Challenges in Nondestructive Testing of Post-tensioned Bridges
Hemant S. Limaye Concrete Science, Inc., Hayward, CA
Ashok M. Kakade Concrete Science, Inc., Hayward, CA

ABSTRACT

Through the use of quality control and quality assurance (QC/QA) programs established by the responsible agency, abnormal situations that do not meet the project specifications are identified. In most cases as a first step visual evidence such as excessive honeycombing or cracking of the structure can raise a concern. If those defects are not visible then hammer sounding is used to detect locations with delamination. If an anomaly is suspected then additional testing is required using nondestructive techniques such as impact-echo, radar and radiography. Furthermore to confirm the results of the nondestructive testing, semi-destructive and destructive methods such as the drilling of small holes and observation with a borescope, and removing cores may be necessary.

The paper describes our experience in using the nondestructive and destructive methods to detect delamination, voids in the grout, and condition of the anchorages in post-tensioned bridges. In addition, the paper identifies limitations and challenges for the techniques imposed by unique design of post-tensioned bridges.

Keywords: Nondestructive testing, Borescope, Chain dragging, Coring, Hammer sounding, Impact echo, Impulse response, Radar, Radiography, Visual survey, Tendon ducts
INTRODUCTION

As a result of the complex design nature of the post-tensioned bridges, construction of these bridges is very challenging. Even by applying the best QA/QC procedures, human factors come in to play and occasionally something may go wrong resulting in non-conformance or structural defects. This paper addresses the most common defects encountered in post-tensioned members and the nondestructive methods used to detect and locate those defects. The most common defects involve the delamination of concrete after the tendons are stressed, de-bonding of the ducts, and determining the grout status of the ducts. The paper does not address issues related to corrosion aspects of the tendons.

Since post-tensioned bridges involve complex designs, they present challenges in applying nondestructive testing methods. Methods discussed in this paper range from very basic techniques such as visual inspection, sounding with a hammer, and chain dragging to state-of-the-art techniques like radar, radiography, impact echo, and impulse response. Every method has its own limitations and challenges in locating the defects.

DESIGN

There are several design categories of post-tensioned bridges and their sizes and shapes vary drastically. One commonality found in all the designs involves their complexity. Many state agencies have standard designs based on span dimensions and are modified for a particular location. Design involves (among other factors) congested reinforcing steel, closely spaced and sometimes stacked tendon ducts, and variable concrete thickness. The areas around anchorages, which are highly stressed, are many times inaccessible. These design characteristics present problems when nondestructive or even destructive tests are used.

Figure 1. A sketch showing the sectional view of the partial segment.

Figure 1 shows a sectional view of the bridge showing tendon duct locations including stacked ducts and thickness variations in the concrete. For clarity, the sketch does not show the top and bottom layers of reinforcing steel. Congested reinforcing steel is depicted in
Photograph 1 and the end anchorage is shown in Photograph 2. Referring to design and as-built drawings showing the details of the tendon duct locations prior to conducting the tests can be helpful.

CATEGORIES OF POTENTIAL DEFECTS

As stated in the introduction, common observed flaws include delamination, de-bonding of the ducts and partial grouting of the ducts; Figure 2. Some of the challenges involve the following (assume access is from the top):

1. detecting a delamination below the duct.
2. gathering information about the grout status if the top concrete is delaminated
3. gathering information about the grout status if the duct is de-bonded.

In these cases, it would be easier to detect anomalies if the access is available from the bottom.

Photograph 1. View of the congested reinforcing steel prior to placing of the concrete.

Photograph 2. View showing the end anchorage.
APPLICABLE TECHNIQUES AND CHALLENGES

There are a variety of techniques (nondestructive and destructive) available to locate distress in the structure. A proper technique (or multiple techniques) is selected based on type of a flaw, overall feasibility, type of access, success in interpreting the results and cost. Visual survey, hammer sounding, chain dragging, radar, impact echo, and radiography are the most applicable nondestructive techniques that can be used in context with this paper. Basic principles of these techniques are described below with the challenges. Detailed description of the techniques is readily available in the literature. Semi-destructive methods such as borescope use and core removal, which are destructive, are useful methods to verify the findings of the nondestructive testing.

