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Transport Infrastructure Ireland

TII Publications

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Stage 1 Structural Assessment of Road Structures

AM-STR-06056
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AM Asset Management & Maintenance

Standards

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TII Publications

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1. Introduction

1.1 General

The purpose of this Standard is to confirm the requirements of a Stage 1 Structural Assessment of road structures. The need for a Stage 1 Structural Assessment of a road structure may arise due to concerns regarding load-carrying capacity following deterioration of a structure, or as part of a programme of assessments by a Road Authority, or if an existing structure is to be widened or amended as part of a Transport Infrastructure Ireland (TII) road or bridges scheme.

This document supplements the requirements of AM-STR-06026 and AM-STR-06002 and provides clarity and further direction in relation to inspection, testing and assessment in particular circumstances.

If this Standard is to be used for the assessment of regional, local or unclassified road structures, the Lead Structural Assessment Engineer should agree with the relevant Road Authority the extent to which the document is appropriate.

If, in the course of an assessment, a structure is found to be inadequate to the extent that an immediate risk to public safety exists, the procedure described in AM-STR-06039 regarding action for “Immediate Risk Structures” shall be followed.

A Stage 1 Structural Assessment Report shall be submitted to the Road Authority following completion of all inspections, investigations and analysis in accordance with Chapter 5 of this Standard.

1.2 Scope

This Standard covers the assessment of bridges constructed of steel, concrete, iron and masonry arches. It does not cover timber structures or stone slab ‘clapper’ bridge decks.

1.3 Assessment Stages

Assessment of an existing structure should be carried out in stages of increasing complexity, with the object of efficiently determining its capacity. 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 if a bridge manager considers an assessment ‘pass’ result is possible, and later stages should seek to remove any conservatism in the assessment calculations.

If a structure fails its Stage 1 Structural Assessment and a bridge manager considers that use of a less conservative method of analysis may identify apparent hidden reserves of strength and yield an assessment ‘pass’ result then a Stage 2 Structural Assessment may be undertaken. This involves the use of more refined analysis and better structural idealisation and further details can be found in AM-STR-06057.

If a Stage 2 Structural Assessment does not demonstrate the adequacy of a structure then a Stage 3 Structural Assessment as defined in documents AM-STR-06039 and AM-STR-06057 should be considered. This more advanced assessment involves the use of specialist techniques such as Bridge Specific Assessment Live Loading (BSALL), reliability-based methods of assessment and load testing according to AM-STR-06014.

2. Inspection for Assessment

The inspection for assessment shall be carried out in accordance with Chapter 2 of AM-STR-06026 'The Assessment of Road Bridges and Structures'. The requirements specified here supplement the requirements of AM-STR-06026. The assessor shall not solely rely on As-Built drawings, if available, and will need to undertake an inspection to verify construction form, measure critical dimensions on site, confirm condition factors and record any deterioration of structural components, identifying the extent of deterioration, loss of section, etc. in the context of potential loss of strength. A detailed sketch showing the critical structure dimensions and location of defects is required for the report. The inspection for assessment must be undertaken by the assessor. Inspection for assessment by an engineer other than the assessor is not acceptable.

2.1 Masonry Arches

All information required to be collected on site during the inspection for assessment is detailed in AM-STR-06026. Measurements which need to be taken include the following:

- Span length (*L).*
- Skew length.
- Rise of arch barrel at crown (r_c) and quarter (r_q) points. Additional dimensions should also be taken at ⅛ and $^1/_{16}$ points should a more rigorous analysis be required.
- Thickness of arch barrel (*d*). The minimum and maximum arch thickness visible should be measured on site. Generally site investigation will not be carried out to determine arch barrel thickness during a Stage 1 Structural Assessment unless the masonry arch has been widened with a more modern structure type. If site investigation works are to be carried out on the widened structure as part of the Stage 1 Structural Assessment then investigative works should also be carried out on the masonry arch unless significant additional traffic management is required. The assessor shall liaise with the Road Authority to establish the extent of site testing.
- The average depth of fill (*h)* at the crown including road surfacing.
- Carriageway widths and parapet dimensions.
- For multi-span arches the pier dimensions should also be taken.

