The UK Highways Agency’s Advice Notes on the Non-Destructive Testing of Highway Structures

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ABSTRACT
The UK Highways Agency has published Advice Notes on the Non-Destructive Testing of Highway Structures. This paper describes the background to these Advice Notes, how they were developed and trialled, what their objectives are, and how they will be extended in the future.

The contents are based on research on various NDT techniques funded by the Highways Agency. The resulting reports have been developed by the Highways Agency’s NDT Steering Committee into Advice Notes to enable these techniques to be used for the investigation of Highway Structures.

The Advice Notes are formed of three tiers; the first tier consisting of General Guidance on NDT; the second tier comprising Areas of Application; and the third tier covering NDT Techniques. This three-tier format enables the Advice Notes to be readily extended in the future to cover further areas of application and other NDT techniques.

KEYWORDS Highway Structures, Non-Destructive Testing, Advice Notes

BACKGROUND
Introduction
The Highways Agency has funded research at the University of Edinburgh into NDT methods for determining the conditions in grouted ducts in post-tensioned concrete and the structure of, and faults in, masonry arch bridges. The NDT techniques researched there have been impact echo (I-E); sonic transmission and tomography; ultrasonic transmission and tomography; electrical conductivity; and ground penetrating radar (GPR).

Impact-Echo
In an impact-echo test, a transient stress pulse is introduced into the test object using a mechanical point impactor. The pulse propagates through the specimen along spherical wave fronts and is reflected at material boundaries. The larger the difference in material properties, the larger is the reflection recorded at the transducer.

The specimens used in the research comprised lightly reinforced rectangular concrete beams containing a steel or a plastic duct, varying in diameter between 60 and 110mm, containing varying amounts of grout from fully grouted to empty. With the steel duct the impact-echo technique was able to distinguish between fully voided, 50% grouted and fully grouted lengths. With the plastic duct the technique was able to distinguish with difficulty between
fully voided and fully grouted lengths, but for plastic ducts it was considered that ground penetrating radar (GPR) would be a preferable technique (see below) [1, 2].

**Sonic Transmission and Tomography**
In sonic transmission a mechanical stress wave is typically initiated on one side of the structure by an instrumented hammer and received on the opposite side by an accelerometer. The velocity of the sonic compression wave reflects the elastic modulus and density of the materials through which it passes and the resulting wave velocity calculated for a measured path is the average of the local velocity along the path. It must pass around voids and dry cracks leading to a longer path with increased transit time and apparently lower velocity.

The experiments carried out as part of the research comprised surveys of a twin masonry arch bridge. Sonic surveys were undertaken on one abutment and its associated wing walls taking both individual transmission and tomographic measurements (the latter comprising a criss-cross network of individual transmission readings permitting a three-dimensional reconstruction of the velocity distribution in the structure). A large hammer was required to achieve adequate depth penetration. The wall thickness was calibrated by drilling, and the results analysed showing lower velocity in materials between the wingwalls indicating cellular construction. Along the wingwalls high velocity areas indicated a continuous homogeneous dense material subsequently revealed by an endoscope to be cement grouted zones.

**Ultrasonic Transmission and Tomography**
In ultrasonic transmission a pulse compression wave with a frequency between 25 kHz and 100 kHz is passed between transmitting and receiving transducers located on opposite sides of a concrete element. The pulse velocity which can be calculated knowing the distance between the transducers, is dependent on the density and elastic modulus and is influenced by moisture. The waves will pass round voids and dry cracks leading to a longer path with increased transit time and apparently lower velocity.

A tomographic survey was carried out on a post-tensioned concrete beam containing metal ducts of which various lengths were fully and partially grouted, and ungrotued. The 40mm diameter ducts could not be investigated in detail, but possible voiding in ducts was discernable.

A second tomographic survey was carried out on a concrete beam containing what were believed to be 100mm diameter ducts. Voiding in one duct was clearly shown by the technique and confirmed by impact echo. See Figure 1.

**Electrical Conductivity**
Electrical conductivity is a measure of the ease with which an electrical current can be made to flow through a substance and is the reciprocal of electrical resistivity. The application of this electromagnetic technique for measuring conductivity involves the use of a transmitter coil energised with an alternating current and a receiver coil located a short distance away. The instrument produces a constantly changing magnetic field which induces eddy currents within the object being tested according to the conductivity of the component materials. These eddy currents produce a constantly changing magnetic field which, in turn, produces a current in the receiver coil.

A conductivity survey was undertaken on a masonry arch bridge abutment and wing wall. With the instrument perpendicular (vertical orientation) to the wall the conductivity measured is representative of the material between 0.1m and 1.5m from the surface, and parallel
(horizontal orientation) to the wall the conductivity is representative of the material between the surface and 1m depth (see Figure 2). Multi-layered surveys are also possible by moving the instrument away from the wall. The conductivity values obtained were high and covered a very wide range, with the lowest values on the abutment wall. It was possible to identify variations in heterogeneity in soil filling in the abutment, and variations in moisture content and salinity.

