Design Manual for Roads and Bridges

Highway Structures & Bridges
Inspection & Assessment

CS 464
Non-destructive testing of highways structures

(formerly BA 86/06)

Revision 1

Summary
This document sets out requirements regarding the non-destructive testing of highways structures.

Application by Overseeing Organisations
Any specific requirements for Overseeing Organisations alternative or supplementary to those given in this document are given in National Application Annexes to this document.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Highways England team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

This is a controlled document.

Contents

Release notes

Version	Date	Details of amendments
1	Mar 2020	Revision 1 (March 2020) Update to references only. Revision 0 (September 2019) CS 464 replaces BA 86/06. This full document has been re-written to make it compliant with the new Highways England drafting rules. The update removes detail regarding testing methodologies available as out of date and now focusses primarily on outcome requirements of testing.

Foreword

Publishing information

This document is published by Highways England.

This document supersedes BA 86/06, which is withdrawn.

Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

Introduction

Background

This document contains the requirements related to the non destructive testing (NDT) of highways structures.

Typical uses of NDT for highway structures are as follows:

1) gaining increased assurance as to the quality of new construction such as weld testing of steelwork;
2) gaining increased assurance as to the integrity of earlier construction where similar types of construction have been shown to be defective, such as detecting voids in post-tensioned concrete;
3) providing an indication of the possible internal structure of old bridges for assessment purposes, such as the structural form of masonry arches;
4) providing supplementary indications of the condition of structures which are showing signs of distress, such as the degree of contamination and corrosion of reinforced concrete bridges exposed to chloride attack; and,
5) recording acoustic emissions from bearings exhibiting cracking or excessive friction or from bedding to bearings undergoing cracking.

The expert interpretation of NDT results can be of assistance with structural appraisal.

Assumptions made in the preparation of this document

The assumptions made in GG 101 [Ref 3.N] apply to this document.

Abbreviations and symbols

Abbreviations

Abbreviation	Definition
AE	Acoustic Emission
ASNT	The American Society of Non-destructive Testing
BiNDT	British Institute of Non-destructive Testing
NDT	Non-Destructive Testing
PCN	Personnel Certificate in NDT
UKAS	United Kingdom Accreditation Service
UPV	Ultrasonic Pulse Velocity

Symbols

Symbol	Definition
dBAE	The unit of logarithmic measure of an acoustic emission amplitude in decibels

Terms and definitions

Terms

Term	Definition
Acoustic emission	Phenomena whereby transient elastic waves are generated by, as examples, plastic deformation, crack propagation, erosion, corrosion, impact, leakage.
Acquisition system	A system consisting of sensors, data acquisition measurement hardware, and a computer with programmable software that acquires data such as an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound, generally by digitising analogue channels and storing the data in digital form.
Bill of quantities	A detailed statement of work, prices, dimensions, and other details, for carrying out the work as per the contract.
Bi-static arrangement	Mode of operation of ground penetration radar when two separate transmitting and receiving antennae are used and Tx and Rx antennas are separated in space.
Coin tap test	Manual test including the tapping of a coin on a surface to establish the integrity of a material that can be subject to delamination/cracking and voids/hollowness.
Gain	Process of amplifying signals to match the dynamic range of the display or the recording device.
Global monitoring	Acoustic emission monitoring technique to identify the presence of active defects in a structure with a minimum number of sensors over long distances.
Ground penetrating radar	An electromagnetic echo sounding method where electromagnetic impulses are transmitted into structure and recorded by a receiver.
Hammer tap test	Manual test including the tapping/dragging of a hammer on a surface to establish the integrity of a material that can be subject to delamination/cracking and voids/hollowness.
Hsu-Nielsen source (pencil lead break)	Device to simulate an acoustic emission event using the fracture of a brittle graphite lead in a suitable fitting.
Impact echo	A send-receive non-destructive test method based on the use of a short-duration mechanical impact to generate transient stress waves and the use of a broadband receiving transducer placed adjacent to the impact point.
Local monitoring	Acoustic emission monitoring technique to provide detailed information on source location, orientation and on the characteristics of defects and failure.
Monostatic arrangement	Mode of operation of ground penetration radar when transmitting antenna is combined in the same housing as the receiving antenna.

Terms (continued)

Term	Definition
Non-destructive testing	A wide group of investigative techniques used to evaluate the properties of a material, component or system without causing damage.
Semi-global monitoring	Acoustic emission monitoring technique to accurately locate and identify the individual defects and to provide a 100% volumetric condition assessment of a structure.
Transducer	Active element of a probe which converts electrical energy into sound energy and vice versa.
Ultrasonic pulse velocity	An in-situ, nondestructive test to check the quality of concrete using the velocity of an ultrasonic pulse passing through the structure.
Sonic tomography	Measurement of stress wave transmitted through structure when section crossed by a net of wave paths.
Sonic transmission	Measurement of stress wave transmitted through structure.

