NONDESTRUCTIVE TESTING FOR VOIDED AND SOFT GROUT IN INTERNAL POST-TENSIONING DUCTS

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Post-tensioned (PT) bridge construction has been used for decades. This construction is popular because it is economical to construct long-span structures over water or difficult terrain or in congested urban areas where traffic disruption can be an issue. PT bridges often have precast or cast-in-place segmental box sections or girders with internal ducts so that tendons can be inserted between bridge segments and stressed so that the sections are in compression under dead and live load. After the tendons have been stressed, the annular space inside the PT duct and around the stressed tendon is filled with grout. The grout's primary purpose is to passivate/protect the tendon from corrosion and, in some designs, the grout also acts as a structural bond between the stressed tendon and the structure. Failures of PT bridge tendons have occurred with little to no signs of distress before failure. Forensic investigations after the failure have shown that in most cases, these failures occurred because the stressed tendons were exposed in a void in the protective grout, and moisture or chlorides were able to infiltrate to the tendon. Another failure mode is soft grout within hard grout that results in a pH difference and a galvanic reaction.

The problem facing bridge inspection engineers is how to detect voided and soft grout conditions inside a metal or polyvinyl cholride (PVC) duct embedded in concrete. Nondestructive impact echo testing technology can help in detection of such issues.

Nondestructive testing for void and soft grout detection in internal PT ducts consists of three elements: 1) ground-penetrating radar (GPR) to accurately locate the duct; 2) sonic/ultrasonic impact echo testing to detect voided or soft tendon grout; and 3) drilling to and opening the duct for borescope documentation of grout and tendon conditions.

Placement of sonic/ultrasonic sensors and the energy generation for impact echo testing needs to be highly accurate, within 1/2 in. (13 mm) of the projected plane of the internal PT duct. High-resolution GPR is used to accurately locate the centerline of the duct. Shop and/or as-built drawings are not usually accurate enough to locate the centerline. GPR data (Fig. 1) are acquired using a 1600 MHz or higher-frequency antenna to locate metal and PVC ducts with the required accuracy. Figure 1 shows GPR data being acquired on a vertical line of coverage on the web of a girder to locate PT ducts. The approxi-

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mate center line of each tendon duct is marked on the concrete surface with different color keel at 1 ft (305 mm) test intervals for sonic/ultrasonic testing (Fig. 2).

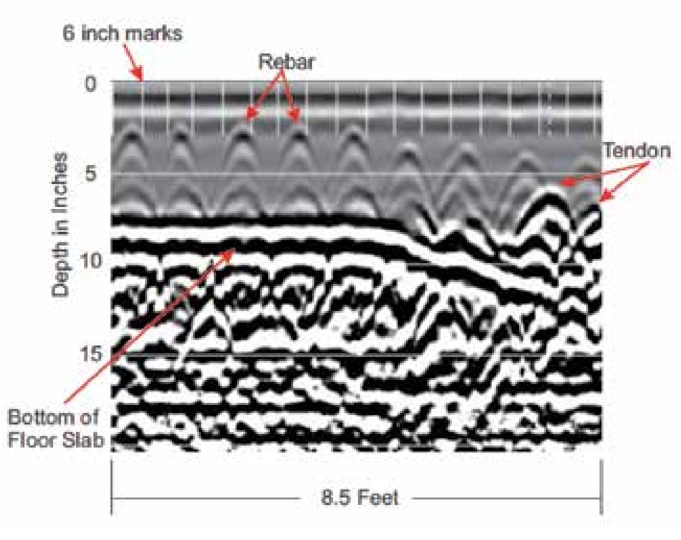

Fig. 1—Annotated GPR record to locate PT ducts.

Fig. 2—(a) GPR to locate web tendons; and (b) tendon locations marked on girder web.

Fig. 3—Impact echo testing.

After the PT ducts are located and marked, sonic/ultrasonic impact echo testing is conducted to evaluate PT duct grout conditions. Sonic/ultrasonic impact echo/resonant (multiple reflections) frequency measurements are obtained with a system developed by the authors' company, NDT Corporation. This system uses a projectile impact energy source, an array of four-sensor array, and a portable computer to archive and provide a quality control field display of data (Fig. 3). Data is acquired at 1 ft (305 mm) intervals with sensors spaced 6 in. (150 mm) apart, which provides continuous overlapping coverage. The sonic/ultrasonic data is obtained by positioning the energy source at one end of the array and incrementing the array every 1 ft (305 mm).

