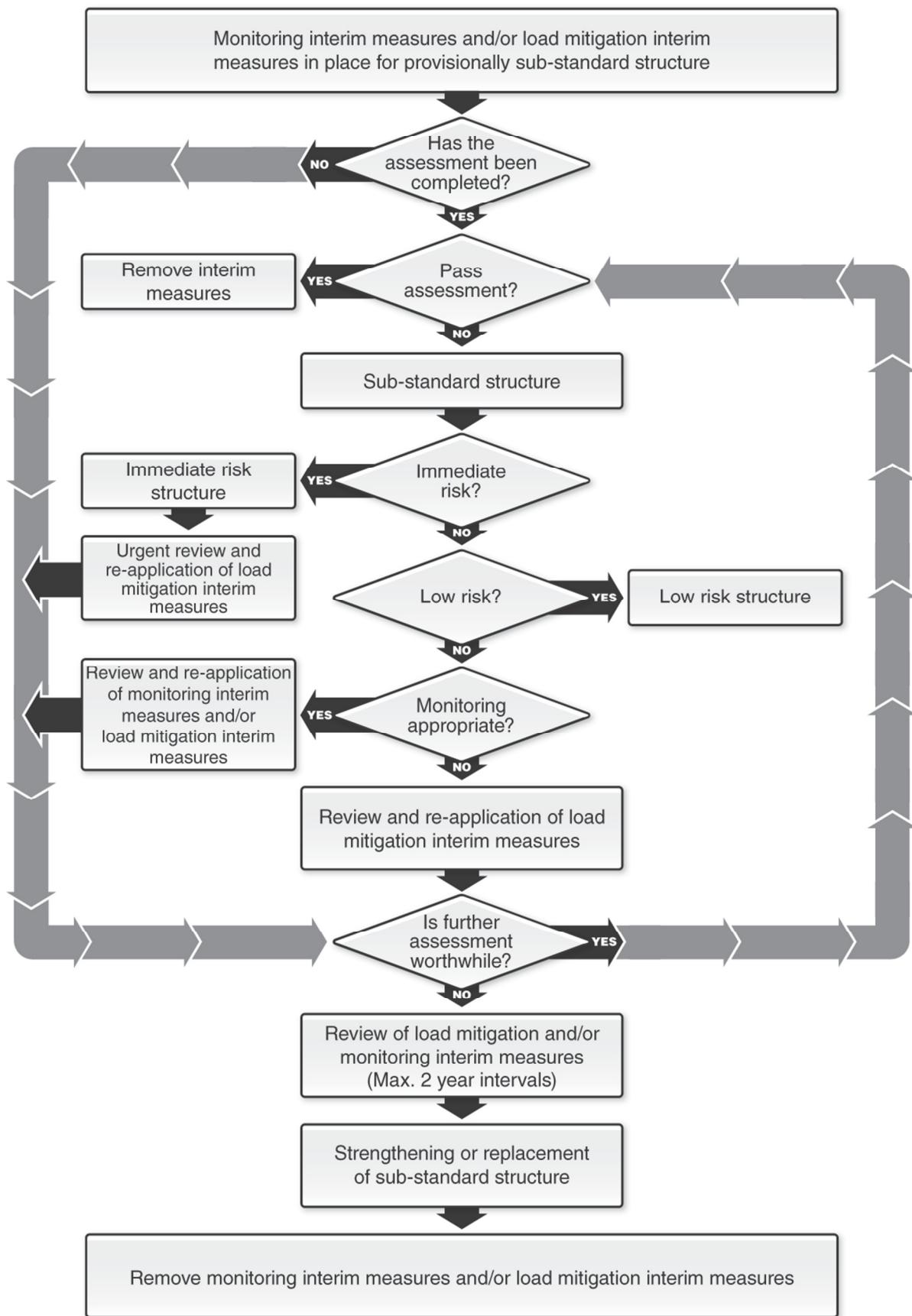


Figure A.2 – Management Processes Flowchart Phase 2 Sub-standard Structures

| Process | Recommended Approach for Reporting | Reference |
|---|---|--|
| Identification of Immediate Risk Structure (Figure A.1) | Interim Measures Feasibility Assessment Emergency action record of agreement | Bridges: Appendix F to Section 3 Appendix K |
| Identification of Low Risk Provisionally Sub-standard Structure (Figure A.1) | Interim Measures Feasibility Assessment | Bridges: Appendix F to Section 3 Retaining Walls: Appendix G to Section 5 |
| Identification of Monitoring-appropriate Structure (Figure A.1) | Interim Measures Feasibility Assessment | Bridges: Appendix F to Section 4 Retaining Walls: Appendix G to Section 6 |
| Interim measures for non-Monitoring-appropriate Structures (Figure A.1) | Interim Measures Feasibility Assessment Interim Measures Proposal Form | Bridges: Appendix F to Section 5 Retaining Walls: Appendix G to Section 7 Appendix H |
| Interim measures for Monitoring-appropriate Structures (Figure A.1) | Interim Measures Feasibility Assessment Interim Measures Proposal Form Monitoring Specification | Bridges: Appendix F to Section 7 Retaining Walls: Appendix G to Section 9 Appendix H |
| Review of interim measures (Figure A.2) | Review of Interim Measure Form | Appendix J |
| Removal of interim measures (Figure A.2) | Interim Measure Removal Form | Appendix L |

Table A.1 – Documentation of Management Processes

APPENDIX B ASSESSMENT STAGES

B1 General

- B1.1 Assessment of an existing structure should be carried out in stages of increasing complexity, with the object of efficiency 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.
- B1.2 The assessment stages considered by the National Roads Authority are as set out below.
- B1.3 The appropriate level of assessment for a structure should be determined in conjunction with the Road Authority in consultation with the Bridge Management Section of the National Roads Authority.
