Drilled shaft imaging with 2D ultrasonic waveform tomography

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Presentation outline

- Introduction and background
- Project objective
- Research approach
- Proof of concept
- Research tasks

Introduction

- Drilled shaft construction is vulnerable to formation of foundation defects. The defects are the result of adjacent soil inclusion, concrete weakening by segregation or mixing with slurry, concrete that fails to flow through the rebar cage, or soft tip condition (poor cleaning).

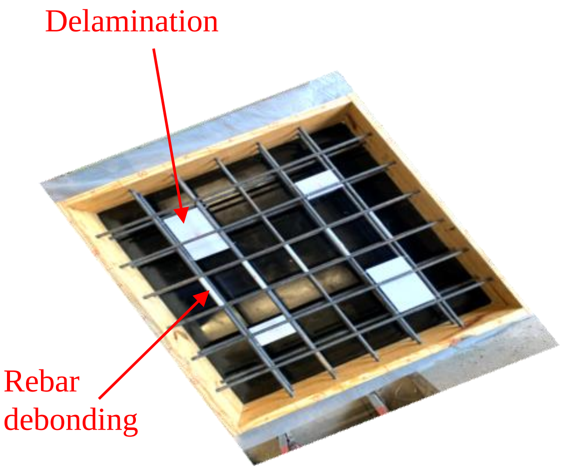
- Defects can cause a large reduction of foundation capacity and compromise long-term durability due to exposure of uncovered rebar to groundwater and corrosion due to soil pH, sulfate and chloride concentrations.

- Problem is particularly critical for foundation elements that are large diameter and non-redundant (e.g., in case of limited space, right of way). The insufficient foundations could cause structural distress/failure. Thus, requiring detailed diagnostic imaging of entire shaft for remediation actions.

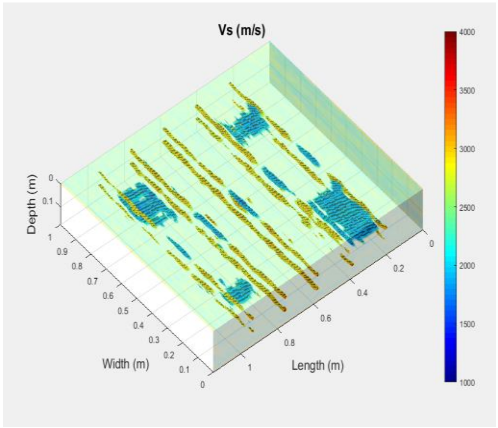
Shafts with defects (Mullins and Winters, 2011) that lead to compromised durability and the loss of capacity

Introduction

- Mechanical wave propagation has been shown to be an excellent approach to diagnostic imaging because of the direct physical connection to mechanical properties and defects. Wave-based techniques (e.g., using ultrasonic and seismic waves) have been used with great effect in structural imaging and engineering geophysics.



- Drilled shaft imaging is much more difficult. This is due to the inherent challenges: 1) large objects with limited access, 2) highly complex waveforms due to curved shaft boundaries and defects and 3) discontinuity in parameter distribution such as concrete-soil or concrete-defect interfaces.



Concrete imaging with ultrasonic FWI (Chen and Tran, 2021)

- The goal of this project is to address these challenges for the development of an advanced ultrasonic method that enables new capabilities of foundation imaging in terms of resolution and accuracy.

Project objective

- The project objective is to develop a new ultrasonic technique for full-volume imaging of drilled shafts.