In carrying out a dimensional survey on the masonry arches the inspector shall ensure that readings are accurate and representative of the whole arch and not just one cross-section. Details of significantly different cross-sections should be recorded given each different cross-section will require assessing if an assessment method other than Archie-M is used. Arch rise dimensions shall be measured using a dumpy level.

In order to determine the various modification factors other additional information needs to be gathered from the visual inspection. This includes:

- The type and condition of material used for the arch barrel i.e. limestone, granite, sandstone, shale, schist etc. (F_b).
- For the Stage I Assessment the Engineer should assume that the fill material is a "well compacted material" unless there is evidence to suggest otherwise such as tracking of the carriageway (F_f).
- The average width of joint shall be measured on the arch barrel (F_w).
- The condition of the mortar joint shall be determined. The inspector shall determine whether the mortar is in good condition or loose or friable (F_{mo}).

- The depth of any loss of mortar in the joints shall be determined (F_d).
- The condition factor (F_{cm}) shall be determined for the structure. Unlike the preceding factors which are based on quantitative information obtained from the visual inspection, the condition of the bridge depends more on the objective assessment of the importance of the various cracks and deformations which may be present in the structure and how far they are counterbalanced by indications of good material and workmanship. This factor is determined by engineering judgment between the values of 0 and 1. Guidance on the choice of factor is given in AM-STR-06002. Where the condition factor is less than 0.4 immediate consideration should be given to the repair of the bridge. The Road Authority shall be notified of this at the earliest opportunity.
- Inspection for axle lift-off.

When carrying out an inspection on a masonry arch the inspector should look out for signs of backing to the arch barrel. Such signs might include a combination of distinctive dry patches on the spandrel wall, leaching at a consistent level or the presence of drain holes in a spandrel wall. Depth of haunching is taken into account in a range of masonry arch assessment methods.

2.2 Reinforced Concrete Slabs

Where As-Built drawings exist for reinforced concrete slabs the assessor shall confirm geometric details by site visit. No intrusive investigations will be required provided the assessor is satisfied the As-Built details are correct.

For structures where no records exist the following information needs to be determined from a site inspection:

- A full dimensional survey of the deck slab to record width, depth and span (skew and square) of slab. Depth of fill over the deck can be determined by trial holes on top of the bridge, preferably hand-dug in the verge. The depth to a concrete slab can be determined also by drilling from the top through soft fill or by taking small diameter cores through the deck if concrete breakouts are not required. The choice of investigation method shall minimize or eliminate damage to the waterproofing membrane where possible. If the waterproofing is damaged during investigations it shall be repaired using a compatible waterproofing repair.
- The carriageway and verge/footway widths shall be measured. The inspector shall note the number of trafficked lanes on the structure.
- The actual span length, taking into consideration the location of bearings, shall be measured and used in the assessment.
- A visual examination of the carriageway shall be carried out to determine whether the road surface is ‘good’ or ‘poor’ in terms of ride quality. The assessor should refer to Chapter 5 of AM-STR-06026.
- The inspector shall identify and carefully record defects which affect the load-carrying capacity of the structure. The location, extent and severity of defects shall be recorded in a sketch to be included in the report.
- A structural investigation of the deck is required to determine concrete compressive strengths, and reinforcement layout, size, type and cover. Chapter 3 contains further details of the investigations.

2.3 Prestressed Beam Decks

Where As-Built drawings exist for a prestressed beam deck the assessor shall confirm geometric details by site visit. No intrusive investigations will be required provided the assessor is satisfied the As-Built details are correct.