1. Scope

Aspects covered

1.1 NDT (non-destructive testing) shall be carried out where required to assure that new construction is in accordance with the relevant specification and design assumptions, and to help establish the condition of existing construction and the appropriateness of assessment assumptions.

1.2 This document sets out the specific requirements that shall be carried out for NDT of highways structures, including:

1) existing structure requirements;
2) commissioning and specification requirements;
3) specific requirements regarding structural form and testing; and,
4) records and certification requirements.

Implementation

1.3 This document shall be implemented forthwith on all schemes involving non-destructive testing on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 3.N].

Use of GG 101

1.4 The requirements contained in GG 101 [Ref 3.N] shall be followed in respect of activities covered by this document.

2. Preliminary work

Assessment of the structure condition

2.1 A visual inspection of the structure shall precede specification of a testing programme.

NOTE An initial visual inspection allows particular circumstances and the current condition of the structure to be taken into account.

2.2 During the preliminary stage, the following factors shall be determined:

1) visual defects that require further investigation;
2) the influence of access and test number on costs;
3) the effectiveness of a staged approach in prevailing circumstances;
4) the cost of tests relative to the potential significance of the irregularities; and,
5) the time required for test results and their interpretation, if further testing is dependent upon results.

NOTE Due to the varied nature of structures and their defects, specification of the same types and number of tests as used on another structure is rarely likely to be appropriate.

2.2.1 In order to assess the current capacity, and the likely durability of a structure and to plan remedial works, the following information should be obtained:

1) age of the structure and the dates of any modifications or repairs;
2) materials with which the structure has been built or modified;
3) properties of these materials, such as strength and ductility;
4) geometry of the bridge, the size of members and details of the joints; and,
5) condition of the members, joints and protection of the structure, including defects; corrosion, and distortion or damage including fatigue damage.

2.2.2 Testing programmes should be devised, upon assessing the following:

1) striking a balance between obtaining sufficient information to make a reasonable judgement on risk, and seeking so much information that the examination itself compromises durability by intrusive sampling;
2) the effectiveness of testing in combination; for example ducts can be located by specialist probes or radar in preparation for intrusive drilling and sampling or impact-echo testing as per guidance in Impact-Echo of PT concrete [Ref 3.I] and NDT 2004 [Ref 4.I];
3) tests can be interpreted in combination; for example a representative sample of locations revealing a particular characteristic can be examined in greater detail by a variety of more detailed tests as per guidance in ACI Technical Report 228.2R-13 [Ref 10.I];
4) particular characteristics can be examined in greater detail by a variety of more detailed tests;
5) testing programmes are only provisional, and can require amendment as a result of continuing testing and interpretation. Staged testing, permitting interpretation of results between each stage, can be appropriate on larger jobs; and,
6) intrusive drilling and sampling can provide invaluable information on materials, corrosion details, void volumes, and atmospheric leakage in order to calibrate the NDT techniques.

2.2.3 The condition evidence required may be obtained by combining different examination and test methods, each one offering particular advantages and disadvantages:

1) visual examination including, for example, looking for corrosion, cracks, deformities, mechanical damage or indication of slip or movement at joints or at the interface between concrete deck and steel beams;
2) testing of small samples of the materials taken from structurally safe locations to determine properties unless these are known with certainty;

3) geometric survey to determine straightness, verticality, deformation and deflection of members, and the positions and sizes of members and details of joints;
4) hammer tapping survey, where appropriate, to determine soundness of bolts and rivets, or corrosion leading to delamination within wrought iron members; and,
5) NDT techniques to locate and/or size defects, and to determine member or paint thickness.

NOTE The effectiveness of NDT methods can be heavily influenced by the geometry and materials of the structure under investigation, such as the depth reinforcement or other key hidden structural elements as per guidance in Martin, J. & Forde, M.C. (1995) [Ref 6.I] and Lyons et al 2005 [Ref 7.I].

Selecting appropriate NDT methods

2.3 The prevailing condition of the structure shall be assessed to determine a suitable combination of tests that together build up a picture of the structure and its condition.

NOTE 1 NDT techniques are not definitive, and require calibration and therefore it can be necessary to frequently evaluate the results from different tests in combination, in order to achieve a meaningful interpretation.

NOTE 2 A return to site, after the analysis of early tests, to undertake further testing can be necessary.

2.4 The effectiveness of each NDT method in the prevailing situation shall be predicted in advance of specification.

NOTE The effectiveness and accuracy of each NDT method for use in a particular structure and in specific circumstances can be different.

