PRACTICAL CONSIDERATIONS OF INSPECTING POST-TENSIONED BRIDGES

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SYNOPSIS

The countrywide programme of inspections on post-tensioned bridges started approximately 4 years ago is well under way, and in some areas nearing completion. A wide variety of approaches to this work have been taken using the general guidance given in BA 50/93 and a number of different testing techniques have been used and developed. Over this period, several hundred structures have been investigated, including some 50 bridges by the authors' company. This paper sets out to discuss the practicalities of inspecting post-tensioned bridges.

1. INTRODUCTION

Post-Tensioned bridges come in a variety of shapes and sizes. Consequently the approach to investigation work will vary from bridge to bridge. Before even exposing a duct, consideration must be given to the individual design, the potential failure points and previous maintenance and inspection records. A site visit will then be necessary to check for traffic management and access requirements, and to visually check for signs of stress or environmental conditions which may promote concrete deterioration in stressed areas.

The main problem with inspecting post-tensioned bridges is that so often there is little or no visual evidence if anything is wrong, and highly stressed areas such as around anchorages are usually inaccessible. Post-tensioned bridges rely on grout within tendon ducts to distribute and lock in stresses to beams and to provide a protective alkaline environment around stressing tendons. Should voids exist within the grout, or as found in some cases, no grout exists at all, there is a danger that air, moisture and contaminants may enter the duct and possibly lead to corrosion of the tendons, especially in the case where ducts have no sheathing.

Care must also be taken to ensure that the actual inspection method does not cause further damage or lead to a more vulnerable environment, for instance by inadvertently introducing water to a voided duct.

This paper is split into two sections. The first section is a brief overview of all the inspection techniques that have been applied with a comment on their usefulness. The second section discusses the problems that may be encountered on site during investigation work, and how these can be avoided or overcome.

2. INSPECTION TECHNIQUES

A summary of the testing techniques that have been employed for post-tensioned bridge investigation work and an assessment of their usefulness is given below.

2.1 <u>Location Of Tendon Ducts</u>

Construction/Design Drawings

As built and design construction drawings will generally be available, showing details of tendon duct dimensions and locations within a structure. Investigations carried out to date show that actual duct positions generally vary little from theoretical positions. The danger of relying on construction drawings is that ducts may have floated during construction, or on site modifications may not have been recorded. This is the best first option. 9 times out of 10 ducts are exactly where drawings indicate.

Ground Probing Radar

Use when no drawing available. Also called impulse radar, this method - in the right circumstances - is able to detect metal sheathed ducts and tendon bundles up to a depth of approximately 400 mm. High Frequency electromagnetic pulses are emitted from an antenna into the structural element under investigation. The impulses are propagated through the element materials at a velocity dependant on their dielectric constant. At interfaces between differing materials, such as steel and concrete, there is a partial reflection of the signal which is received back at the antenna. The latest radar equipment is lightweight, portable, and able to store data directly onto disk. The major limitation of radar is that reinforcing steel in the concrete will also return strong signals, and the close mesh of rebar often found in deck slabs and around anchorages will effectively prevent the reflected signal from tendon ducts being identified. It is also difficult to use in tight corners. On the positive side, ground probing radar is a rapid method of determining tendon profiles on bridge facias and soffits, where concrete is generally not heavily reinforced.

Electromagnetic Covermeter

In the right conditions this method can detect ferrous ducts and tendons up to a depth of 100 mm. Covermeters are commercially available apparatus, commonly used on construction projects for determining the depth of cover and the location of steel reinforcement bars. The antenna head detects the presence of ferrous objects within its field, and the strength of the signal will be determined by the distance of the object from the antenna. The depth of penetration is generally limited to approximately 100 mm, and it is can be very difficult to differentiate between rebars, ducts and tendons. Although of limited use, this method is a relatively cheap alternative when the depth of cover to the duct is low, typically on beam facias.

Impact Echo

This mechanically based technique measures the impulse obtained from striking small metal balls on the concrete surface. It will only work at shallow depths and when ducts are voided. It is not often used , especially as a covermeter is far quicker and cheaper alternative for shallow investigations.