- B1.4 If at any stage of the assessment process, it is deemed that there will be no obvious benefit in continuing, assessments may be stopped subject to agreement with the Road Authority. All such deliberations and decisions should be carefully recorded and a close out report / file issued to the Roads Authority detailing the works completed and the reasons for the suspension of the assessment.

Stage 1 Assessment

- B1.5 Stage 1 is the simplest level of assessment, giving a conservative estimate of load capacity. Structures assessed to Stage 1 shall follow the procedures outlined in NRA BD 303 (The Stage 1 Structural Assessment of Sub-Standard Road Structures).

Stage 2 Assessment

- B1.6 Stage 2 Structural Assessment involves the use of more refined analysis and better structural idealisation. Structures assessed to Stage 2 shall follow the procedures outlined in NRA BD 304 (The Stage 2 Structural Assessment of Sub-Standard Road Structures).
- B1.7 As part of the Stage 2 Structural Assessment process the Structural Assessment Engineer shall be required to; review the findings of all available calculations (both design and assessment); comment on the level of conservatism upon which any assumptions have been founded; and correlate the findings of the most recent Stage 1 Structural Assessment with the findings of the Inspection for Assessment.
- B1.8 Stage 2 Structural Assessment shall make use of both material testing to determine characteristic strength or yield stress, and also Worst Credible Strength or Worst Credible Yield Stress when it is considered that the use of such factors would result in a structure achieving the required load rating.

Stage 3 Assessment

- B1.9 Stage 3 Structural Assessment involves the use of specialist techniques such as Bridge Specific Assessment Live Loading (BSALL), reliability-based methods of assessment and load testing.
- B1.10 For long span bridges (loaded lengths greater than 50m), where the 40 Tonne Assessment Live Loading fails by a small margin, the use of BSALL may be beneficial.
- B1.11 Load tests should be complementary to the analytical process and are not to be considered as a replacement for the usual assessment procedures. Guidance for load testing of bridges is given in clauses 3.28 and 3.29 of NRA BD 21 with further advice contained in NRA BA 54, 'Load Testing for Bridge Assessment'.