2.4.1 Staged work should be identified to enable targeted testing and determine more detailed information about features identified in earlier tests.

NOTE Additional tests can be required in order to determine the extent of structural features or faults.

2.4.2 Prior to commissioning the NDT, a site visit should be undertaken to assess the structure and the suitability of the proposed testing strategies, as well as to determine any specific requirements.

2.4.3 The testing strategy should be chosen through consultation between the designer and the testing contractor.

2.4.4 NDT should only be used where, after allowing for the accuracy of the testing, the results would usefully inform on the assessed capacity of a structure.

NOTE 1 A sensitivity analysis can be necessary prior to commencing the works to identify whether NDT testing is sufficiently accurate to be useful.

NOTE 2 Trial NDT testing can be necessary to establish that a full set of testing provides useful data.

3. Commissioning, specification and tender requirements

3.1 Extents of the commissioning shall be identified when developing the scope to ensure the NDT technique utilised is appropriate to the work carried out.

3.2 NDT shall not damage the structure or result in weakening an already damaged structure unless specifically permitted within the works specification.

3.2.1 Where NDT techniques do not provide definitive results regarding the structures condition, intrusive testing may need to be carried out in parallel.

Accreditation

3.3 Accredited organisations shall be used to carry out any NDT work.

3.3.1 Accreditation of personnel and organisations carrying out NDT testing should be conducted against BS EN ISO/IEC 17020 [Ref 1.N] and BS EN ISO 9712 [Ref 6.N].

3.4 NDT testing shall be carried out by a supplier with a UKAS accreditation.

Tender documentation and specification

3.5 The tender documents setting out the testing specification shall include a description of the works required.

3.5.1 The following information should be included within the tender documentation:

1) location of structure;
2) as-built drawings providing general arrangement, structure and materials of the bridge;
3) elements of the bridge to be tested;
4) whether the structure of the bridge is to be determined or confirmed;
5) whether faults in the bridge are to be detected and/or known faults are to be investigated;
6) results of previous testing such as drilling-in so that the testing organisation can use these for calibration purposes;
7) information on any known faults;
8) preliminary hazard information such as adjacent highways, railway lines, water courses or overhead electrical equipment;
9) information on live services present such as buried cables which impact on the accuracy of the data;
10) as-built drawings providing reinforcing details, duct types and sizes, profiles, locations and depth of cover;
11) which ducts and which lengths of ducts are to be tested in detail;
12) whether other ducts or intermediate lengths of the above ducts are to be tested at sample locations. Interval to be stated; and,
13) confirmation of tendon material.

3.5.2 The testing organisation should be asked to confirm all hazards such as adjacent highways, railway lines, water courses or overhead electrical equipment themselves and carry out risk assessments.

3.5.3 A bill of quantities may be drawn up giving:

1) mobilisation costs;
2) cost of test and interpretation at each test location (different costs for different degrees of access difficulty); and,
3) cost of testing report.

3.6 A specification shall be produced setting out the requirements of the NDT testing.

3.6.1 The deliverables from testing organisations should be stated in the tender documentation and specification.

3.6.2 The following information should be set out as a deliverable as part of the tender documentation and the specification:

1) the name and precise location of the structure using Ordnance Survey co-ordinates;
2) the date, time and weather, including temperature when the survey was undertaken;
3) the dimensions of the structural elements;
4) the location and size of the test areas including orientation relative to North;
5) the surveying method chosen for the accurate positioning of the equipment on the structure, and how this is indicated, both on the raw data outputs and on the interpretative drawings;
6) plots of the measuring grids;
7) the trade name, model and frequency of standard instrumentation used, specification of non-standard instrumentation and similar details of any interpretative software;
8) the type of survey carried out, a clear description of the methodologies of collection of the data, the test locations used and a demonstration as to whether these were able to locate structural features, faults or voids at all locations required;
9) the personnel involved in the survey, including their qualifications and experience;
10) raw and, if applicable, filtered data to provide a clear view of the quality of the data print-out in a format such that it can be interpreted by a second opinion;
11) a clear indication of the accuracy and sensitivity of the survey based upon the choice of the hardware provided in a format so that the specifying engineer can compare the claimed accuracy with the plots and further interpretation carried out at a later date;
12) a plot of results in tabular and graphical format and an interpretation of these;
13) drawings showing the positions of structural elements and of clear voiding or faults, together with size or volume, of possible voiding and other defects, together with their location and extent;
14) an indication of the accuracy of the information provided in (8) above, and the likelihood of there being unidentified defects;
15) a discussion of the number of readings and a demonstration of whether these were able to locate structural features, faults or voids at all locations required;
16) the results of complementary NDT or in situ tests, such as confirmation of the presence or absence of voids by physical drilling and endoscopic inspection;
17) photographs of structure including close-ups of areas investigated; and,
18) a reference to this document.

