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Nondestructive Evaluation of Defects in Tendon Ducts of Post-tensioned Concrete Bridge Girders

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ABSTRACT

The integrity of grouted tendons in existing post-tensioned concrete bridge girders is crucial for structural safety and the protection of travelers. Instances of failure, such as those seen in the Bickton Meadows Footbridge and Ynys-Y-Gwas Bridge in the UK, highlight the importance of reliable inspection methods. Although numerous nondestructive evaluation (NDE) techniques have been researched to identify defects like voids, strand corrosion, and broken wires within tendon ducts, universally accepted methods remain elusive. This paper outlines the creation of laboratory specimens that mimic real-world defects in bridge tendons. It details the application of an ultrasound NDE method, which utilizes ultrasonic waves to determine defects in grouted tendons. The advancement of this NDE technique could potentially enhance the inspection and overall safety of existing post-tensioned concrete bridge girders. This paper serves as a progress report of the ongoing research into the proposed NDE method.

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1. Introduction

A majority of segmental or spliced girder bridges in the United States use bonded post-tensioning steel strands, typically grouted with cementitious materials. The quality of this grouting is crucial as it affects the service life of the post-tensioned tendons, which are the primary reinforcement. Deterioration of these tendons can negatively impact the structural performance of the bridge girders, posing a safety risk to the traveling public. Several states have reported issues with corrosion, section loss, or broken strands in grouted tendons, particularly in bridges exposed to highly corrosive environments. Notable cases include the Interstate 35W bridge in Minneapolis, Minnesota, the Mid-Bay Bridge and Sunshine Skyway Bridge in Florida, and the Varina-Enon Bridge near Richmond, Virginia (Thompson et al. 1992; Hansen 2007). These problems are primarily attributed to voids, bleed water, or cracks in the cementitious grout used in the tendons (Salas et al. 2008). Since visual inspection for internal corrosion is nearly impossible, identifying a feasible solution to detect possible corrosion without significantly interrupting traffic is essential. This research aims to propose a Non-Destructive Evaluation (NDE) method to detect broken wires or strands and voids in ducts.

Numerous researchers have studied various NDE methods for identifying defects in grouted tendons. For instance, Terzioglu et al. (2018) investigated Ground Penetrating Radar (GPR), Impact Echo (IE), Ultrasonic Echo (USE), and Ultrasonic Tomography (UST), to inspect grout defects in a full-scale post-tensioned U-girder specimen. They found that while GPR and UST could identify tendon profiles, they could not detect tendon defects. Conversely, IE and USE provided somewhat useful results in identifying grout defects in the tendons. They recommend using GPR, the fastest and least labor-intensive method, for locating tendons and employing IE or USE for pinpointing grout defects. However, they reported that IE and USE were unable to distinguish between water, voids, or compromised grout conditions.

On the other hand, guided wave-based NDE is promising in detecting defects along multi-wire cables, such as overhead power-lines, over long distances (e.g. Legg et al. 2015). Furthermore, numerical models exist that can be utilized for damage localization and characterization (e.g. Bischoff et al. 2014). However, this methodology has not been applied to tendon ducts.

2. METHODS

2.1 NDE approach

The proposed NDE approach is depicted in Fig. 1. A function generator is used to produce a short ultrasound burst that is amplified by a power amplifier that drives a piezoelectric transducer attached to the tendon. A guided wave propagates along the tendon and is altered by any defects along its propagation path to the sensor. A measurement from the sensor is recorded using an oscilloscope. It should be pointed out that this work focuses on assessing the guided wave-based NDE approach for the tendon only.

