

Final report:

Non-Destructive Testing Methods for Integrity Determination of Concrete Structures

Summary

Today, it is well recognised that methods that can be used to do assessments of existing structures without the need for destructive tests has the potential to become increasingly important tools as a part of work being invested to structures. The companies that offer these methods, however, experience difficulties to sell services that rely on such methods. At the same time, the owner organisation's knowledge about using non-destructive testing as a part of a concrete investigation is limited. In order to change this, the potential profit that can come out from using non-destructive methods needs to be clarified in a simple and descriptive way.

In 1999 the Nordic Industrial Fund funded an initiative on technology and methodology development on non-destructive testing for existing concrete structures:

“Non-destructive testing for integrity determination of concrete structures”

The project was initiated from both service provider companies and owner organisations, with the ambition to reach cost-effective methodology for surveying through establishment of guidelines. These guidelines should rely on comprehensive field studies on real problem cases. The project started in 1999 and was ended in September 2003.

This project was inspired by the need to know the actual capabilities of non-destructive testing techniques for use on concrete structures. A number of common problem types have been considered and the best available techniques chosen to investigate them. The process has involved construction of a number of models with well-defined details and idealised defects. Whether the artificial defects actually can reflect the true situation on site can be argued, but this was a necessary starting point to enable us to describe the potential capabilities. Various examples have also been chosen from a diversity of real structures.

It is clear that the conditions on site are generally much more difficult and involve a number of unknown factors, not least the variability of the concrete, so that we can rarely predict NDT performance or hope to achieve the same results as in the laboratory. The performance on older structures is often poor due to a number of factors, including variability of concrete quality in one and the same structure, a less uniform and lower quality concrete, the condition of the concrete will have changed over sections and globally with time, and the fact that less is known about the structure. Modern concretes are generally of higher quality and lend themselves better to NDT. Since the quality of NDT-performance is directly related to the quality of the concrete then it would seem logical that NDT is of more value to modern construction and will be of greater use in the future. If NDT is to be more widely accepted then it must be improved in many areas, but the greatest asset to improved NDT must be better concrete.

Why do we need NDT?

There are various situations in which NDT can be needed:

- Compliance testing
- Collection of specific data and parameters
- Condition assessment
- Damage assessment

Compliance testing is perhaps one of the most straightforward tasks, for example measurement of reinforcement cover, concrete thickness or the position of a pre-stressing cable. Modern techniques are capable of accurately describing these details.

The other applications have to be considered in their context of course, but are generally more difficult to describe using only NDT. One reason for this difficulty is the fact that all concrete structures are in some way unique, for example in terms of materials, construction methods and environment and its effect on the concrete. The best approach to these problems is to combine NDT with intrusive testing and traditional inspection methods. There is no rule stating that NDT excludes other forms of inspection, yet the two are rarely discussed or researched together.

Choice of NDT methods

In this work, we have chosen to study a relatively small but important selection of problem cases and have chosen what we consider the best techniques for these. There is always a best technique for a specific job, if seen from a purely engineering perspective. The prevailing conditions, for example, accessibility, costs and time may force the choice of an alternative technique, although this will invariably be at the cost of quality, e.g. accuracy and reliability.

NDT as an alternative inspection method

Despite a generally wide expression of interest in non-destructive testing methods, they are rarely applied in practice. It is often argued that the methods are qualitative and of limited use to the structural engineer, that the results are ambiguous and not sufficiently qualified for this purpose. It is perhaps better to define the objectives and consider the most suitable techniques and combinations thereof in order to make an objective assessment of the techniques in specific situations, rather than to focus on why we should not use them. Considerable advances have been made in recent years, which enable us to obtain vast amounts of useful information and as we have demonstrated in the four years since this project was carried the civil engineering community needs a re-assessment of NDT.

Much speculation has been made in recent years about the existing and potential capabilities of NDE with respect to specific types of problem. Little data has however been available from actual laboratory or field tests to clarify these points, despite the relatively simple problem definitions. This has been the basis for our work, which has been conducted over a four-year period in the laboratory on carefully defined mock-ups, as well as extensive field tests.

What kind of concrete structures are considered?