The projectile impact produces stress waves that are reflected from the back wall and detected by an array of sensors. Each sensor measures the amplitude of the stress wave in time (time-domain plot). The sensor array is placed at the marked 1 ft (305 mm) intervals along the top quarter point of the duct (Fig. 3). Time domain data are used to measure the compressional and shear wave velocity values (strength of girder concrete), and the frequency domain data is a Fourier analysis of the time domain data to determine the resonant frequency (thickness) of the concrete elements being tested.

NONDESTRUCTIVE TESTING OF PT DUCT GROUT

A typical section of a concrete PT girder and segmental box is shown in Fig. 4. Energy input with a projectile impact creates a compressional wave that propagates through the concrete in the horizontal/thickness directions and is reflected back through the concrete from the back surface of the girder.

This energy is trapped between the two girder surfaces and resonates at a frequency that is a function of the compressional wave velocity and the web or slab thickness. When the thickness and the compressional wave velocity remain constant, which is the normal condition for a fully grouted duct, the resonant frequency is expected to be constant. For the example that follows, the slab thickness is 10 in. (250 mm), so the thickness resonant frequency would be approximately 8.0 kHz. When the resonant frequency is significantly lower than 8.0 kHz or is missing, then anomalies along the wave path such as soft grout or air voids (the velocity of soft grout is estimated to be 4000 ft/s [1200 m/s], air is 1000 ft/s [305 m/s], and the velocity of the concrete is 13,500 ft/s [4100 m/s]) results in a longer path time and lower thickness frequency because the sonic ray path is diffracted around the void (Fig. 5).

The principal criterion for evaluating the tendon ducts is the resonant frequency value of thickness of the concrete girder or box web. The resonant frequency of a free-free faced element (wall face to wall face) in its simplest form is given by

$$f = V/2T$$

where f is the resonant frequency; V is the velocity of the sonic/ultrasonic wave in concrete; and T is the thickness of the element for the web wall.

The resonant frequency for a fully grouted duct typically is slightly lower than the thickness of the concrete in which the tendon is located. If the duct is voided or has soft grout, the wave will effectively travel (diffract) around the void/soft grout along a longer time path (Fig. 5)/lower frequency than that for a fully grouted duct. When duct voids, soft grout, grout delaminations, or honeycombing in the concrete around the duct exist, the arrival of the diffracted wave may destructively interfere with the normally reflected (direct wave), preventing identification of the normal thickness resonant frequency and in some cases introducing spurious beat frequencies or no coherent frequencies. (Fig. 6).

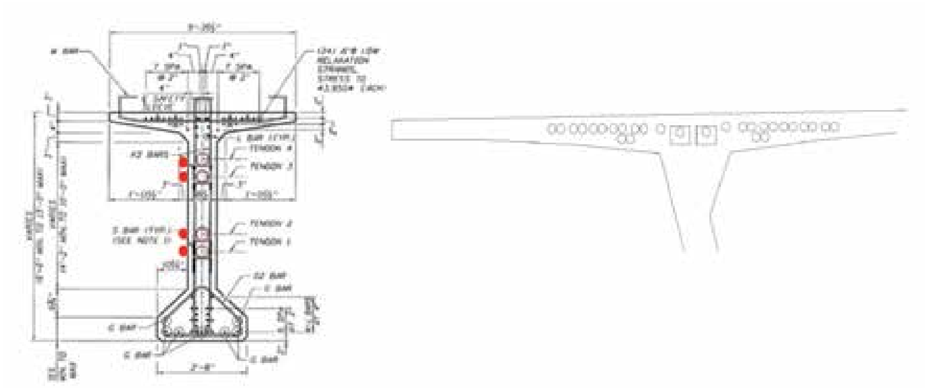

Fig. 4—Typical sections of post-tensioned I-girder and segmental box. (Note: 1 in. = 25.4 mm.)