3.6.3 The deliverables required from the testing organisation(s) should be set out in the specification and are given below:

1) raw and filtered data (or traces);
2) contoured plots where applicable;
3) diagrammatic type interpretation; and,
4) interpretation of the data.

3.7 Where drilling and subsequent sealing of holes is carried out as part of the NDT, these activities shall be carefully specified and supervised to avoid potentially serious damage to the structure.

3.7.1 The NDT specification should require test locations or traverse lines across the structure to be clearly marked.

3.7.2 A diagrammatic interpretation of the results from the NDT should be required within the specification.

3.7.3 Markers should be shown on the records or traces indicating lateral locations where apparatus is moved across the section of the structure under investigation.

3.8 After testing has been carried out, all breakout and holes shall be repaired.

4. Undertaking non-destructive testing (NDT)

4.1 Visual inspections shall be carried out prior to more detailed NDT being undertaken.

4.2 Personnel undertaking NDT shall be competent and accredited in accordance with BS EN ISO/IEC 17020 [Ref 1.N].

5. NDT records

5.1 Records shall be kept regarding the non-destructive tests adopted on structures with comments and conclusions by the Overseeing Organisation.

NOTE A form for NDT records is provided as Appendix A.

5.2 Testing organisations shall provide an interpretation of the cross-sections in relation to the internal constituents of the structure and the raw data.

5.3 The results from a survey shall be presented in a format which can be clearly understood and unambiguously related to the internal constituents of the structure.

5.3.1 The deliverables from the testing organisations should include diagrammatic type interpretation (such as CAD drawings).

6. Specific structure/method requirements

Concrete testing

6.1 Where concrete strength testing is required, this shall be set out in the specification.

6.1.1 Estimation of compressive strength may be carried out using indirect methods such ultrasonic pulse velocity (UPV) and rebound hammer testing as per guidance in ACI 228 Committee Report [Ref 5.I], ASTM C805-02 [Ref 15.I], ACI Technical Report 228.2R-13 [Ref 10.I].

6.1.2 Ultrasonic pulse velocity (UPV) and rebound hammer tests should comply with BS EN 12504: parts 2 and 4 (BS EN 12504-2 [Ref 10.N] and BS EN 12504-4 [Ref 9.N]).

Post-tensioned concrete structures

6.2 For testing of conditions within post-tensioned ducts, the following information shall be included:

1) the location of the ducts and tendons;
2) the presence and characteristics of voids within ducts;
3) the existing degree of tendon corrosion; and,
4) the probability of future corrosion.

NOTE Guidance on NDT of post tensioned structures is set out in CS 465 [Ref 8.I], and CS TR72 [Ref 2.N].

Masonry arches

6.3 The appropriateness of different testing techniques shall be evaluated depending on disruption costs, depth of the investigation required, the extent and the nature of the structure to be investigated in accordance with recommendations of RILEM [Ref 12.I] and McCann et al [Ref 11.I].

6.3.1 Visual inspection may be used to identify the geometry of the arch, the surface condition of the masonry and the location of surface defects.

NOTE 1 Masonry arch bridges are highly variable in their geometry and construction.

NOTE 2 Hollowness of the masonry can be identified, in conjunction with visual inspection, by hammer tap testing or coin-tap-testing on the surface.

NOTE 3 Routine investigations, used to supplement a visual inspection, generally comprise trial holes excavated on top of the bridges, through the surfacing and fill to expose the upper surface of the barrel or any backing.

NOTE 4 Where the initial inspection indicates the need, or the purpose of the survey requires it, further investigation can be carried out by coring to determine the nature and condition of the internal masonry.

6.3.2 Cores may be used to determine the compressive strength of the masonry.

Impact echo

6.4 Procedures shall be adopted to minimise damage to the surface caused by the impactor used for the impact echo tests to ensure the concrete surface does not crumble on impact.

NOTE Minimising damage to the structure being tested reduces inaccuracies in the results from the impact echo test.

6.4.1 Impact echo testing may be carried out in line with guidance set out in Carino & Sansalone 1992 [Ref 1.I] and Carino & Sansalone 1984 [Ref 9.I].

NOTE Carino, N. J. et. al. NDT 2004 [Ref 4.I] describes impact echo test method and provides information about where the techniques can be applied.

6.5 The limitations of impact echo testing shall be assessed prior to carrying out any testing.

NOTE 1 *Dense reinforcement can affect the accuracy of impact echo testing readings - see Martin, J. & Forde, M.C. (1995) [Ref 6.I].*

NOTE 2 *Outer ducts can mask impact echo readings from inner ducts - see Carino & Sansalone 1992 [Ref 1.I].*

6.5.1 Vacuum testing rather than sonic techniques should be used to determine the volume of the voids in grouted ducts as a precursor to re-grouting them in accordance with The Concrete Society's Technical Report 'Durable post-tensioned concrete structures', 2010 CS TR72 [Ref 2.N].