Stitch Drilling

This may seem a crude method of locating tendons, however, as tendon ducts are generally located where drawings indicate they should be it is not unusual to hit first time. A second hole may sometimes be required to ensure access to the top of the duct. This method does not take too long for shallow ducts and it is conclusive. Although destructive, it is not overly so if 25 mm diameter drills are used, and ducts are where they should be.

Radiography

This method is the only non destructive technique that can locate tendon ducts and 'see inside ducts' to check the state of grouting. Access is required to both sides of the structural element, which is not always practical close to anchorages and on deck soffits. A gamma or x-ray source is placed on one side of the structural element and a photographic plate which records the image is placed on the other. Extreme safety precautions are required to safeguard personnel and the general public. The cost is prohibitively expensive and the disruption usually unacceptable for routine investigations

2.2 Exposing Tendon Ducts

Percussive Drilling

This is least destructive and most elegant method of investigation ducts. Typically a 25 mm diameter drill is used to the duct sheathing, which is then removed by hand chisel. When tendons are located at depth, an endoscope will be required to inspect progress.

Stitch Drilling

If it is required to expose a larger section of tendon, stitch drilling can be used if ducts are fairly shallow.

Diamond Coring

Good for visual inspection but there is a danger of damaging tendons. Also, there is the potential danger of cooling water entering voided duct. It is best to overcore a plugged small diameter inspection hole, and breakout last 20 mm by hand.

Water jetting

Not advised unless absolutely necessary such as in areas of congested steel. Thin ducting can easily be punctured and water can enter ducts at pressure. This is quite a messy technique and operators experienced in this type of work should be employed.

Mechanical Breaker

A crude and quite destructive method of exposing larger sections of ducts, but effective for exposing shallow ducts for a good visual inspection. Also, little danger of damaging tendons seriously or introducing water.

Dry grit blasting

This technique has been used on one or two contracts The method avoids the problems associated with using water, however it is very slow and quite expensive.

2.3 Exposing Tendon Anchorages

Mechanical Breaker

For simply removing capping concrete, at locations where anchorages can be accessed from the side, and where there is little secondary steel, this has been found to be the easiest and most economical method of exposing anchorage plates. However, when breaking out through dense steelwork progress can be both slow and tedious.

Water Jetting

High pressure water jetting if often the only method that can be used to expose anchorages from the deck and through steel reinforcement. Quite quick but messy and expensive.

2.4 Inspecting Tendons, Grout, Ducts, Voids and Anchorages

Rigid Endoscope

Relatively inexpensive but skill is required to obtain good quality photographs.

Flexible Endoscope/CCTV

The only method to visually explore voided ducts, and check tendon condition. Images are recorded in real time however, it can be quite expensive.

Pressure Testing

A simple test using a single pressure vessel of known volume will give approximate void volume, using the simple gas law equation P1xV1 = P2 (V1+V2+VV) where VV is void volume. It will also indicate if leakage is occurring and check continuity of voids between investigation holes. More expensive and precise pressure testing equipment is available, however, in practice, the results obtained have not been found to justify the substantial additional costs involved.

Vacuum Testing

Sometimes employed in place of pressure testing but quite expensive.

In-Situ Stress Determination of Tendons

Strain gauges fixed onto tendons are used to measure the stress relief obtained by drilling a small hole in the tendon. From the results obtained, the dead load stresses can be calculated to an accuracy of +/- 14 N/mm.

R.I.M.T. Testing

Experimental technique which originated in Italy, to check for corrosion and voiding around tendons by injecting high frequency signal down tendon. Trails were carried out with the DoT and TRL, and the results proved to be inconclusive.

Radiography

In the right circumstances radiography can give a clear picture of voiding within grout and severe loss of tendon section. Access is required to both sides of the beam, and the x-ray obtained can be confused when tendons lie side by side. The technique cannot show minor deterioration of tendon condition, and is cost prohibitive.

Grout sample for chemical analysis

Tests for chloride and sulphate content on grout will give an indication of environment surrounding tendons, and whether it is offering protection. Cement content determination will give information on the grout mix used.

