NONDESTRUCTIVE DETECTION OF FRACTURES IN PRESTRESSED AND POST-TENSIONED CABLES

By

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INTRODUCTION
The post-tech cable break detection (CBD) system is a nondestructive method for locating fractures in prestressed cables and both bonded and unbonded post-tensioned cables. The method was first developed in the early 1990s in Germany and has recently been used on a variety of commercial projects in North America and Europe.

PHENOMENON AND CAUSES OF STEEL FRACTURES

There are various reasons for fractures in prestressing steel tendons—some of which have led to structural collapses. All types of steel are at risk of breaking if they come into contact with corrosive media. In bonded prestressed structures such as bridge or parking decks, this can occur when the top of the deck is not adequately waterproofed, allowing corrosion-causing chlorides to breach the concrete surface and begin a corrosive attack on the prestressing steel. In unbonded post-tensioning, only moisture is needed to cause corrosion. With grouted post-tensioning, problems exist with chlorides being cast into the grout and bleeding of water from the grout mixture at peaks along the tendon profile and end anchorages. Additionally, in all cases, it is possible that corrosion of the prestressing steel started prior to its installation.

SCIENTIFIC PRINCIPLE

The method is based on using magnetism to locate fractures and areas of significant section loss in steel prestressing and post-tensioning strands. The physical principle is described in the following.

If two electromagnets of opposite orientation are connected at their tops with a solid iron bar, any embedded steel in the concrete underneath that should happen to be passed over will also become magnetized, completing the magnetic loop. Figure 1 shows this basic principle and orientation.

Fig. 1—Magnetization process.

The steel portion of the tendon above the green arrow in Fig. 1 becomes magnetically similar to a permanent bar magnet after the electromagnet is passed over it. The end of the tendon on the left has a magnetic north pole (N) and on the right a magnetic south pole (S).

Using appropriate sensors and specially designed software capable of reading and interpreting magnetic flux, the graphs in Fig. 2 and 3 are produced. In Fig. 4 and 5, the magnet flux lines are illustrated entering and exiting the bar magnet at each of the poles. Due to the close proximity of the poles to one another at fracture locations, the transverse component of the magnetic flux is most distinguishable during measurements and is shown in Fig. 2 and 3. These figures are essentially a graphical representation of the natural magnetic phenomenon.

Figures 4 and 5 show the behavior of a solid bar magnet and a bar magnet with a fracture at its midsection.

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Figure 2 correlates with the solid bar magnet shown in Fig. 4. The transverse component of the magnetic flux shows a more positive flux at the left-hand side and a less positive flux at the right-hand side. The midsection is relatively neutral because no transverse flux is emitted from that area.

Figure 3 correlates with the fractured magnet shown in Fig. 5. There is a dip toward a less positive...
flux between approximately 400 and 440 cm (160 and 170 in.), and then an abrupt change to a more positive flux. This represents a fracture because an intermediate polarity reversal has been detected.

In a real structure, the tendons are magnetized by passing a magnet over top of them (in most cases on the surface of the concrete), inducing the magnetic field. The sensor unit, which contains a series of sensors that measure magnetic flux, is passed over the cable. Using specially designed data collection and analysis software, the magnetic flux at any location is measured and recorded. An XY plot is produced as the readings are being taken. These data are further analyzed using a refined software package that analyzes the data at a more in-depth level and the location(s) of the suspected fracture(s) are confirmed.

When magnetizing a structure, both the mild reinforcing steel (reinforcing bar) and the high-tensile steel (prestressed and post-tension strands) are magnetized and will deliver a signal to the data-collecting sensors. This can create a signal that is difficult to differentiate between a fracture of the prestressing steel and a transverse reinforcing bar stirrup. Similarly, lap joints in longitudinal reinforcing bars cause unclear magnetic flux readings. To address this problem, a technique has been developed to clear up this signal to better identify the fractures. Mild steel and high-tensile steel have different magnetic properties. The magnetizing technique and software used in the Post-tech CBD System uses the different magnetic properties to be able to distinguish between the magnetic field reading for the mild reinforcing and

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**Fig. 2**—Transverse magnetic flux as function of distance along magnet. (Note: 1 cm = 0.394 in.)

**Fig. 3**—Transverse magnet flux as function of distance along magnet. (Note: 1 cm = 0.394 in.)

**Fig. 4**—Solid bar magnet.

**Fig. 5**—Bar magnet with fracture at midsection.
the high-tensile prestressed or post-tensioned steel.

The accuracy and magnitude—referred to as the peak-peak amplitude of the fracture information—is dependent on the clarity of the signal received by the sensors. The peak-peak amplitude is shown in Fig. 6. Some of the factors that affect the quality of data are:

- The number of fractured wires in cable;
- The concrete cover over the cable;
- The width of the fracture;
- The amount of mild reinforcing in the area; and
- The degree of tensioning.

METHODS

Two post-tech CBD methods exist for the evaluation of real structures. These include the line scan method and the rotating scan method. The line scan method is used to evaluate individual or bunched cables longitudinally, whereas the rotating scan method is used to evaluate many cables transverse to its direction of travel in a short amount of time. Both methods are discussed in the following.

Line scan

The line scan method requires the unit to be passed over the cable along its length to create the magnetic field. Once the length of the cable to be investigated has been magnetized, the unit is passed over the cable again with the magnet turned off and the sensors turned on so the data can be collected. If mild reinforcement is present, several passes are made over a cable at varying degrees of magnetization to clarify the data and verify the possible fracture location.