6.5.2 The test report from the impact echo test should include the following:

1) the likely impact frequency achieved and the ball bearing sizes used at each location; and,
2) a discussion of the ball sizes and frequencies used and a demonstration of whether these were appropriate for locating voids at all locations investigated.

Sonic tomography for masonry arches

6.6 The tender documentation setting out the NDT testing scope shall set out specific requirements associated with sonic tomography.

6.6.1 The tender documents should include the requirement that the following additional information is provided:

1) the number of sonic transmission transits required through each element and whether tomography is to be used; and,
2) all available construction details of the structure to be tested.

6.6.2 The testing organisations providing sonic tomography testing should be asked to state:

1) the type of sonic survey proposed and proposed transit locations; and,
2) details of the hammer to be used.

6.6.3 The specification setting out the requirements for the sonic tomography testing should require details of the sonic survey carried out and the transit locations used.

NOTE *Colla et al (1997) [Ref 13.I] describes sonic tomography test method and provides information about where the techniques can be applied.*

6.6.4 The sonic tomography test method may be used when surveying the structure of masonry arches to identify construction details, voids and poor compaction of fill materials as per recommendations in Colla et al (1997) [Ref 13.I].

NOTE *The tomographic procedure can be very time consuming unless multiple receiving transducers are used.*

6.6.5 Anomalies identified during sonic tomography testing should be further investigated by drilling or excavation.

6.7 Surface damage to the structure during sonic tomography testing shall be minimised.

Ground penetrating radar

6.8 The following additional information shall be required within the tender documentation for ground penetrating radar (GPR):

1) trade name, model and frequency of both the main frame and the antennae, including date of most recent calibration;
2) probable range and choice of antennae to be used together with justifications;
3) likely filtering to be used;
4) likely number of points to be recorded; and,

5) expected standard of interpretation of the results, such as voids detected or no voids detected – together with a percentage confidence level.

6.8.1 GPR may be employed both for structural monitoring in time and for checking the outcome of repair interventions as per ASTM D6087-03 [Ref 14.I].

NOTE ASTM D6087-03 [Ref 14.I] and Malhotra, V.M et. al. NDT 2004 [Ref 4.I] describe the GPR test method and provide information about where the techniques can be applied.

6.9 Testing objectives shall depend on the geometry and material of the structure.

6.9.1 Test locations should be dictated by engineering objectives such as areas of high load concentrations or areas critical to the structural integrity.

6.9.2 Any variation in material quality or condition throughout the structure should be measured if possible.

6.9.3 Dimensions including spans, deck widths, structural depths etc. should be measured accurately to enable subsequent mapping to be undertaken.

6.9.4 The deliverables from the testing should include the following information:

1) whether used in monostatic or bi-static arrangement;
2) the number and frequency of the operating antennae;
3) the time range used and rate of data recording (number of scans per second, number of samples per scan, etc.);
4) whether filtering and gain were applied and of which kind;
5) use of survey wheel on the antenna and antenna orientation in relation of the direction of scan;
6) calibration of radar equipment;
7) precise settings used on the instrumentation, as the systems have varying capabilities and data can be recorded in a number of ways;
8) clear description of the methodologies of collection of the data;
9) whether transmission or reflection mode survey has been carried out and the surface distance covered by transmitting and receiving antennae;
10) test results compiled in the form of grey-scale plot accompanied by time window or depth scale; and,
11) 2-D and 3-D interpretative model.

Acoustic emission

6.10 Prior to commissioning the acoustic emission (AE) monitoring, the root cause, damage mechanisms and an awareness of how and when the damage is likely to propagate shall be identified in order to specify the duration and extent of monitoring.

NOTE 1 BS EN 13554 [Ref 5.N] describes the AE test method and provide information about where the techniques can be applied.

NOTE 2 A short AE monitoring duration can miss defects inactive under prevalent conditions whereas extended monitoring can provide no further new information.