**Ground Penetrating Radar (GPR)**

The principle behind ground penetrating radar is one of applying high frequency electromagnetic impulses to the structure through the use of antennae. The electromagnetic pulse will be partially transmitted and partially reflected at each interface in a multi-layer system represented by a change in the dielectric properties of the structure material. By recording the energy reflected from (or, alternatively transmitted through) different interfaces, a representation of the subsurface may be built up. Surveys can consequently be performed in reflection or transmission mode.

Two experiments were carried out. Firstly a transmission radar survey on a masonry arch bridge. A low velocity of the electromagnetic signal between the wing walls indicating a higher dielectric constant than would be expected for construction or fill materials, suggested a high moisture content in the fill, indicative of a drainage problem. A reflection survey from the arch barrel based on the assumed dielectric constant for the brick gave a different barrel thickness to that found by a previous trench, showing that there are cases where a single GPR data section is insufficient to resolve structural detail. Scanning through the fill from road level above the bridge showed the extrados and intrados of the arch. Back analysis of known depths provided a high dielectric constant for the fill showing it to be wet. A radar scan of the parapet wall, the thickness of which could be readily measured, gave the dielectric constant for the wall material, and this was then used to estimate the spandrel wall thickness as the scan was moved down the wall opposite the fill below road level.

Secondly a lightly reinforced concrete beam incorporating a 63mm diameter plastic duct containing a steel tendon and fully grouted over part of its length, was scanned by GPR. When the GPR bow-tie antennae were parallel to the long axis of the duct, it was not possible to distinguish the grouted from the ungrouted length. However with the GPR antennae perpendicular to the long axis of the duct, the grouted length could be clearly distinguished from the ungrouted length. This result was also obtained from numerical modelling of that GPR experiment.

**CONTENTS**

The three tiers of the Advice Notes are shown in Figure 3.

**First Tier**

This is formed of a general guidance document which contains the following chapters.

1. The Role of Non-Destructive Testing
   This gives examples of the uses of NDT, and explains some advantages and limitations of NDT.

2. Scope
   This chapter explains that while the Advice Notes do not endeavour to provide full details of techniques in common use, the second tier documents do summarise the full range of available techniques to demonstrate the choice open to the engineer. It explains that the principal objective behind these Advice Notes is to publicise the outcome of the latest research, particularly that commissioned by the Highways Agency, and to extend the
Advice Notes in future to cover further research. It adds that where possible the
documents provide sources of further information.

3. Format of Advice Notes
This chapter details the contents of the second and third tiers and lists areas of application
which may be considered in the future.

4. How to use the Advice Notes
This explains that the first tier document indicates the type of problems which can be
addressed by NDT, and that if it appears that NDT can assist the user with a type of
problem, reference can be made to the second tier section relevant to the application in
question. This will show the types of information that NDT can provide and whether it is
likely to be useful. Reference can then be made to the tables of various NDT techniques
that can be used. The tables show which techniques are in common use, which are at
development stage, which are more economical to use, and which give more detailed
information.

Having identified NDT techniques which the user considers might be appropriate for the
problems with his or her application, the user is then referred to the relevant third tier
documents to learn in detail about the techniques, how the equipment is used and the
benefits and the limitations. A final choice can then be made on the technique or
techniques to be used, on the extent of the survey and the detail required.

The first tier document can then be used to provide guidance on Commissioning and
Specification, augmented by additional guidance relevant to the particular techniques
chosen obtained from the third tier documents. Several words of guidance then follow on
how to proceed.

5. Commissioning and Specification
This chapter provides guidance on:
• Testing organisations
• Information supplied to tenderers
• Consistency of bids
• Information required of tenderers
• Evaluation of tenders
• Commissioning
• How to use results
• NDT reports
• Certification procedure
• Records of use of the techniques

Second Tier
This tier covers areas of application. The first document is “Assessing the Conditions in
Grouted Ducts in Post-tensioned Concrete” and the second is “Surveying the Structure of
Masonry Arch Bridges”. The chapters in these documents are entitled:-

1. Background to this area of NDT Application.
2. Formulating a Test Programme
   • Maintenance activities that may require support by testing
   • Information required from a test programme.
3. Potential Testing Techniques
   • Table of test techniques.
   • Summaries of various test techniques under the following headings:
     – Principles behind technique
     – Advantages
– Equipment required – Disadvantages
– Accuracy – Notes on use of technique