Anchorage capping sample for analysis

As above

<u>Assessment of Surrounding Concrete</u>

Covermeter
Half Cell Potential
Resistivity
Carbonation
Dust/Core sample for analysis
Rebound Hammer
Ultrasonic Testing
In-situ stress determination of concrete

All of the tests mentioned above can be used to give an indication of the condition of concrete surrounding the post-tensioning system. They should only be used however, if conditions on site indicate a possible environmental or physical problem which may effect the post-tensioning system, such as cracking, spalling or staining of beams. Otherwise investigation funds are best spent on the main task in hand - investigating tendons.

3. SITE CONSIDERATIONS

An inflexible approach to phase three investigations can lead to inefficient or inconclusive testing of structures. By its very nature, an investigation cannot be bound by the constraints of a typical contract document as both the quantity and scope of the investigation will need to be developed as a result of active feedback between the inspection team and Project Manager.

3.1 <u>Locating ducts</u>

In practice, due to the measured economical approach governing the initial scope of phase three investigations, the areas in which internal examinations of tendon ducts are carried out are almost always at critical sections. When this is not the case, it is usually due to access considerations.

Critical sections including anchorage locations, mid-span areas and regions over intermediate supports are often areas where the tendon duct are tied to form the design profile of tendon ducts. Consequently the location of the ducts can often be successfully determined by use of design or as-constructed drawings. The problem arises when ducts ‘float’ upwards during casting, however, in practice this has not been found to occur on many bridges.

Where intrusive investigations are carried out between critical points or when no construction drawings are available, Non-Destructive testing may be employed to confirm the location of the duct before commencement of intrusive drilling procedures. The results of such testing can prove to be inconclusive due to the presence of secondary reinforcement, which can confuse the signals obtained, especially when ducts are greater than 200 mm from the surface.

A working knowledge of design principles, experience of similar structures and exploratory small diameter drilling has been found to be the most cost effective way of determining duct location and does not disturb structural elements excessively.

On some bridges, the presence of surface cracking and slight discoloration/shadows on beam facias has indicated the profile and location of the tendon duct, where it lies close to the surface.

3.2 Duct Intrusive Investigations

The design of the structure generally governs the location of duct intrusive investigations, and as previously mentioned are usually carried out at critical sections.

At the location of duct intrusive investigations it is generally desirable to gain access to the top section of the tendon ducts, particularly at high points close to anchorages and over piers, as in practice this has proven to be the area in which voiding is most likely to occur. In practice, significant voiding within tendon ducts has been found to be relatively uncommon, and where they do exist, others are generally found within the same structure. Voids are generally very small and limited to the top 5 mm of duct section, with tendons being well covered. However, totally voided ducts are occasionally found.

Where the spacing between beams is too small or non-existent, access to the top of the deflected tendon duct can become impossible unless access holes are cut through lower flanges of I beams (including reinforcement), at great expense and disruption. In such instances, access to the tendon duct can only be made through the soffit of the prestressed element thus making access to the top of the duct very difficult.

The presence of unrecorded secondary reinforcement can also make access to ducts difficult, however, angled drilling can generally bypass this obstruction. In areas where there is a large amount of secondary reinforcement exists, such as close behind anchorages, water jetting is often the only method that can effectively be employed to expose duct sheathing without cutting rebar. Great care must be taken as voided ducts can easily be punctured allowing water to enter the duct and increasing the risk of corrosion to the tendons. Water jetting also requires shielding to protect passing traffic and pedestrians from flying debris, and consideration must also be given to where the run-off water is going to flow.

Figure 1. Tendons exposed by Diamond Overcoring

Diamond over-coring of intrusive holes to enlarge access can also introduce water, used as a coolant, into voided tendon ducts. There is also the additional risk of severing tendons during these procedures. Alarm systems are available that connect to coring and drilling equipment to indicate when contact with metallic duct sheathing is made. However, should the duct sheathing be plastic, or not exist, the alarm or cut-off will not work, and in the case of coring a slight contact can be sufficient to severely damage tendons.