NOTE 3 Typical uses of AE are as follows:

1) detection of cracking and failure in concrete structure;
2) detection of deterioration in reinforced concrete bridges, in particular for providing information on the condition of half joints and hinge joints, and detecting reinforcement corrosion;
3) detection of the residual strength of concrete beam;
4) detection of wire fractures in steel cables in both suspension and cable stayed bridges; also detecting tendon wire breaks in post-tensioned concrete bridges tendons;
5) detection and location of cracks in welded steel structures;

6) *detection of fatigue cracks in steel box-girder bridges;*
7) *detection of fatigue cracks in shear studs and degradation of concrete surrounding the studs;*
8) *detection of deterioration in bearings;*
9) *detection of fatigue cracks in steel corbels;*
10) *determine whether the structure is in a stable condition or deteriorating and how it compares with other structures of a similar type;*
11) *monitoring welded steel such as steel box-girders, orthotropic bridge decks and welded I-beam girders, steel corbels, shear studs and bridge bearings; and,*
12) *detection of secondary effects of steel fatigue such as plastic deformation and crack face fretting (rubbing).*

6.10.1 The raw data from AE monitoring should be made available if requested.

6.10.2 A final report on the condition of the structure should include:

1) the make, model and frequency range of the proposed sensors along with a calibration certificate for a typical sensor;
2) the method used to hold the sensor to the structure;
3) the method of coupling the sensor;
4) the method for verifying sensor sensitivity, location accuracy and attenuation of the structure; and,
5) make and model of AE data capturing system.

6.10.3 Global and semi-global monitoring should be used for steel plate structures.

6.10.4 Local monitoring may be used for both steel and the more heavily damped concrete structures.

6.10.5 The chosen testing strategy should identify the level of monitoring (number of sensors and information required) and the duration of monitoring.

6.10.6 The monitoring of fatigue cracking in a steel structure using an AE technique should be performed with a representative period of vehicular loading, such as one day on motorway bridges or two or more days for less frequently trafficked bridges as per Mori & Obata 1998 [Ref 2.I].

6.11 Where appropriate, AE shall be used for long-term/permanent monitoring.

6.11.1 Long-term/permanent AE monitoring should be used in the following circumstances:

1) when the defect is serious and failure or an increase in damage size could lead to the closure of a structure;
2) where damage propagation is sporadic with long intervals in between where a short period of monitoring could miss AE activity;
3) sub-standard bridges, as described in CS 470 [Ref 4.N] as examples, detection of wire breaks in suspension cables, cable stays and post-tensioning tendons; and,
4) where a structure requires periodic evaluation to assess degradation.

6.12 The location accuracy of the AE monitoring system shall be verified before the start of a test.

6.13 The position of detected AE sources found during testing shall be verified at the end of the test.

6.13.1 Verification tests should use Hsu-Nielsen source (pencil lead break) device to simulate an AE event in accordance with BS EN 1330-9 [Ref 7.N]).

6.13.2 Active AE locations may be followed up with more sensor-intensive monitoring.

6.13.3 Where defects are suspected within a structure, it may be beneficial to use a more intensive strategy such as semiglobal or local monitoring from the outset to provide accurate source location.

6.13.4 Specific additional requirements such as specific method of installation, test objectives, outputs from monitoring or limitations should be set out where required for AE monitoring in accordance with BS EN 13554 [Ref 5.N].

6.14 The resonant AE frequency applicable to the structural material shall be used.

6.14.1 Resonant AE sensors with frequency of 30-100 kHz should be used for concrete structures and resonant AE sensors with a frequency of 100 and 200 kHz for metallic structures.

6.14.2 Higher frequency resonant sensors should be used in high noise environments but only for local monitoring.

6.14.3 Broadband AE sensors should only be used for source characterisation and fundamental studies in the laboratory.

6.14.4 Interpretation of the AE signals should include a simple source location to identify the most active areas.

6.14.5 An analysis of the AE hit rate, rise time and duration should be performed.

6.15 The tender documents setting out the testing specification for AE shall include:

1) the objectives of the test and the level and duration of monitoring that is required;
2) any available information about the actual known condition of the structure; and,
3) any available information about previous AE testing and/or monitoring.

6.15.1 The following additional information should be included within the tender documentation for AE testing:

1) the specification for the AE system that is proposed; that is its make and model, and type of;
2) acquisition system; such as hit based acquisition, feature extraction capability and type of source location provided;
3) the number, type and specification of the AE sensors that are to be used;
4) an indication of where the sensors are to be located, how they are to be mounted, their separation and the procedure for checking their sensitivity when installed;
5) a general indication of the type of analysis that are to be undertaken;
6) details of relevant experience and background in testing,
7) the accuracy and reliability that are anticipated;
8) references of previous work;
9) details of the qualifications, training and experience of the testing engineers (that is, to ASNT TC-1A Level 2 AE or BiNDT PCN Level 2 AE certification);
10) procedures for reviewing the test results and qualifications of the personnel. These are to be carried out by more experienced personnel with a qualification such as the ASNT Level 3 (or equivalent); and,
11) details of their quality system used (BS EN ISO 9001 2017 [Ref 8.N]).