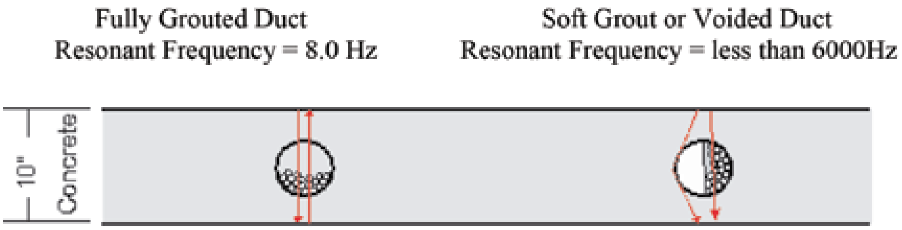

Fig. 5—Sonic wave paths for fully grouted and void ducts. (Note: 1 in. = 25.4 mm.)

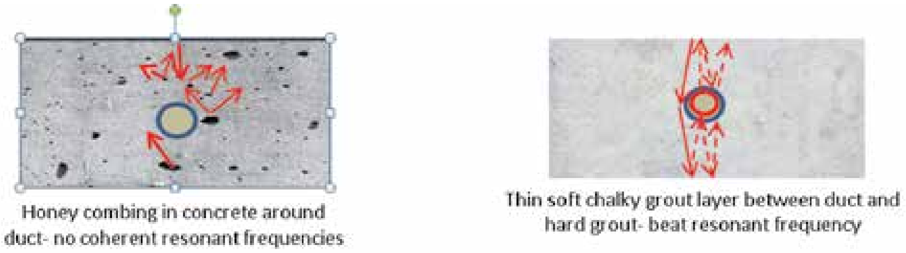

Fig. 6—Diffracted sonic wave paths.

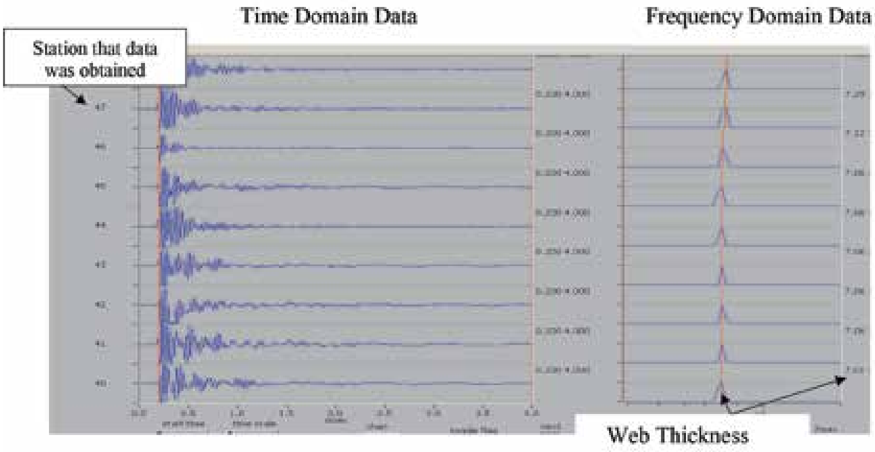

Fig. 7—Samples of sonic/ultrasonic data associated with ducts filled with hard grout.

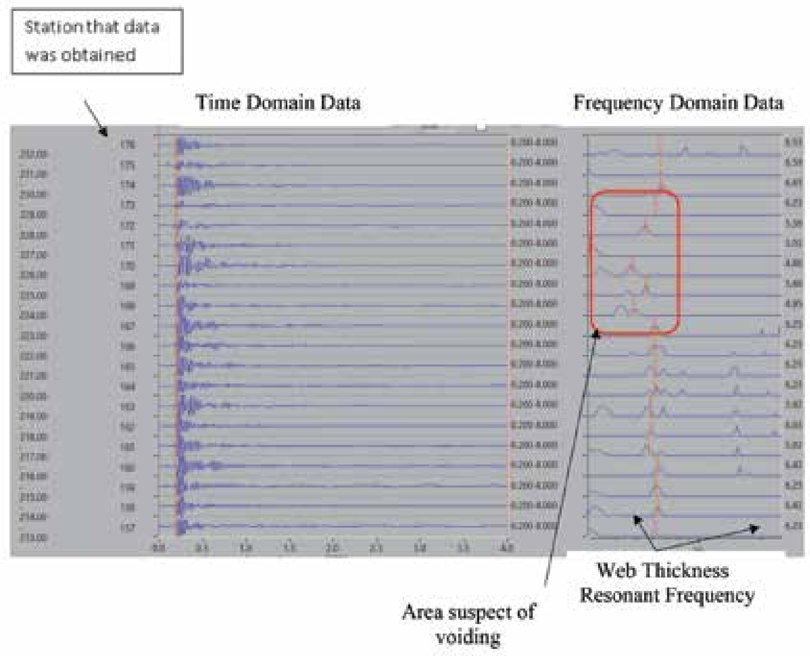

Fig. 8—Samples of time domain and frequency domain "suspect" data.