Technical Approval and Certificates

- B1.12 Requirements for Technical Approval relating to assessment of structures are given in NRA BD 303 and NRA BD 304. It is essential that there is dialogue between the Assessment Team and the National Roads Authority when the scope and complexities of assessment develop, particularly where this requires increasing input of subjective judgement.
- B1.13 Amendments to a TAR are required for each subsequent level of assessment proposed and should be included as an addendum to the original TAR.

APPENDIX C RELIABILITY BASED METHODS OF ASSESSMENT

C1 Reliability-based Methods of Assessment

- C1.1 Following assessments at Stage 1 and Stage 2, reliability-based methods of assessment may be used with the agreement of the National Roads Authority within a Stage 3 Assessment. 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.
- C1.2 Some guidance on reliability-based methods of assessment is included in Appendix C2.

C2 Reliability-based Methods of Assessment

- C2.1 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.
- C2.2 Stage 1 and Stage 2 Assessments, as described in Appendix B1, 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 National Roads Authority.
- C2.3 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.
- C2.4 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 National Roads Authority should 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.
- C2.5 The procedures for reliability and deterministic analyses are illustrated in Figures C.1 and C.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).
- C2.6 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.

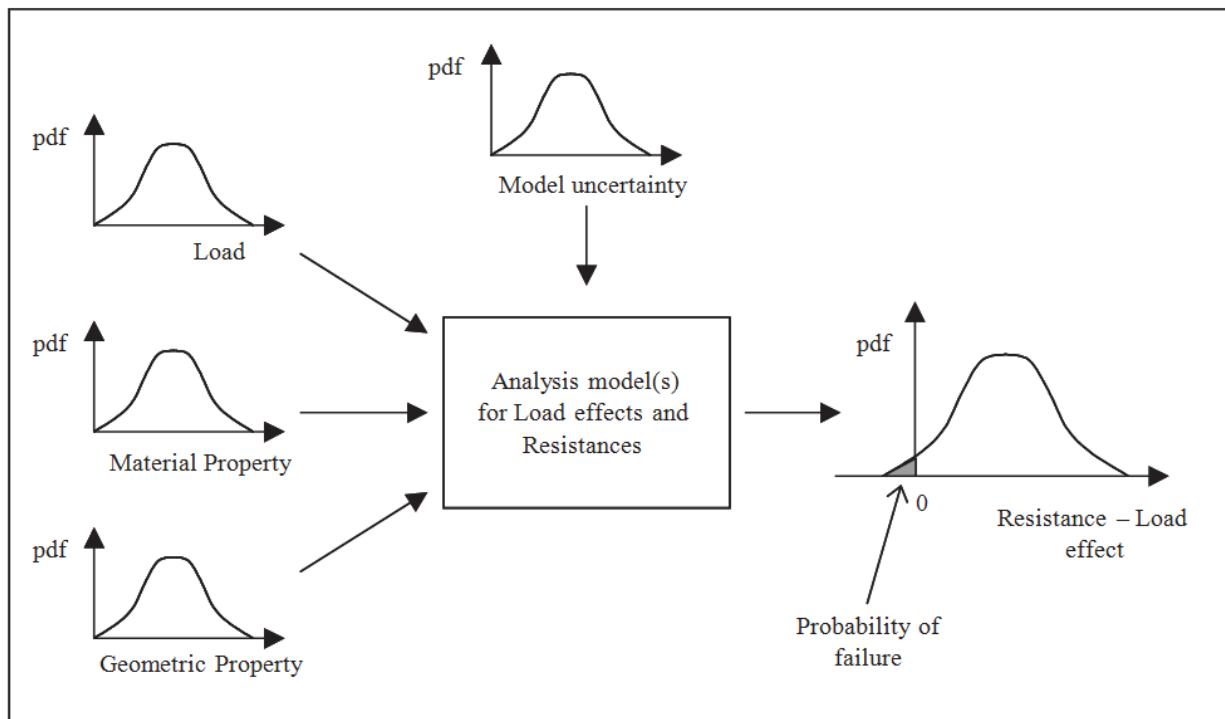