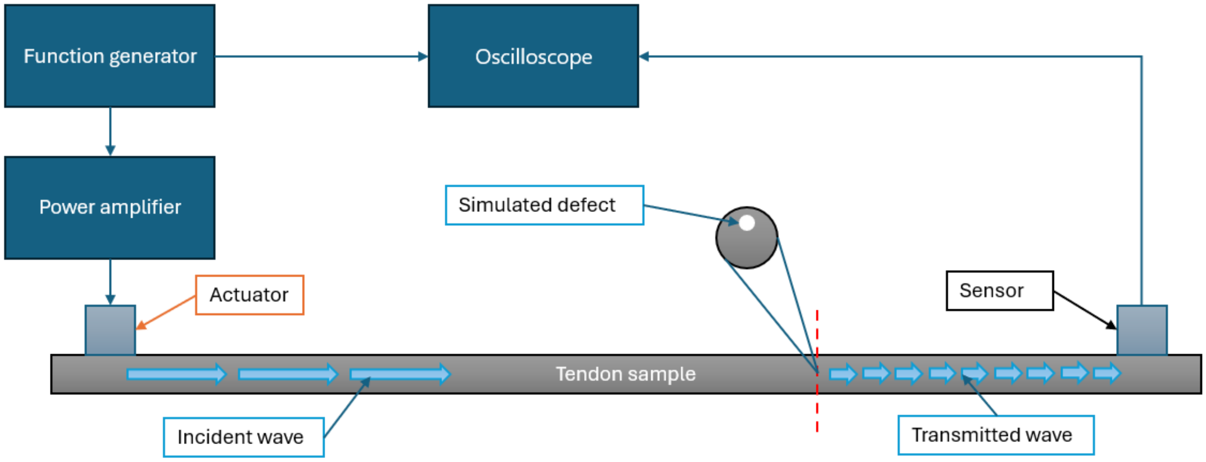

Fig. 1 Sketch of the guided wave-based NDE approach

2.2 Sample fabrication

The authors prepared several tendons with corrugated steel ducts, grout, and steel strands, simulating real bridge applications using both short and long tendons, measuring 16 inches and 48 inches, respectively (Fig. 2). This paper focuses on the NDE of the short tendons grouted in 10-in. long ducts to identify pre-planned defects. To simulate broken wires, some steel wires or strands were intentionally cut, and portions of the strands were blocked to create voids. Fig. 3 shows the three grouted strands, i.e., Strand 1, Strand 3, and Strand 7, as discussed in this paper. Most strands, including Strand 1 and Strand 3, were grouted in a single duct. However, Strand 7 was grouted in a duct with three strands.

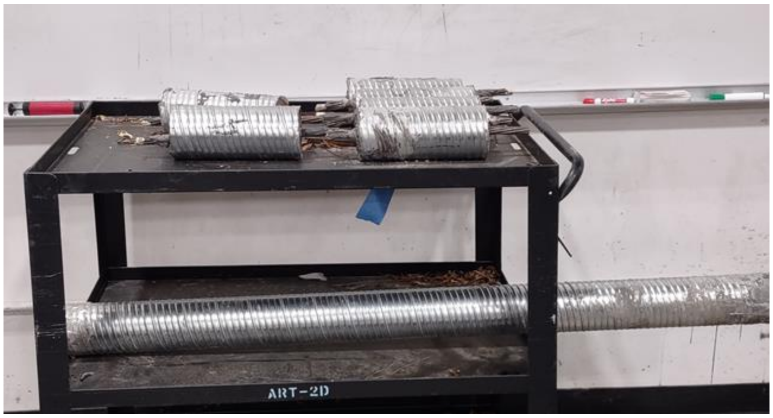

Fig. 2 Custom samples fabricated for this research

Fig. 3 Short tendons being grouted

2.3 Experimental setup

Several preliminary guided wave-based NDE experiments with the fabricated samples are conducted. A short sinusoidal tone burst of 8 cycles (Hann-windowed) is excited at 192kHz using an arbitrary waveform generator and then amplified to approximately 100Vpp using a power amplifier. The burst period is set to 40ms to ensure waves are fully attenuated prior to the next excitation. To improve signal to noise ratio (as no gain filter is used on the sensor side), an average over 2000 repeated measurements is taken with each measurement running for 400µs. First, baseline measurements are conducted on the isolated Strand 0 as shown in Fig. 4. Broadband transducers are clamped to an individual wire of the strand with an abundance of ultrasound gel couplant between the wire and the transducer. Actuator and sensor are placed 355mm apart from each other, roughly in the middle of the strand. The strand is isolated from the t-slotted profile it rests on using foam pads. Measurements are repeated several times, each time re-clamping the transducers to confirm repeatability of the test method.

Fig. 4 Reference ultrasound NDE experiment along Strand 0

For all grouted samples, light prepping is performed: excess cement is removed from the exposed ends on the strand and light sanding is performed. Then, transducers are clamped to an individual wire as shown in Fig. 5. Experiments are repeated multiple times for each strand.

Fig. 5 Sample ultrasound NDE experiments across grouted Strand 3

3. RESULTS

3.1 Pristine samples

Fig. 6 shows the baseline measurements for Strand 0 (left). That is, the raw signals of three repeated measurements are plotted in the range from 100-250μs. It can be seen that all signals have high signal-to-noise ratio (SNR) and are in close agreement, indicating high repeatability of the experiment. In addition, measurements from Strand 1 are shown as well (right). It can be seen that high repeatability across three repeated measurements is still achievable. However, the signal amplitude has dropped by approximately one order of magnitude. In other words, grout and duct lead to substantially attenuated signals across the same propagation distance. Nonetheless, a good signal to noise ratio can still be achieved. Further, waves also appear to arrive at the sensor later, indicating a drop in group velocity due to the changed "environment" between the strands.