This has been governed by the interests of the project partners and of course by practical considerations including method limitations. The type of concrete element considered is typically 300 to 1500mm thick, which could be a bridge slab or beam, slender dam wall or nuclear containment wall. The concrete is accessible from both sides, although much of the testing has been carried-out from one side only. Pre-stressed structures have been given priority, as have wall structures around 1000mm thick bearing in mind the interests of the nuclear industry.

Mock-ups for acoustic and radar measurements have been made using normal structural concrete with maximum aggregate size 25-32mm. Two large mock-ups, B1 and B2 have been constructed (see chapter on mock-ups) as well as several smaller models for radiographic tests.

What are the problem definitions?

The original primary objectives have been to establish the capability to detect voids in concrete and voids in pre-stressed cable ducts embedded in concrete. A list of end-user requirements with respect to task priorities are summarised in the table below.

Of the 17 items (objectives) listed, the detection of voids and mapping of concrete homogeneity were considered most important, as well as the detection and sizing of cracks perpendicular and parallel with the concrete surface.

These priorities are obviously based on the individual requirements of the end-user in this project and do not entirely reflect the importance in a more general sense. For example, dam structures have rarely a corrosive environment nor pre-stressing, so associated problems are relatively uninteresting for this particular owner. The number of problem cases and variables is so great that it is not possible to treat them all in depth or come up with a universal solution. A small number of problem cases have been investigated in a way that we hope will allow judgement to be made of potential capabilities under various conditions.

The measurement of concrete thickness is generally regarded (within the NDT community) as too simple a problem to be of interest. We have found, however, that this can be extremely difficult and have therefore devoted some time to this fundamental problem as it has a bearing on many other objectives, e.g. measurement of depth (to reinforcement and voids) and concrete quality.

Concrete cracking was a high priority although too difficult a problem to treat in this work. Some simple tools using ultrasonic wave velocity have previously been established to determine the depth of ideal surface-opening cracks in simple geometries. This is rarely the case in real life, however, as cracks are often a complicated network, closely spaced and not necessarily perpendicular to the concrete surface. No models have been studied of this particular damage case although some fieldwork has included cracked concrete.

Mapping reinforcement and cable ducts was given quite low priority by the end users. However, it is not possible to investigate the condition of either of these if we cannot locate them, and the internal geometry of concrete has a significant bearing on the performance of techniques and can affect our results, so from the inspector's perspective we must give this

subject priority. Like measurement of concrete thickness, re-bar mapping is a fundamental task that is a necessary part of the investigative process.

Application and purpose	Comment	Ranking (%)
Detection of voids & in-homogeneity, typically to locate construction flaws	Quantify void detection threshold in thick sections (size of void and depth)	41.8%
	Detect voids > 20mm in grouted tendon ducts	41.8%
Detection and sizing (depth, width, length) of cracks normal to the surface	Improve variable performance statistics associated with depth measurement of surface cracks.	41.8%
Detection of delamination (cracking parallel with concrete surface)	Improve variable performance statistics for detecting large laminar flaws at > 10mm depth and larger than 100mm in any direction	39%
Measurement of concrete thickness to obtain as-built details	Measure concrete thickness with single-sided access with sensitivity of $\pm 5\%$ section thickness.	37.8%
Mapping/sizing of steel reinforcement and tendons to establish as-built details	Enhanced resolution to measure reinforcement diameter with sensitivity of $\pm 10\%$	20.0%
	Resolve multiple layers of reinforcement, identifying individual bars at spacing <150mm and depths >30mm and measure bar diameter with sensitivity of $\pm 10\%$	20.0%

Table 1. Ranking of end-user requirements. Voids and cracks have high priority while reinforcement mapping is given low priority

Which non-destructive testing techniques have been considered?

Radiographic, electro-magnetic and acoustic methods have been tried extensively in this work. Some of the methods were quite well tried at the outset of this work, others were relatively new - at least in terms of concrete inspection, while some were (fortunately) welcome additions to the original plan. The most significant new technologies that have benefited this work are the A 1220 Ultrasonic Pulse Echo unit from Spectrum, Russia and the Computed Radiography system from Agfa Strukturix. In addition, considerable improvements were made in radar antenna design quite early on in our work (ref. Malå GeoScience and Luleå University).