Figure C.1 – Illustration of Reliability Analysis Procedure

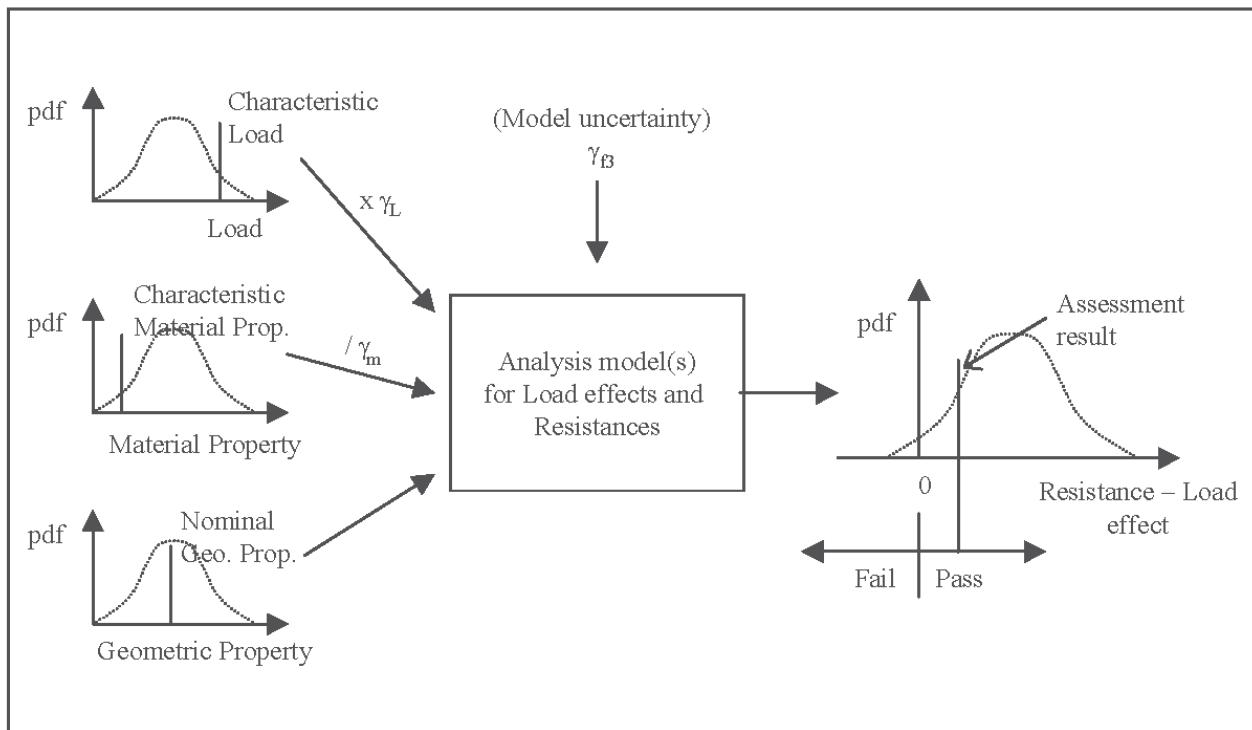


Figure C.2 – Illustration of Deterministic Analysis Procedure

APPENDIX D MONITORING OF SUB-STANDARD STRUCTURES

D1 General

- D1.1 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.
- D1.2 The class of monitoring must be selected to suit the circumstances of the particular structure and its assessed inadequacy in order to provide the level of additional assurance required. The class and type of monitoring must be appropriate for the likely failure mechanism of the structure (or part of structure to be monitored). At the lowest level monitoring may be limited to visual inspection and recording information.
- D1.3 All road structures are, as a minimum, subjected to basic visual inspections (Routine Inspections) annually or in the event of special incidents, and more detailed inspections (Principal Inspections) every one to six years (depending on the condition of the structure, the traffic on the structure and the expected rate of damage development) as described in the NRA Eirspan Bridge Management System.
- D1.4 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.
- D1.5 The extent of monitoring will depend on the type of structure, its condition, current circumstances, Load Mitigation Interim Measures proposed, the assessed structural inadequacies and likely failure mechanism. 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.
- D1.6 Where weight restrictions on a bridge or structure have been implemented, consideration should be given to ensuring adherence, the likely extent of compliance, level of policing and need for systematic monitoring.
- D1.7 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.