For structures where no records exist the following information needs to be determined from a site inspection:

- A full dimensional survey of the deck to record width, depth, span (skew and square) and dimensions of prestressed beams if visible. Depth of fill over the deck can be determined by trial holes on top of the bridge, preferably hand-dug in the verge.
- The carriageway and verge/footway widths shall be measured. The Engineer shall note the number of trafficked lanes on the structure.
- The actual span length, taking into consideration the location of bearings, shall be measured and used in the assessment.
- A visual examination of the carriageway shall be carried out to determine whether the road surface is ‘good’ or ‘poor’ in terms of ride quality. The assessor should refer to Chapter 5 of AM-STR-06026.
- The inspector shall identify and carefully record defects which affect the load-carrying capacity of the structure. The location, extent and severity of defects shall be recorded in a sketch to be included in the report.
- A structural investigation of the deck is required to determine beam type and strand and reinforcement details. Chapter 3 contains further details of the investigations.

3. Site Investigation and Testing for Assessment

The following investigations and testing shall only be carried out where no records exist for a structure. In the case of masonry arch structures for which there will be no records, no site investigation works will be carried out unless the arch is widened with a slab as described in Section 2.1. The following requirements are in addition to the requirements of AM-STR-06026.

3.1 Determination of Masonry Arch Thickness and Depth of Fill

To determine the masonry arch thickness and depth of fill over the arch barrel, it will be necessary to dig a trial hole over the crown of the arch. Prior to carrying out any site works all services shall be located. The trial hole should be excavated by hand. Levels shall be taken for the crown (extrados and intrados) and carriageway. The Engineer should note the type and condition of fill, the presence of haunching or internal spandrel walls over the arch. In certain circumstances where the digging of trial holes is not feasible due to the presence of an excessive depth of fill, the arch thickness shall be determined by the extraction of small diameter arch barrel cores from beneath the bridge.

3.2 Reinforced Concrete Slab

Using a covermeter the Engineer shall first locate the main longitudinal reinforcement at mid-span or as close to mid-span as is possible on the deck soffit. A grid measuring 2.0m square shall be chosen. The longitudinal reinforcement pattern shall be marked on the deck soffit. Turning the covermeter head through 90° the transverse reinforcement shall be marked on the soffit also. The Engineer shall confirm an intersection between the transverse and longitudinal reinforcement and select this node as a breakout location. The breakout area shall measure 150mm x 150mm and shall be centred on this node. A saw-cut 20mm deep shall mark the boundary of the breakout and the operative shall remove the concrete in such a manner as to avoid damaging the reinforcement. On exposure of both transverse and longitudinal reinforcement the following shall be recorded:

- Cover to main reinforcement.
- Diameter of longitudinal and transverse reinforcement.
- Condition of reinforcement.
- Reinforcement type i.e. mild or high yield steel.

Once the cover to the reinforcement and the rebar size has been determined, the covermeter can be calibrated and a complete and accurate covermeter survey carried out on the deck.

To determine the shear reinforcement, similar procedures shall be followed on the deck surface in a 1.0m x 1.0m test panel adjacent to the support.

A maximum of 3 no. 100mm diameter cores shall be retrieved from the slab soffit at non-critical locations to test for concrete compressive strength. All samples shall be extracted and tested in accordance with IS EN 12504: 2009 and IS EN 13791: 2007.

For portal frame and box culvert structures it may be necessary to determine the reinforcement arrangement at the top/rear of the walls by breaking out locally.

3.3 Prestressed Beam Deck

For prestressed beam decks structural investigations are required to determine the beam type and dimensions, and the strand and reinforcement arrangement. A trial hole shall be dug in the verge or carriageway directly over the end of an internal beam and ballast wall. If excavating in the verge great

care shall be taken in locating and avoiding service ducts. In situations where a ballast wall exists it may be necessary to completely remove this locally in order to see the end of the beams. If possible reinforcement should be left in place.

A vernier callipers shall be used to determine the diameter and spacing of strands in the prestressed beam.

Shear links in precast prestressed beams need to be located and sized. This can be achieved by breaking out the concrete infill over the beams at the beam ends. To determine the spacing of the links, a covermeter survey shall be carried out on the soffit of the beam. If determination of the spacing of the links by covermeter proves to be unsuccessful, further links shall be exposed from the deck surface.