VISUAL SURVEY

The visible distress in the concrete structures is indicative of a potential underlying damage mechanism. All state agencies have requirements in their QA/QC program to conduct observations during and after construction. Usually, there are five basic types of inspections; initial, routine, in-depth, damage and special inspection. As the name implies, initial inspection is the first inspection conducted soon after construction or rehabilitation and it provides a reference for all future observations. Routine inspections are periodic observations to note changes from the previously observed condition. If a significant change is noted then an in-depth inspection is carried out using the appropriate nondestructive or destructive testing methods. Damage inspections are carried out when there is a physical damage resulting from an accident or environmental effects. Based on results of the afore mentioned inspection types, a special inspection may be carried out to gather additional information. Usually, based on the distress observed, visual surveys are supplemented with the use of appropriate nondestructive methods.

Visual surveys are the most important part of any type of testing. It provides important information to the experienced person. Observed conditions or features can be related to the
quality of construction including workmanship and material, and serviceability of the structure. To gather the best information possible the inspection team needs to be experienced in the fundamentals of bridge structures, planning and organizing, nondestructive testing, safety, etc. Minimum qualifications of the personnel are outlined in AASHTO’s Manual for Condition Evaluation of Bridges.

HAMMER SOUNDING AND CHAIN DRAGGING

Hammer sounding and chain dragging are simple, inexpensive methods to detect concrete delamination. An area with a hollow sound indicates a delamination in the concrete. The method is subjective and can detect shallow delaminations depending on a person’s trained ear. Chain dragging, which is mostly used for horizontal surfaces, is relatively fast and suspect areas can be tested further with other applicable nondestructive methods. Hammer sounding can be used for vertical walls, ceilings, and soffit areas. Special access may be needed to test the soffit and the walls from exterior.

RADAR (Radio Detection and Ranging)

Radar technique is based on the propagation of electromagnetic energy through the materials with different dielectric constants. It is similar to sonic and ultrasonic pulse echo methods except that the frequency range is different. Today, there are many commercially available devices on the market and choosing one is a challenge by itself!

Besides the equipment, there are several challenges in application of this method. One of the basic challenges is that it is difficult to estimate the system’s depth of penetration before the test is performed. Since the depth of penetration depends on moisture content, conductivity, and the mineral composition of the concrete, each bridge is different. Sometimes even on the same bridge, there are variations in concrete properties from span to span. In addition, closely spaced reinforced steel poses problems too. In heavily congested areas (Photograph 3), reflections from the reinforcing steel are so strong that they hide the reflections from the steel ducts located below. Therefore, it is extremely difficult even to locate the ducts. Sometimes, by changing the scanning direction of the antenna, a better radar plot is obtained.

Another challenge is the interpretation of data to detect flaws such as delamination or void in midst of all the steel. Newer software techniques such as color transform, changing the scales and various types of filtering can result in highlighting certain observed features. Experience and knowledge of the person operating and interpreting the results is of great importance.
IMPACT ECHO METHOD

Impact echo technique involves introducing mechanical energy, in the form of a short pulse into a member under investigation. Reflected stress waves are monitored by a sensor and are transformed into a frequency domain using a Fast Fourier Transform (FFT) method. The resulting amplitude spectrum is used for identifying dominant frequencies to determine the condition of the member. Usually tests are conducted in the interested area using a suitable grid. Testing consists of impacting the concrete surface near the sensor and monitoring the frequency content on the waveform analyzer or the special instrument. At each sensor location, the procedure is repeated several times to assure that a repeatable response is produced.

Figure 3 shows the spectrum plots (Amplitude versus frequency) of the tests conducted over a fully grouted tendon ducts in the region of variable concrete thickness. Spectrum plot “A” shows a frequency of 4400 Hz representing a concrete thickness of 17-in. based on a stress wave propagation velocity of 12,500 ft./per second. Similarly, spectrum plots “B” and “C” show frequencies of 6200 Hz and 7400 Hz representing concrete thicknesses of 12 and 10-in. respectively. Spectrum plot “D” shows a frequency of 9400 Hz representing a thickness of 8-in. indicating a possible flaw. Additional testing conducted in the vicinity of this test indicated that there was an anomaly at the location. A core removed in this area confirmed the finding. Therefore, the challenge is to interpret the results accurately. Experience and judgment are necessary when coming to such a conclusion.