- D1.8 Two or more of these types of inadequacy may be present in combination. For structures falling within the scope of D1.7 (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 D1.7 (i), the assessment calculations provide the basis for identifying the critical areas for monitoring.
- D1.9 Any of the inadequacies described in D1.7 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.
- D1.10 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 D1.7 (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.
- D1.11 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.
- D1.12 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.
- D1.13 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.
- D1.14 When attempting to foresee possible modes of failure it should be borne in mind that the live load capacity factor, C (see NRA BD 21) 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.
- D1.15 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.

D2 Classes of monitoring

- D2.1 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 I. 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

- D2.2 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 National Roads Authority. 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.
- D2.3 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 NRA BD 21.

Class 2 – Detailed Monitoring

- D2.4 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 NRA BA 86.
 - (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.
- D2.5 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

- D2.6 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.
- D2.7 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.

D3 Selection of Appropriate monitoring Class

- D3.1 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.
- D3.2 A monitoring 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.
- D3.3 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.
- D3.4 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.
- D3.5 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

D3.6 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, here 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.

D3.7 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.

D3.8 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.

D3.9 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.

D3.10 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.

D3.11 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.

D3.12 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

D3.13 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.

D3.14 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 NRA BD 21 and Clause 4.6 (ii)(c) where 'C' is the live load condition factor and 'K' is the Reduction factor) 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

D3.15 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 E SUB-STANDARD STRUCTURE SUMMARY

E1.1 The form set out below provides a model for recording the progress of the assessment process in accordance with Clause 2.12. The form should be used to record any changes in the status of the Sub-standard Structure. A sample completed form is included to illustrate its application.

Structure Name:

Structure Ref. No.:

| | | | | | | |
|--|--|-------------------------------|--|--|--|--|
| Assessment/ Review | Stage: | Stage 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: | | | | | |
| Documentation | Form used: date: | | | | | |
| Additional Notes | | | | | | |

Sample Form – Sub-standard Structure Status Summary Sheet

Structure Name: Spectacle Bridge
Structure Ref. No.: CL-N67-00300

| Assessment/ Review | Stage: Date: | Stage 1 Assessment | Stage 2 Assessment | Stage 3 Assessment | Interim Measures Review | Strengthening Feasibility |
|--|---|--|--|---|--|--|
| | Date: Report reference: Assessed capacity: Sub-standard status: | 01/05/06 43216/AR1 18 tonnes Provisionally Sub-standard | 01/08/06 43216/AR2 26 tonnes Provisionally Sub-standard | 01/12/06 43216/AR3 26 tonnes Sub-standard | 01/11/08 43216/MR8 26 tonnes Sub-standard | 01/01/10 43216/SFR1 26 tonnes Sub-standard, pending strengthening |
| Interim Measures Feasibility Assessment | Date: Is the structure an Immediate Risk Structure or a Low Risk Provisionally Sub-standard Structure? | 08/05/06 Low Risk Provisionally Sub-standard Structure | 08/08/06 Low Risk Provisionally Sub-standard Structure | 08/12/06 No | 01/11/08 No | N/A N/A |
| | Is the structure monitoring-appropriate? | Monitoring-appropriate Structure | Monitoring-appropriate Structure | Monitoring-appropriate Structure | Monitoring-appropriate Structure | N/A |
| Interim Measures Proposal | Date: Recommendations: | 08/05/06 No interim measures proposed. | 08/08/06 No interim measures proposed. | 12/12/06 Load Mitigation IM: Weight restriction 26 tonnes, or Monitoring IM: see Monitoring Spec. 43216/MS1 | 01/11/08 Weight restriction 26 tonnes, with continued monitoring. | 01/01/10 Strengthen structure with FRP |
| Interim Measures Approval | Date: Approval/Rejection: | 22/05/06 TAA approval of lack of IM | 22/08/06 TAA approval of lack of IM | 05/01/07 Monitoring IM approved | 15/11/08 Weight restriction and monitoring approved | N/A N/A |
| Actions | Implementation date: Details/ref: Provisional finish for monitoring: Removal date: | 22/05/06 No IM imposed. Assessment to progress to Level 2 N/A N/A | 22/08/06 No IM imposed. Assessment to progress to Level 3 N/A N/A | 01/02/07 See Monitoring Spec and Monitoring Reports 43216/MR1-43216/MR8 01/02/10 30/06/10 | 01/12/08 Restriction sign, purchase order no: PO43216-1. Monitoring reports 43216/MR9-13. Prioritise for strengthening N/A 30/06/10 | June 2010 Structure strengthened; see design drawings 43216/FRP/DR10 102, and spec. 43216/FRP/SP1 N/A N/A |
| Documentation | Form used: date: | Appendix F 22/05/06 | N/A | Appendix I 01/02/07 | Appendix J 01/12/08 | Appendix L June 2010 |
| 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 2 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 F