A single small diameter hole is usually sufficient to examine tendons with an endoscope, and the hole can always be enlarged if further investigations are warranted. Stitch drilling, although not elegant, has proved to be a reliable and safe method of enlarging initial intrusive holes and although slower than coring, there is no risk of introducing water or cutting tendons inadvertently.

Whatever intrusive method is used, it is essential that experience personnel are used, who understand what they are looking for. All mechanical intrusive methods should stop at the duct, preferably 10 mm before it, and the final section of concrete and duct sheathing then removed by hand chisel.

3.3 Grout Removal and Testing

Often a large range of testing is requested on grout samples obtained as part of intrusive duct investigations and this is generally without regard to the amount of sample required to conduct such testing. As a guide, to carry out Chloride ion content, cement content and sulphate content analysis on a grout, a 15g sample is required. Intrusive investigations of tendon ducts are usually carried out through small localised holes which limits the availability of grout material and in some cases close proximity of tendons to the duct sheathing further reduces the available sample size. In cases where there is no duct sheathing and grout colour is comparable to that of the parent concrete it is difficult to obtain a pure sample of grout material.

In practice, grout composition has been found to vary little across samples taken from a single structure, and it is recommended that the full range of chemical analysis is only carried out on a small representative sample and in areas of suspected contamination.

3.4 Anchorage Intrusive Investigations

The exposure of anchorages within a structure and particularly the end anchorages of longitudinal prestressing tendons require considerable intrusion into the structure and great expense. This may include the removal of surfacing, waterproofing, joints, run-on slabs and ballast walls. All too often anchorages are inspected at areas where reinstatement is difficult and this can lead to an increased risk of corrosion. The time taken to expose, inspect and adequately reinstate longitudinal anchorages generally requires extensive traffic management measures, and this together with labour and material costs can often absorb a high percentage of the budget allocated to the inspection of a particular structure.

Initially, intrusive investigations should be carried out into ducts as close behind anchorages as possible. If ducts are fully grouted, this may mitigate the requirement for anchorage investigations as stress transfer to the structural element will be maintained by re-anchorage of the tendons, should the end anchorage fail. Although this may result in cracking resulting from associated bursting forces and thus lead to durability implications, the risk of sudden collapse is reduced.

Water jetting is often employed to expose anchorages due to the large amount of secondary reinforcement located in these regions. The polishing effect of such intrusive procedures and water ingress to the surrounding concrete can limit the information gained from visual examinations. Water run-off from this method will usually flows down the joints at some point and care should be taken to ensure that this will not cause disruption to traffic if below, or environmental pollution to rivers.

BA 50/93 advises that operatives should not stand behind anchor plates during intrusive procedure as a safety precaution. However, this generally proves to be impractical, and if the tendon duct leading to the anchorage can be examined beforehand the risk is minimised.

3.5 NDT Testing

Non-Destructive testing is quite often specified in Post-tensioned bridge investigation contracts to determine the potential for corrosion of reinforcement. Whilst this may provide information required for a general principal inspection in accordance with BA 35/90, quite often the information obtained is not relevant to the task in hand - investigating the post tensioning system. In any event, the testing of grout itself for contamination will give the best indication of the potential for tendon corrosion.

4. THE PREFERRED APPROACH

Quite often, investigation contracts are set out with a specification and a bill of quantities indicating all work to be done. On a significant number of contracts however, the scope of work will need to change as the investigation proceeds. The discovery of voids generally requires further investigation work to determine the extent of voiding, and the lack of 'as constructed' drawings can sometimes lead to surprise discoveries and the abandonment of all investigation work.

Is it necessary to have big expensive investigation programs involving numerous trial pits to check anchorages, removing joints, ballast walls, barriers, surfacing and waterproofing with NDT test panels on the deck surface when the condition of the anchorage may be irrelevant if all ducts are fully grouted up and the stresses are locked in.

The most successful contracts are those where the Engineer and the investigation team work as a partnership and where there is flexibility to adapt the programme of work to the day by day findings of the investigation work.

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