6.16 The application of AE monitoring shall include the following steps:

1) aim of the test;
2) preliminary survey;
3) selection of AE system;
4) selection of sensor;
5) sensor location;
6) sensor mounting and coupling;
7) instrumentation settings;
8) mounted sensor sensitivity check;
9) noise and attenuation study; and,
10) parametric data and environmental conditions.

6.16.1 The selection of the AE system should enable waveform feature recognition with separate data channels, be able to measure individual signal amplitude (dBAE), risetime, duration, absolute energy and counts, as an absolute minimum and have a sufficient sampling rate for feature extraction and waveform analysis.

6.16.2 Suitable sensors should be selected depending on:

1) material, geometry and size of the structure under test;
2) working environment;
3) type of data analysis required;
4) sensitivity and frequency range required; and,
5) signal attenuation in the material under test.

6.16.3 Global monitoring of the whole structure should use large spacings between sensors and local monitoring closer spacing.

6.16.4 Clamps should be used to hold the sensors in place and cables to be held in position to avoid interference from electromagnetic signals.

6.16.5 The settings of the AE instrumentation should be in accordance with the equipment manufacturer's recommendations where records are to be kept of the settings used during the test.

6.16.6 The sensitivity of sensors should be checked in accordance with procedure BS EN 1330-9 [Ref 7.N], where the checks are to be done at the beginning, at the end and if possible in the middle of the test.

6.16.7 A noise and attenuation study should be performed.

6.16.8 During AE monitoring additional formation, such as displacement and/or strain, together with the environmental conditions under which the measurements were made such as wind, temperature and rain, should be recorded and utilised when setting the threshold value of the equipment.

6.16.9 The following universal AE set-up information should be included for an acoustic emission bridge investigation:

1) the threshold used for recording signals and whether AE waveforms were also recorded and the corresponding threshold;
2) the type and accuracy of source location and whether location accuracy is based on an experimental investigation on the structure or previous investigations, including references;
3) the background noise level. Where background noise were unacceptable, details of the methods used to control it, such as guard sensors, using location analysis to exclude known sources of noise from the analysis, or other established methods.

6.17 The complementary use of other NDT techniques shall be assessed to confirm the findings obtained from the AE investigation.

7. Interpretation of results

7.1 The data collected shall be interpreted with reference to what it means in terms of physical features or material properties.

NOTE 1 Testing assists in the determination of the condition of a structure at a particular time. It can be necessary or cost effective to take remedial action at that time, or it can be considered safe and economical to delay remedial action.

NOTE 2 Where remedial action is delayed, it can be prudent to monitor deterioration to ensure safety is maintained and to determine the optimum time for remedial action.

7.1.1 Monitoring may be carried out by retesting at intervals or by continuous monitoring whereby equipment is installed which records information at short intervals on a regular basis.

7.2 The accuracy of predicted NDT results shall be checked before reliance is placed on the results.

7.3 The limitations of the NDT technique used shall be taken into account in assessing the results.

Results

7.4 The following key issues shall be assessed prior to installing continuous monitoring:

1) robustness of site equipment and its ability to withstand elements of the weather and sited to minimise the risk of vandalism;
2) maintenance of system including its power source by either battery or mains with battery back-up;
3) data logging capacity and its potential to store the required data between downloads and transferring the data to an offsite computer remotely;
4) facilities for analysing potentially large volumes of data.

7.5 Results from testing shall be used to inform future maintenance strategies including whether to:

1) repair;
2) monitor by automated monitoring or repeat testing;
3) leave unrepaired and revert to standard inspections.

7.6 When establishing the monitoring requirements, any additional monitoring required in conjunction with the main data shall be specified.

NOTE 1 Additional monitoring can include an accurate measure of the temperature at the same time as strain measurements or core and surface temperature monitoring to allow temperature gradients to be determined. This can be particularly applicable where solar radiation can induce large thermal differences, causing displacements and strains.

NOTE 2 Ambient air temperatures alone cannot fully determine differential structure temperatures.

8. Certification

8.1 Certification shall be provided for all NDT carried out on a structure.

8.1.1 The certification should confirm that:

1) quality assurance procedures have been followed;
2) that the client's brief has been followed as stated in the report;
3) that the experience and qualifications of the personnel carrying out and interpreting the survey are as stated in the report;
4) that the survey, testing, interpreting the results have been carried out with reasonable professional skill, care and diligence;
5) taking account of the contract terms and conditions and resources devoted to it in agreement with the client.