3.4 Transverse Reinforcement in Precast Beam Deck Slabs

The Engineer shall determine the size, type and spacing of transverse reinforcement in precast beam deck slabs using one or both of the following methods:

- Drill a pilot hole vertically upwards between beams and use a depth probe covermeter to locate the position of transverse reinforcement. A small diameter core is taken at the reinforcement location between beams to determine bar size and type, assuming that the strands of the beam will not be interfered with.
- Locating and exposing reinforcement on edge of deck/fascia.

3.5 Encased Steel Beams

Localised breakouts of the concrete should be undertaken to expose the bottom flange and web of encased steel beams. The size and spacing of encased steel beams are recorded; an ultrasonic thickness gauge can be used to determine the thickness of the sections without having to expose both sides. It may be necessary to expose the full height of the beam if it is a non-standard section. The most appropriate location for breakouts is on the edge beam.

3.6 Determination of Steel Thickness

Steel thickness for plate girders or encased steel beams can be measured using vernier callipers or, for components with one side hidden, an ultrasonic thickness gauge. Corrosion deposits must be removed from the test area using a wire brush to ensure an accurate measurement. Corrosive deposits on a hidden surface do not disturb the reflections and in turn no surface preparation is necessary when measuring steel thickness by ultrasonic thickness gauge. Prior to taking a measurement a contact liquid must be applied to the test position. For laminated steel plates most ultrasonic thickness gauges will measure the thickness of the first layer only.

3.7 Reinforced Concrete Arches

For reinforced concrete arches the intrados and extrados reinforcement size shall be determined by localised breakout at the edge of the arch. Spacing of the intrados reinforcement shall be determined by covermeter survey. The extrados reinforcement spacing shall be determined using pilot drill holes and depth probe covermeter. This shall be carried out at a number of non-critical locations. The pilot drill holes can also be used to determine the depth of arch.

3.8 Reinstatements

All trial holes, deck breakouts, verges, joints etc. shall be fully reinstated after completion of site investigation works.

All concrete breakout areas including ballast walls shall be reinstated in accordance with CC-SPW-05500. The Engineer shall ensure that all repairs are cured adequately and that deck surface repairs are allowed sufficient time to set prior to the reinstatement of fill materials.

Trial holes over masonry arches shall be backfilled with an appropriate fill material to Cl 804 of CC-SPW-00800, compacted in accordance with the Specification. Core voids in masonry arch barrels shall be reinstated using appropriate materials and finished with a mortared section of stone from the core.

On decks where a waterproofing membrane exists, this shall be reinstated with a compatible, approved system with adequate overlaps provided.

Trial holes dug in carriageways shall be reinstated with either a 20mm dense bitumen macadam or hot rolled asphalt. Prior to the reinstatement of the surfacing material the edges of the trial hole shall be saw cut and the deck shall have a tack coat applied. The saw cut edges shall be dressed with hot poured bitumen before and after the placing of the surfacing material.

3.9 Notification of Relevant Authorities

Prior to carrying out any site investigation works the Engineer shall advise the Road Authority of the extent of the works and the anticipated start date and duration. Site investigation works shall only be carried out by approved testing houses and civil contractors with experience of similar work.

4. Assessment Methodology

For all structural types the Engineer shall determine the load carrying capacity of the structure in accordance with this Standard, AM-STR-06026 and AM-STR-06002. An assessment of HB loading shall be undertaken and a HB rating given. It is not sufficient to state that a structure has failed its assessment for 40/44T Assessment Live Loading; a capacity must be given. For cases where structures are found to be incapable of carrying the full 40/44T Assessment Live Loading, specified limits on gross vehicle weights shall be stated in the report, along with a HB rating.

4.1 Single Span Arches

Single span masonry arches shall be assessed using the Modified MEXE method in accordance with AM-STR-06002 'The Assessment of Road Bridges and Structures' provided the limitations on the appropriate use of this method are not exceeded. In instances where arch geometry or arch conditions render a MEXE Analysis inappropriate then one of the following methods of analysis shall be used to assess the arch:

- Three-hinge limit analysis method
- Rigid block method

Masonry arch bridges were sometimes constructed with voussoir fascia stones which are larger than the arch barrel stones behind the voussoir fascia stones. For structures where the actual arch barrel thickness (d), is known, the actual arch barrel thickness shall be used in the Assessment. For structures where the arch barrel thickness is unknown, the analysis shall return an upper and lower bound capacity rating for the structure based on depths of d and $0.6d$ of the fascia voussoirs stones for the upper and lower bound ratings respectively.