INTERIM MEASURES FOR FEASIBILITY ASSESSMENT FOR BRIDGES

(To be completed when a potentially Sub-standard Structure is identified.)

1. GENERAL DETAILS

1.1 Structure name and assessment reference:

Structure Ref No:

(National Roads Authority or other Road Authority to confirm)

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 G INTERIM MEASURES FOR FEASIBILITY ASSESSMENT FOR RETAINING WALLS

(To be completed when a potentially Sub-standard Structure is identified.)

1. GENERAL DETAILS

1.1 Structure name and assessment reference:
Structure Ref No:

(National Roads Authority or other Road Authority to confirm)

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 Principal 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 H PROPOSAL FOR INTERIM MEASURES

1. GENERAL DETAILS

1.1 Structure name and assessment reference:
Structure Ref No:

(National Roads Authority or other Road Authority to confirm)

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) including maximum duration and date for formal review.

2.4 Summary of Recommended Monitoring Interim Measures, if appropriate (refer to Monitoring Specification, attached as an appendix) including maximum duration and date for formal review.

2.5 Proposal made by:

..... Date:

..... Lead Structural Assessment Engineer

..... Date:

..... Principal for assessing organisation

3. ACCEPTANCE OF INTERIM MEASURES

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

..... Date:

..... NRA Regional Bridge Manager¹

..... Date:

..... NRA Project Manager - Structures¹

Notes:

¹ National Roads Authority and/or Roads Authority to sign to confirm that recommended Load Mitigation Interim Measures and Monitoring Interim Measures have been accepted.

APPENDIX I MONITORING SPECIFICATION

I1.1 As stated in Clause 5.16, 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 Appendix F and G). 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 NRA BD 21 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 progression 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 National Roads Authority.

(7) Review of monitoring Requirements

This section should include provisions for regular review of the monitoring regime, its planned maximum duration (see Clause 5.18), and also any procedures following observed behaviour of the structure, such as an increased or reduced monitoring frequency.

(8) Protocol for Monitoring, Reporting and the Escalation of Decision Making

This section should include the protocol for monitoring, reporting and escalation of decision making including a definition of roles and responsibilities, contact details for all parties including out of hours and/or deputies and a list of senior management for escalation.

(9) Emergency Response and Communication Plan

This should include the protocol for emergency response and communication, contact details for all parties including out of hours and/or deputies and a list of senior management for escalation and stakeholder suppliers to be informed.

- I1.2 The Monitoring Specification should be developed following a special inspection unless recent inspection records are adequate for the purpose.

APPENDIX J REVIEW OF INTERIM MEASURES

1. GENERAL DETAILS

1.1 Structure name and assessment reference:

Structure Ref No:

(National Roads Authority or other Road Authority to confirm)

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. EXISTING INTERIM MEASURES

2.1 Summary of existing Load Mitigation and/or Monitoring Interim Measures (details attached as an appendix if appropriate) including maximum duration and date for formal review.