8.2 Certification requirements for the NDT processes carried out shall be set out within the specification.

8.2.1 Certification requirements should be agreed with the Overseeing Organisation.

9. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Ref 1.N	BSI. BS EN ISO/IEC 17020, 'Conformity Assessment Requirements for the operation of various types of bodies performing inspection'
Ref 2.N	The Concrete Society. CS TR72, 'Durable Post-Tensioned Concrete Structures'
Ref 3.N	Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 4.N	Highways England. CS 470, 'Management of sub-standard highway structures'
Ref 5.N	BSI. BS EN 13554, 'Non destructive testing. Acoustic emission testing. General principles.'
Ref 6.N	BSI. BS EN ISO 9712, 'Non-destructive testing. Qualification and certification of NDT personnel'
Ref 7.N	BSI. BS EN 1330-9, 'Non-destructive testing. Terminology - Part 9 - Terms used in acoustic emission testing'
Ref 8.N	BSI. BS EN ISO 9001, 'Quality management systems. Requirements' , 2017
Ref 9.N	BSI. BS EN 12504-4, 'Testing concrete - Part 4 - Determination of ultrasonic pulse velocity'
Ref 10.N	BSI. BS EN 12504-2, 'Testing Concrete in Structures - Part 2 - Non-destructive testing - Determination of rebound number'

10. Informative references

The following documents are informative references for this document and provide supporting information.

Ref 1.I	ACI Materials Journal, Vol 89, No 3, May/June, 296- 303. Carino, N.J. & Sansalone, M. . Carino & Sansalone 1992, 'ACI Materials Journal. Detection of voids in grouted ducts using the impact-echo method'
Ref 2.I	Nondestructive Testing Communications. 4:11-21. Mori,Y., Obata, Y. (1998). Mori & Obata 1998, 'Characteristics of Acoustic Emission source in a fatigue crack'
Ref 3.I	U.S. Department of Transportation. Federal Highway Administration. Publication No. FHWA-RD- 92-096. Dec 1993. pp84. Ghorbanpoor, A. . Impact-Echo of PT concrete, 'Evaluation of Post-tensioned Concrete Bridge Structures by the Impact-Echo Technique'
Ref 4.I	Taylor & Francis Group, LLC. Malhotra, V.M., Carino, N.J. NDT 2004, 'Handbook on Nondestructive Testing of Concrete Second Edition, 2004'
Ref 5.I	ACI, September/October 1988. J Mater . ACI 228 Committee Report, 'In-place methods for determination of strength of concrete'
Ref 6.I	Construction and Building Materials 1995, 9, No. 4, 245-255. Martin, J. & Forde, M.C. (1995) . Martin, J. & Forde, M.C. (1995) , 'Influence of concrete age and mix design on impulse hammer spectrum and compression wave velocity'
Ref 7.I	Corrosion Science, 47, No. 2. Feb. 413-433. Lyons, R., Ing, M., and Austin, S. A. (2005). Lyons et al 2005, 'Influence of diurnal and seasonal temperature variations on the detection of corrosion in reinforced concrete by acoustic emission'
Ref 8.I	Highways England. CS 465, 'Management of post-tensioned concrete bridges'
Ref 9.I	NBS Technical note 1199. U.S. Dept. of Commerce/National Bureau of standards. 1984. pp34. Carino, N.J. & Sansalone, M.. Carino & Sansalone 1984, 'NBS Technical note 1199. Pulse-Echo Method for Flaw Detection in Concrete'
Ref 10.I	ACI (2013). ACI Committee 228. ACI Technical Report 228.2R-13, 'Report on Nondestructive Test Methods for Evaluation of Concrete in Structures'
Ref 11.I	NDT&E International, Elsevier Science, Vol 34, 2001, 71-84. McCann, D.M. & Forde, M.C.. McCann et al, 'Review of NDT Methods in the Assessment of Concrete and Masonry Structures'
Ref 12.I	R.C.de Vekey ed . RILEM, 'Rilem Recommendations of Non Destructive Tests For Masonry, MS.D.3: Radar Investigation of Masonry, pp131-134; MS.D.4: Measurement of Local Dynamic Behaviour for Masonry, pp135-137; MS-D.8: Electrical Conductivity (2001)'
Ref 13.I	NDT & E International, Vol. 30, No. 4, 249-254. Colla, C., Das, P.C., McCann, D.M. & Forde, M.C.. Colla et al (1997), 'Sonic, electromagnetic and impulse radar investigation of stone masonry bridges'
Ref 14.I	ASTM, West Conshohocken, PA, USA. ASTM D6087-03, 'Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar in Annual Book of ASTM Standards, Vol. 04.03'
Ref 15.I	ASTM, West Conshohocken, PA, USA. ASTM C805-02, 'Standard Test Method for Rebound Number of Hardened Concrete in Annual Book of ASTM Standards, Vol. 04.02'

Appendix A. Technique records

Table A.1 Technique records for NDT testing

Technique/ Equipment	Structural Element	Dimensions of Element	Form of Element	Materials of Element	Structural Dimension	Void Size	Cracking Detected	Comments