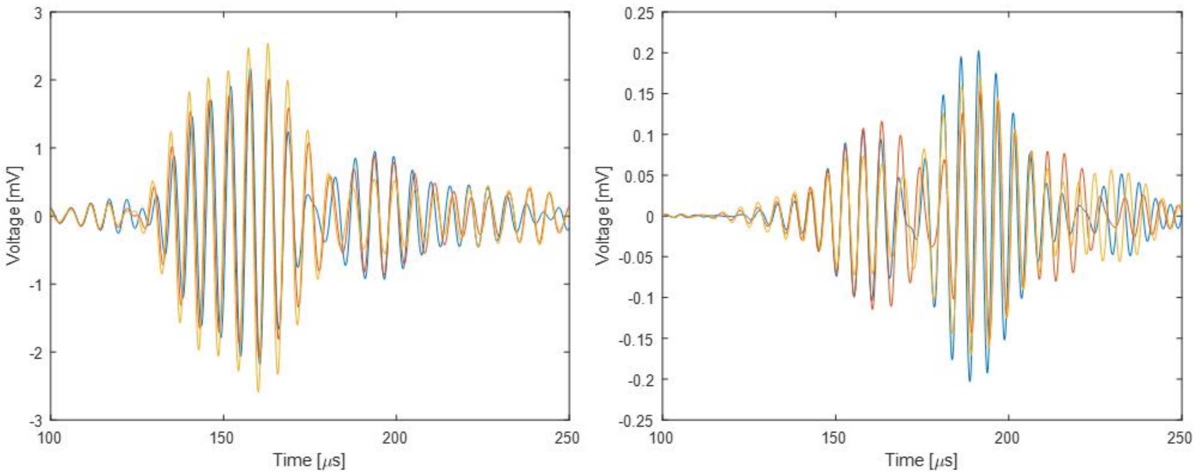

Fig. 6 Time history of recorded sample measurements along undamaged strands: Strand 0 (left) and Strand 1 (right)

3.2 Defective samples

A sample measurement series across a strand with a defect, here Strand 3, is shown in Fig. 7 (left). This strand contains an artificially introduced void at the strand-grout interface approximately in the middle of the sample. It can be seen that the signal amplitude is even lower than in the previous case while the SNR is still high. At the same time, higher variability across different measurements can be observed. Comparing the signal characteristics to that of the pristine case, significant differences can be observed. This indicates that automated damage detection should be feasible. Another sample signal from Strand 7 is shown as well (right). This strand contains a similar void-like defect as Strand 3. However, Strand 7 is placed in a duct with a total of three strands. Yet again, the signal characteristics are different from all previous cases, which indicates that neighboring strands influence the wave propagation behavior but damage detection is likely still possible.

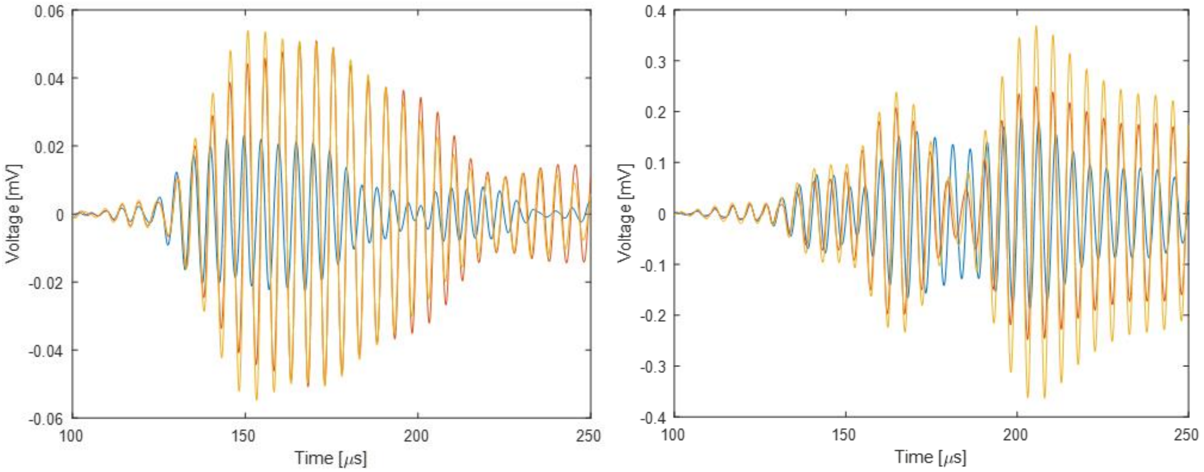

Fig. 7 Time history of recorded sample measurements along damaged strands: Strand 3 (left) and Strand 7 (right)

4. CONCLUSIONS

A custom set of samples of grouted tendons were manufactured. A guided wave-based NDE approach was used to take sample measurements across the samples.

- Compared to the bare strand, a significant reduction in amplitude can be seen for measurements along grouted strands, leading to a lower SNR in the field.
- Nonetheless, clear measurements are possible for all grouted strands by attaching the transducers to a single, exposed wire.
- Significant differences can be observed between measurements across samples with different defects.

Future work will focus on exciting guided waves in the strands remotely, and exploring optimal experiment parameters.

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