• Selection of the most appropriate techniques, considering
  – Obtaining a balanced amount of information
  – The effectiveness of tests in combination
  – Adopting a flexible testing programme
  – Techniques appropriate to the materials being investigated
  – Locating features prior to investigating them
  – Proceeding cautiously
  – The accuracy likely to be obtained
  – Calibratory and confirmatory drilling
  – Building up a picture of the structure

• Notes on use of technique

Third Tier
This tier covers NDT Techniques. The documents comprise
• Impact Echo (I-E)
• Sonic transmission and tomography for masonry bridges
• Ultrasonic transmission and tomography for post-tensioned concrete bridges
• Electrical conductivity
• Ground penetrating radar (GPR)

The chapters comprise
• Introduction
• Details of the technique under the following headings
  – Principle of Method – Limitations
  – Accuracy – Equipment and Procedure
  – Applications – Interpretation
  – Advantages – Examples

• Where applicable, application of the technique to a particular area of application under the above headings.
• Commissioning and specification guidance particular to the technique.
• Sources of further information.

TRIALLING
Commissioning
Atkins Highways and Transportation was commissioned by the Highways Agency, latterly through TRL, to locate suitable structures on which to carry out trials of the Advice Notes. Curdsworth River Bridge, a brick masonry arch structure, was chosen for the trials using sonic transmission and tomography (see Figure 4), ground penetrating radar (GPR) and electrical conductivity. Cresswell Viaduct, a post-tensioned concrete structure, was chosen for the trials using impact echo, ultrasonic tomography, and ground penetrating radar (GPR). Both structures were chosen the on basis of age and ease of access, the latter to minimise costs.

Objectives
The principal reasons for the trial were to determine whether the guidance in the Advice Notes would enable suitable contract documents to be prepared by a consulting engineer, (the Atkins team involved in the trial was independent of the Atkins staff involved in editing the Advice Notes), and whether the successful tenderer would carry out a satisfactory NDT investigation working to these contract documents.
A spin off benefit would be confirmation that the NDT techniques themselves were effective. Feedback was provided to the Steering Committee at four stages, namely before and after tender, after the NDT investigation, and after subsequent confirmatory drilling. Minor improvements were made to the Advice Notes as a result of the feedback received.

**Masonry Arch Bridge**
On Curdsworth River Bridge the NDT techniques determined approximate thicknesses of the arch barrel, spandrel walls and wing walls with fill behind. The piers were identified as not being continuous through the thickness of the structure, and their thickness estimated. Bands showing increased moisture content were identified towards the outside of the bridge over the arch soffit. Further increased levels of moisture content were found adjacent to two weepholes to one side of the arch soffit. The fill materials showed areas of voiding/less consolidated areas adjacent to both elevations.

**Post-Tensioned Concrete Viaduct**
On Cresswell Viaduct the surveying was carried out on the southern span of the bridge on the internal edge beam under one side of the central reserve. The majority of the testing was carried out on the profiled duct within the outer flange of the assessed I-beam. Eight separate areas of possible voiding were identified within the within the length of beam tested (approximately 23m).

**Reporting**
A full report was produced which gave the findings for each technique as well as for the combined technique approach. A presentation of the findings was made to the Steering Committee. Comments were made on the validity of the contents of each Advice Note and suggestions made for corrections, improvements and additions.

**Confirmatory Investigation**
Confirmatory drilling was subsequently carried out on the I-beam of Cresswell Viaduct at two of the duct locations identified as having possible voiding. It was found that the ducts were formed of cast voids rather than with metallic sheaths as initially expected. The first area, a discrete area was found not to be voided and it is believed that the feature identified from both the impact echo and ultrasonic tomography could be as a result of a localised void not identified from the drilling, or from an area of variable quality concrete within the flange. The second area, a continuous 1.2m length of possible voiding was confirmed as being voided above the location of the tendon strands as determined by impact echo. The voided area was determined as extending further along the duct than was identified from the impact echo survey, but was confirmed as being continuous by blowing dust between the drill holes.

**THE WAY AHEAD**
The Highways Agency would welcome feedback from the use of the Advice Notes so that improvements can be made in the next addition.

Acoustic Emission has already been researched at the University of Edinburgh, and will be the next addition to the third tier documents.

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who gave the presentation on, and carried out the trials; and to Dr A. Bansi and Mr K. Bates of Atkins who prepared and supervised the trials.

**Note:** The voids are formed by an air gap or a polystyrene box-out. Contours show areas of high and low velocity as per the key. Low velocity indicates voiding/poor concrete. High velocity represents good unvoided concrete.

**Figure 1 – Ultrasonic Tomographic Plot showing Voiding in Grouted Ducts 0.4m from Front End of Beam**

**Figure 2 – Electrical Conductivity Survey on Curdsworth River Bridge**
REFERENCES