IMPULSE RESPONSE

This is a comparative technique in which “mobility” or inverse of the stiffness is compared between the test locations. The test involves striking the structure surface with an instrumented hammer near a velocity sensor and obtaining a response ratio (velocity/force) with the use of a waveform analyzer. If one location is known to be “good”, results at other locations can be compared to the value obtained at the “good” location. The technique can be
used in the immediate vicinity of the end anchorages.

Just like the impact echo method, this is a “local” method meaning that a result is obtained at the tested location only and the tests need to be carried out at a number of locations on a grid format.

![Amplitude spectrum plots for the tests conducted over a variable thickness slab.]

Figure 3. Amplitude spectrum plots for the tests conducted over a variable thickness slab.

RADIOGRAPHY

In a way it is ironic to test concrete with radiography since concrete is usually used to shield radiation. However, radiography can provide valuable information for post-tensioned bridges. The method requires access from both sides of the wall or slab being tested. A radiation source is positioned at a distance on one side and a sheet of x-ray film is attached on the other side. The radiation source can be Iridium-192 or Cobalt-60 depending on the concrete thickness. Co-60 has a greater energy output and hence, it can penetrate thicker
concrete and requires lesser exposure. Co-60 is also much more bulky and heavier than Ir-192.

When it is necessary to drill and remove a concrete core, it is important to locate reinforcing steel and post-tensioning ducts accurately. Two factors- namely image enlargement and shift- can pose challenges. A reinforcing bar closer to the source appears larger than the bar closer to the film side. Since the source emits energy in a conical shape, embedded objects located some distance away from the center line appear shifted from their true location.

Absorption of radiation varies from concrete to concrete and therefore, lot of experimentation is needed to determine the optimum exposure time and source to object distance for a chosen source to obtain high quality images. In addition, a large radius area around the testing site needs to be evacuated to avoid high radiation exposure. Photograph 4 shows a radiograph of ducts showing the interior tendons.

Photograph 4. Radiograph of ducts showing the interior tendons (courtesy of HESCO).

BORESCOPE EXAMINATION

This is a semi-destructive method in which a small diameter hole is drilled for inserting a borescope to observe interior conditions. The unit incorporates fiber optics and a light source to illuminate the cavity. Observations can be recorded via a still or a video camera. The method is very useful in confirming the results of the nondestructive testing. The challenge is to choose the location of the hole so that tendon duct is not damaged. The use of special concrete drill bits to detect the ducts and stop before causing the damage are useful. It is necessary to keep track of the depth and rotational reference so that the defect can be precisely located.
CONCRETE CHIPPING AND CORING

When the nondestructive methods are not able to pinpoint the exact type of anomaly, it is necessary to either chip a section of the concrete off to expose the tendon duct or to drill and remove the concrete core. For example if the impact echo testing results are not able to distinguish between a de-bonded duct and partially grouted duct, chipping the concrete is helpful to observe the condition of the duct; Photograph 6. If the duct is not de-bonded, then a small opening can be made in the duct without disturbing the tendons to observe the grout status; Photograph 7.

Sometimes, especially during a construction phase, it is absolutely necessary to drill and remove a core to verify the condition. When the ducts are located next to each other and there is no space between them, most likely coring will result in damaging two ducts as shown in Photograph 8.

Photograph 5. View of the crack as observed through a borescope.

Photograph 6. De-bonding of the duct from the concrete.
SUMMARY

This paper has presented the applicable nondestructive methods that are being used to test post-tensioned bridges. Each bridge (because of its complex design) presents a unique challenge in applying the nondestructive techniques. Application of a single method is not enough to evaluate the critical components of the post-tensioned bridge. Most of the methods require multi-disciplinary knowledge and extensive hands-on training. The real challenge is to find personnel with such an expertise. Continued efforts are needed to improve the existing nondestructive technologies as well as to educate and train individuals to apply the methods successfully.

REFERENCES

1. ACI Committee 228, Nondestructive Test Methods for Evaluation of Concrete in Structures; ACI 228.2R-98.