2.2 Details of any changes to the structure since the implementation of Load Mitigation and/or Monitoring Interim Measures (including but not restricted to structure condition, structure usage, structure loading).

2.3 Summary of recommended action (if continuation of existing Load Mitigation and/or Monitoring Interim Measures is recommended, include maximum duration and date for next formal review).

2.4 Proposal made by:

.....

Date:

.....

Lead Structural Assessment Engineer

.....

Date:

.....

Principal for maintaining organisation

3. ACCEPTANCE FOR CONTINUATION OF INTERIM MEASURES

3.1 Acceptance of recommended Load Mitigation and/or Monitoring Interim Measures (if appropriate)

.....

Date:

.....

NRA Regional Bridge Manager¹

.....

Date:

.....

NRA Project Manager - Structures¹

3.2 Acceptance of continuation of Load Mitigation and/or Monitoring Interim Measures (if required)

.....

Date:

.....

NRA Project Manager - Structures¹

Notes:

- ¹ National Roads Authority and/or Road Authority to sign to confirm that recommended Load Mitigation Interim Measures and Monitoring Interim Measures have been appraised and their technical efficacy agreed.

APPENDIX K IMMEDIATE RISK STRUCTURE: EMERGENCY ACTION RECORD OF AGREEMENT/INCIDENT LOG

**Immediate Risk Structure
Proposals for Emergency Action
Record of Agreement/Incident Log**

Date:

| | |
|--|--|
| Structure Name | |
| Roads affected | |
| Comment on NRA BD 79 procedures | |
| Brief description of need | |
| Emergency Action (include timescale for undertaking action) | |
| Additional comments (include a brief explanation as to why the particular emergency action was chosen) | |

The above emergency proposals are agreed by:

| | |
|---|---|
| Signature: Name: Representing: Date: | Signature: Name: Representing: Date: |
| Signature: Name: Representing: Date: | Signature: Name: Representing: Date: |

APPENDIX L INTERIM MEASURES REMOVAL

1 GENERAL DETAILS

- 1.1 Structure name and assessment reference:
Structure Ref No:
(National Roads Authority or Road Authority to confirm)
- 1.2 Location, route and county/area:
- 1.3 Structure type, form, span, skew:
- 1.4 Obstacle crossed or facility carried:

2 PROPOSAL TO REMOVE EXISTING INTERIM MEASURES

- 2.1 Summary of existing Load Mitigation and/or Monitoring Interim Measures (details to be attached as an appendix if appropriate).
- 2.2 Summary of proposal to remove existing Load Mitigation and/or Monitoring Interim Measures (to include details of completed strengthening and/or replacement works to be attached as an appendix if appropriate).
or
- 2.2 Summary of justification to make the weight limit a permanent measure and no longer subject to periodic reviews.
- 2.3 Proposal made by:

..... Date:

..... Lead Structural Assessment Engineer

..... Date:

..... Principal for organisation

3 ACCEPTANCE FOR REMOVAL OF INTERIM MEASURES

3.1 Acceptance of recommended removal of Load Mitigation and/or Monitoring Interim Measures (if appropriate)

..... Date:

..... NRA Regional Bridge Manager¹

3.2 Acceptance to remove Load Mitigation and/or Monitoring Interim Measures (if required)

..... Date:

..... National Roads Authority and/or Road Authority

3.3 Acceptance to remove Interim Measures¹

..... Date:

..... NRA Project Manager - Structures¹

Notes:

¹ National Roads Authority and/or Road Authority to sign to confirm that recommended removal of Load Mitigation and/or Monitoring Interim Measures have been appraised and their technical efficacy agreed.



Bonneagar Iompair Éireann
Transport Infrastructure Ireland



Ionad Ghnó Gheata na
Páirce,
Stráid Gheata na Páirce,

Baile Átha Cliath 8, Éire



Parkgate Business Centre,
Parkgate Street,
Dublin 8, Ireland



www.tii.ie



+353 (01) 646 3600



info@tii.ie



+353 (01) 646 3601