Listed as follows are the three primary data characteristics detected by the impact echo testing and the grout conditions determined from drilling and a visual inspection of the internal duct conditions:

CONDITION 1—Full-thickness frequency with no spurious resonant frequencies: fully grouted duct.

CONDITION 2—No full-thickness frequencies or full thickness frequencies with spurious low resonant frequencies: thin (<1/4 in. [6 mm]) soft grout layer, duct corrosion, or honeycombed web concrete.

CONDITION 3—Low full-thickness frequency: duct suspected of having soft grout or a void.

Condition 1 is representative of a tendon duct that is fully grouted; it could have limited minor voids (debonding) between the concrete and the duct. Tendons with this condition are considered to be fully covered with grout and the grout is mostly bonded to the duct wall.

Condition 2 is considered to be an anomalous condition that is due to a layer of soft, chalky, or brittle grout inside the duct, duct tape, or corrosion on the duct or high air entrapment in the web concrete. Spurious frequencies are due to destructive interference due to the conditions listed in Fig. 6.

Condition 3 represents a tendon duct which is either partially or completely filled with soft grout or voided with possible tendon exposure.

Examples of the sonic/ultrasonic data for Condition 1 and 3 are provided herein. Figure 7 is an example of Condition 1. Sonic/ultrasonic impact echo thickness resonant frequencies are in the range of 6.5 to 7.4 kHz and drilling verified ducts filled with hard grout.

Figure 8 is an example of Condition 3. Sonic/ultrasonic impact echo thickness resonant frequencies are in the range of 4 to 6.5 kHz.

QUALITY CONTROL

Confirmation and calibration of nondestructive test results are accomplished by drilling a 1 in. (25 mm) diameter hole to the duct and using a tool specifically made to open metal ducts for visual observation of grout condition. Grout conditions inside the duct and the drill hole side wall conditions are documented using a video borescope (Fig. 9 and 10).

CONCLUSIONS

Limitations

Impact echo testing requires specific conditions to effectively evaluate PT ducts for soft or voided grout conditions: a near-parallel concrete surface no greater than 2 ft (610 mm) apart. These conditions exist for most of the length of PT ducts in most post-tensioned bridges.

Problematic areas

- Top-draped PT ducts passing into the top girder flange near piers or over box ceiling slab;
- Bottom-draped PT duct passing into bottom girder flange or below box floor; and
- Over the top of piers or at abutments.

When ducts are side by side in a girder or segmental box wall or over each other in a deck or floor slab, results are not as definitive as to which duct soft grout or voiding is in.

Experience has shown that impact echo testing results indicate three conditions: 1) full wall/slab thickness resonant frequency—no voiding hard grout; 2) spurious (no or highly variable) thickness resonant frequencies—PT duct grout condition unknown; or 3) low wall thickness resonant frequencies—soft or voided grout. Impact echo results typically indicate approximately 75 to 85% for Condition 1, 10 to 20% for Condition 2, and 5 to 10% for Condition 3. Drilling verification of Condition 1 "Good" unvoided grout has detected hard grout with a small (less than 1/4 in. [6 mm]) bleed water void in virtually every case. Drilling verification of Condition 3 (voided or soft grout) has detected voids or soft grout approximately 80% of the time and tape at duct joints, grout debonded from the ducts, and undocumented cracking in concrete in test area. Drilling of Condition 2 (conditions unknown) have found, in most cases, defects (honeycombing and cracking) in the concrete above or around the ducts and in some cases voiding in the duct grout. These findings would indicate the impact echo testing has an effectiveness of evaluating internal duct grout conditions of at least 80 to 90%.

Fig. 9—Borescope inspection.

Fig. 10—Borescope image inside PT duct.

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