For arch structures where $h > d$ (where h is depth of fill), the guidance given in AM-STR-06026 for the MEXE analysis shall be used with results corroborated using a three-hinge limit analysis method or a rigid block method.

For masonry arches which have been repaired using sprayed concrete applied to the intrados, the Engineer shall not take into account the concrete thickness in the Stage 1 assessment calculations unless the concrete arch is believed to be acting compositely with the masonry arch barrel, is dowelled to the existing masonry arch and founded on abutments. An appropriate mortar factor shall be used and the Engineer shall include commentary in the report on what mortar factor was used and why.

If the characteristic strength of the masonry is required, Figure 4.3 of AM-STR-06026 shall be used.

Should the structure not achieve a 40/44T Gross Vehicle Weight (GVW) rating under the initial analysis, the Engineer shall undertake a sensitivity analysis to determine whether simple repairs such as repointing the masonry arch barrel, or crack-stitching, or restraining outward wall movement using tie-bars and pattress plates would increase condition factors such that a 40/44T GVW capacity is achieved. In particular where loss of mortar depth is considered, the report shall state whether, and to what degree, full repointing of the arch increases the assessed capacity. The assessor shall also examine and report on the effects the presence of backing may have on results.

On completion of the Stage 1 assessment, the Engineer shall report his/her findings stating what assumptions, if any, have been made.

When reporting on the findings of the structural assessment for structures that do not achieve a 40/44T GVW capacity rating the Engineer shall, using engineering judgement, indicate whether the 40/44T GVW capacity can be achieved using further analysis in a Stage II assessment.

If the Engineer considers it unlikely that a 40/44T GVW rating can be achieved using further analysis then the Engineer shall recommend strengthening works, giving details and indicative costs.

For sub-standard structures the Consultant shall determine, in accordance with AM-STR-06039, The Management of Sub-Standard Structures, whether the structure is an Immediate Risk or Low Risk Structure and shall recommend interim measures as deemed appropriate. The Consultant shall consider the appropriateness of the interim measure and its suitability for the structure and route in question. For example, a weight restriction on a National Route may not be considered appropriate for a structure which is not showing any signs of distress; monitoring the structure at regular intervals may be more appropriate. It is recommended that the Consultant liaises closely with the Road Authority with regards to this. Forms in the appendices of AM-STR-06039 shall be completed and included in the Assessment Report as necessary.

Masonry arches shall be assessed for HB loading in the Stage I Assessment.

4.2 Multi-Span Arches

Multi-span arches shall be assessed using the Modified Mexe method if they possess piers which are short and wide, otherwise they shall be assessed using a three-hinge limit analysis method or a rigid block method. Similar principles as detailed in Section 4.1 shall apply to multi-span arches as apply to single span arch structures in assessment.

4.3 Concrete Slabs/Prestressed Beams/Composite Decks

Initial assessments of concrete/prestressed beam slabs and composite decks shall be carried out using the strip method analysis. The deck shall be assessed in accordance with AM-STR-06026 for 40/44T Assessment Live Loading and 45 units HB Loading. Should the structure fail to attain a 40/44T GVW capacity then a more rigorous assessment in the form of a grillage analysis shall be carried out and a revised capacity and HB rating given.

If after carrying out the above analysis the structure still fails for 40/44T Assessment Live Loading, the Engineer shall determine whether a 40/44T GVW rating can be achieved using further detailed analysis in a Stage II Assessment. If it is considered that a 40/44T GVW capacity is unlikely to be achieved then recommendations shall be made in the report for strengthening. The Consultant shall determine, in accordance with AM-STR-06039, whether the structure is an Immediate Risk or Low Risk Structure and shall recommend interim measures as deemed appropriate. The Consultant shall consider the appropriateness of the interim measure and its suitability for the structure and route in question. For example, a weight restriction on a National Route may not be considered to be appropriate for a structure which is not showing any signs of distress; monitoring the structure at regular intervals may be more appropriate. It is recommended that the Consultant liaises closely with the Road Authority with regards to this.