The line scan unit can be used to investigate cables in slabs by passing the unit over the top surface of the slab (as shown in Fig. 7) or from the side of a girder (as shown in Fig. 8).

The line scan unit can also be adapted to scan the underside of a slab (Fig. 9) or girder (Fig. 10). Data collected during a scan of fractured strand are shown in Fig. 11.

Rotating scan

The rotating scan system (Fig. 12) is used to investigate cables running transverse to its direction of travel. The unit consists of a vehicle that propels two large electromagnets that magnetize the tendons as the vehicle passes over. The trailer in the rear is equipped with rotating bar housing sensors, which, in conjunction with a sophisticated software system, are capable of reading and interpreting the magnetic flux density. Typical applications for the rotating scan...
system are post-tensioned bridge deck systems and parking garage investigations.

The software produces an image from this data in grayscale format. The image is shown in Fig. 13. A bright white signal at one end represents a south pole and a dark black signal at the other end represents a north pole. Similar to the fractured bar magnet shown in Fig. 5, a fracture is indicated by the presence of an intermediate white spot (south pole) and a black spot (north pole) right next to each other along a tendon.

The data shown in Fig. 13 was obtained from a real bridge structure. The span was over land, allowing for the underside of the bridge to be investigated for calibration purposes.

Photos of the fractured tendon detected from the surface shown in Fig. 13 are shown in Fig. 14(a) and (b).

**PROJECT HISTORY**

Both methods have been used extensively in Europe, and are now being used more frequently in North America. In Europe, the line scan has been used since 1998 to evaluate girders in many factory buildings that have a history of broken cables as well as in bridges and roof slabs, including double-tee precast/prestressed girders. The rotating scan system was used on several bridge decks in 2002 and 2008 to investigate the transverse post-tensioned bars that have deteriorated and were failing due to corrosion.

In North America, line scan projects included the evaluation of external post-tensioning tendons, precast prestressed box girders, and grouted post-tensioned tendons in web and lower flange of long span AASHTO girders. Both line and rotating scan systems were used for evaluation of transverse and
longitudinal tendons in parking garage decks and the rotating scan projects involved transverse tendons in bridge decks.

In almost every application, fractures in the prestressing steel have been detected. In each case, at least one detected fracture location has been opened to confirm the reading.

**CHAMPLAIN BRIDGE**

In September 2008, Vector Corrosion Technologies and the Technical University Berlin worked with The Jacques Cartier and Champlain Bridges Incorporated (JCCBI), a Federal Crown corporation to perform two sets of investigations on the Champlain Bridge in Montreal, QC, Canada. The project consisted of investigating two sets of post-tension systems:

1. The post-tensioned cables in the girders; and
2. The transverse post-tension bars in the bridge deck.

**Girder investigation**

The girders are fabricated using a series of 24 sets of post-tensioned cables, 14 of which are draped and 10 running in the bottom flange of the girder. The girder investigation was performed using the line scan method in two different configurations.

The center portion of the girder, where all the cables are in the bottom flange, was investigated by running the line scan magnet and sensors on the underside of the flange. In this case, the magnet/sensor unit was run on a track system set up on scaffolding to allow the unit to pass as close to the underside of the girder as possible to obtain the best results. This investigation found no fractures in this portion of the girder.
CASE STUDIES

The draped portions of the cables were tested from the side of the girder using the line scan unit. Here, the magnet/sensor unit was suspended on a rail that was attached to the side of girder along a path to best follow the location of the drape in the cables. The unit was again passed as close to the concrete surface as possible to get the best results. In this case, three different locations were tested and, at one location, possible fractures were found in one of the cables.

Deck transverse bars investigation

The bridge deck and girder system have transverse post-tensioned tendons, spaced at approximately 3 ft (900 mm) on center, that hold the deck girder system in place to work as one unit. Over the years, these post-tensioned bars have been attacked by deicing salt chlorides, creating corrosion damage and some known broken tendons.

The transverse post-tensioned tendons in an area of six spans of one lane were tested using the rotating scanner system. Over one night, traffic was diverted so one lane could be investigated. The rotating scanner was run over the area and approximately 300 tendons were magnetized and then scanned with the rotating scanner unit traveling behind the magnet. Of the 300 tendons tested, there were six locations where possible fractures were detected. Upon reviewing the break locations after the completion of the deck investigation, it was found that two of the possible fracture locations were in a portion of the deck that could be easily investigated from the underside. These locations were then viewed from the ground and both locations showed signs of spalling due to corrosion damage of the steel. Upon closer investigation of the tendons themselves at these locations, it was found that breaks in the post-tensioned tendons were clearly evident.

CONCLUSIONS

With the continued degradation of aging North American infrastructure, nondestructive methods of structural evaluation are becoming increasingly important.

The post-tech CBD system is an effective nondestructive method capable of detecting fractures and significant loss of cross section in prestressed cables and unbonded, bonded, and bar post-tensioned tendons, without the need to excavate the concrete. There are two systems available for detecting fractures on different types of structures, the line scan method and the rotating scan method. The line scan method is used to evaluate one cable at a time while the rotating scan method is used to evaluate several cables at one time. Structures can be evaluated relatively quickly, with minimal disturbances to the occupants or traffic. The equipment has been evaluated by independent institutions in laboratory and field tests. In all cases, the results obtained from the measurements have correlated well with actual conditions. These systems proved effective in location fractures on a project on the Chaplain Bridge in Montreal, QC, Canada.