There are other methods that have not been included and which may have performed better than the chosen ones in specific situations. There are also other designs of similar equipment available on the market, which may be better or poorer than those chosen. The package of techniques chosen is however a fairly comprehensive one.

Radiographic methods

Betatron 7.5 PXB, accelerator and Computed Radiography
Iridium and Cobalt isotopes

Electro-magnetic methods

Ground Penetrating radar with antennae frequencies 500 MHz to 1 GHz.
Cover meter

Acoustic methods

Ultra-sonic Pulse Echo

Impact Echo

Spectral Analysis of Surface Waves

Ultra-sonic wave velocity

Fieldwork has included six bridges, two dams and a nuclear containment wall. In addition, many site investigations including bridges, nuclear containments and tunnels out-with these projects have contributed to the accumulation of data and experience.

An important deliverable from the project is this Owners Guide that summarises possibilities and limitations for a number of non-destructive technologies, focussing on prioritised problems from the owners point of view.

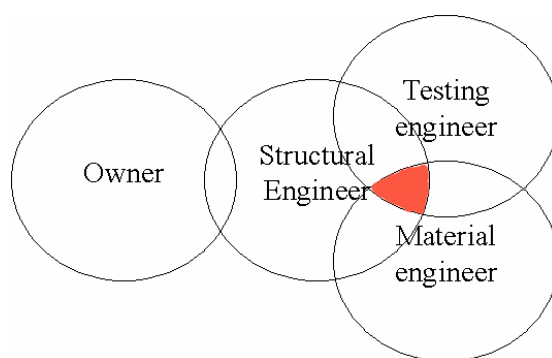


Figure 2. The common way of arranging a problem study for an existing structure damaged in some way.

Figure 2 illustrates the responsibilities of a typical structural problem study. First, the owner contracts a structural engineer to evaluate the structure. In case the structural engineer is familiar with problems that can occur for existing structures, he asks a material engineer for the input that he needs to be able to do representative calculations. Most likely, the structural engineer is not very familiar with non-destructive methods, i.e. the testing engineer will not be involved in the project. However, if this is the case, the area that all three disciplines meet is rather limited.

To be noted is that the owner never is involved in the direct contact with other engineers in the project but the structural engineer. It is through him, the decision is taken if to invest in non-destructive investigations or not. To be considered at all, the testing engineer must present the benefit that he can contribute with in a clear and understandable manner! It cannot be expected that the owner want to be directly involved in the process how to assess the structure in practice, but only in the end results.

The consequence of this common practice is that companies involved in non-destructive testing of concrete have difficulties to sell their services. Moreover, there is a very low driving force to carry out further technology development. One way to change this is to clarify the benefit that is possible to achieve in a simple and descriptive way. Moreover, the testing engineer certainly benefit from a good understanding of structural engineering problems, so that the efforts from non-destructive testing actually add the useful information that there is an real need for. This means that for non-destructive investigations to become an

accepted tool, structural engineers and material and test engineers speak the same language. In other cases non-destructive testing will be made from wrong expectations, with results that does not contribute with information that can be used in the assessment of an existing structure.

For non-destructive testing to become a widely accepted tool, it is necessary that structural engineers, material engineers and non-destructive testing engineers mean the same thing in their verbal communication. In other case, there is an obvious risk that investigations based on non-destructive methods are made on wrong expectations, i.e. with results that does not contribute to an assessment with useful information. The opposite is valid too. If the capacity of non-destructive testing cannot be brought out to a wider extent there is an obvious risk that assessment projects becomes costly due to unwanted surprises that could have been anticipated if non-destructive methods had been used.

The content of this Guide will give all owners of constructions, structural engineers, and material engineers a basis for validating whether non-destructive testing is interesting to use in specific problems faced.

It has been our objective to demonstrate the capacity of NDT methods applied to reinforced concrete structures, with emphasis on the end-user. This has involved sensitivity studies on existing techniques and introduction of new techniques. Laboratory and field work in parallel and improvement in techniques has given a realistic insight into performance today as well as potential capabilities.

The results of this work are communicated in user guide form – “A Practical Guide to Non-Destructive Testing of Concrete Structures” and applied experiences from filed studies.

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