4.4 Substructure and Foundations

A qualitative assessment shall be carried out on the sub-structure and foundations of all bridges in accordance with Chapter 8 of AM-STR-06026.

4.5 Parapets

A qualitative assessment shall be carried out on the parapets. For masonry parapets the report shall state whether the parapets meet the height, length and density requirements of BS 6779.

5. Reporting

Reports shall be produced to a consistent standard format for each structure assessed. The format of these Assessment Reports shall be as follows:

1.0 Location Map

2.0 Executive Summary (With Table)

3.0 Introduction

4.0 Description of Structure

5.0 Visual Inspection of Structure

6.0 Site Investigation Results

7.0 Assessment of Structure

8.0 Conclusions

9.0 Recommendations

Appendix A	List of Drawings and Sketches (to include plan and cross-section drawings and defect sketches)
Appendix B	Photographs (From Assessment Inspection)
Appendix C	Site Investigation Results
Appendix D	Calculations
Appendix E	Sub-Standard Structure Summary (Form in Appendix E in AM-STR-06039)
Appendix F	Interim Measures Feasibility Assessment (Form in Appendix F in AM-STR-06039)

The Executive Summary Table shall have the following column headings; Structure ID/Structure Name/Structure Type/Length/No. of Spans/Assessed Capacity/HB Rating/Comments.

The cover page shall consist of the TII and Consultants Logo on the top left hand and right hand corner of the cover page respectively. This shall be followed by the text (example):

Brian Boru Bridge

Structure ID: CC-N08-001.01

Stage 1 Assessment Report

This shall then be followed by an elevation photograph of the bridge with revision status and date to be printed at the foot of the page. All reports shall be spiral bound and a digital copy of the report shall be forwarded to the Road Authority along with a CD containing all photos from the site visits. Photos shall be date-stamped. Photos from other reports shall not be used in the Assessment report; the report shall contain only photos from site visits related to this Structural Assessment.

When presenting data from software packages, only input data and summary output shall be presented in Appendix D of the report.

6. References

6.1 TII Publications (Standards) References

AM-STR-06002 - The Assessment of Road Bridges and Structures

AM-STR-06014 - Load Testing for Bridge Assessment

AM-STR-06026 - The Assessment of Road Bridges and Structures

AM-STR-06039 - The Management of Sub-standard Road Structures

AM-STR-06057 - The Stage 2 Structural Assessment of Sub-Standard Road Structures

6.2 Other Miscellaneous References

Safety of Historical Stone Arch Bridges (Dirk Proske, Pieter van Gelder. Springer Verlag 2009)

FIB Bulletin 45. Practitioners guide to finite element modelling of reinforced concrete structures. (CEB-FIB Task group 4.4. June 2008)

Finite Element Design of Concrete Structures. Second Edition (G.A. Rombach. Thomas Telford 2011)

Limit Analysis and Concrete Plasticity. Third Edition (M.P Nielsen, L.C. Hoang,. Taylor Francis, 2011)

Nonlinear mechanics of Reinforced Concrete (K. Maekawa, A. Pimanmas, H. Okamura. Spon Press 2003)

Steel Structures. Design Using FEM (Rolf Kindman, Mattias Krauss. Ernst & Sohn 2011)

Appraisal of Existing Structures. Third Edition 2010. Published by The Institution of Structural Engineers. ISBN 978-1-906335-04-5

Bridge Assessment and Testing – Update (2009-2010). TRL, Transport Research Laboratory 2010, Ref CT128.3

Guidance on the assessment of concrete bridges. Technical Guide 9, 2007, Concrete Bridge Development Group

Masonry arch bridges: condition appraisal and remedial treatment. CIRIA Publication C656, 2006

Enhancing the capacity of concrete bridges. Technical Guide 10, 2008, Concrete Bridge Development Group

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