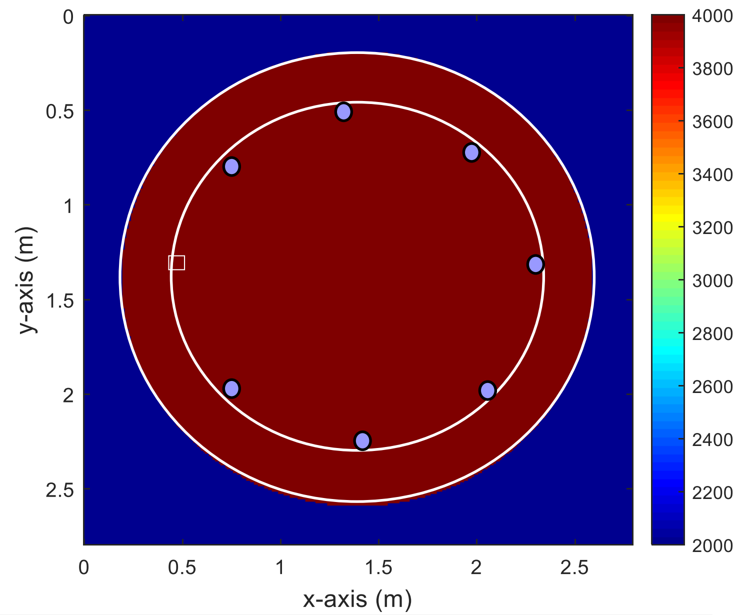
- The technique will enable to characterize the whole drilled shaft at high-resolution (cm-pixels) for assessment of concrete and defects both inside and outside the rebar cage.

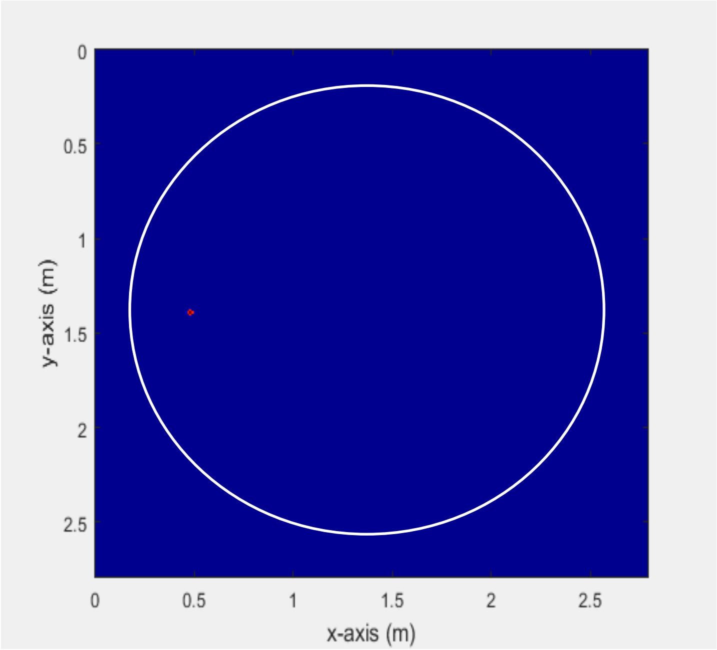
Research approach

This project will develop a 2D acoustic full waveform inversion (2D AFWI) method of ultrasonic waves and verify the method with synthetic and field experiments.

The ultrasonic waves are acquired from the standard Crosshole Sonic Logging (CSL), using a transmitter and a receiver moving along water-filled access tubes. Data collected from individual pairs of tubes at each depth will then be combined for multi-channel shot gathers, and then inverted to extract the shaft's 2D P-wave velocity (*Vp*) image at the depth.

Individual 2D images at depths (1 ft intervals along shaft length) will be stitched together for a 3D image of the whole shaft.





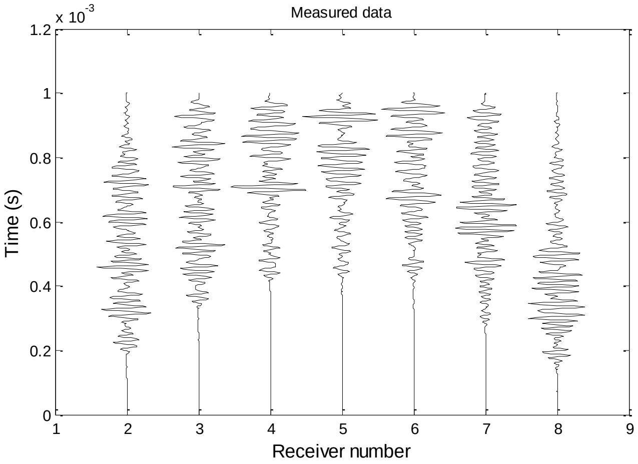
Proof of concept

Preliminary 2D AFWI algorithm has been implemented. It is based on a solution of 2D acoustic wave equations and the classic cross-adjoint inversion method.

The test shaft was at Pearl Harbor Memorial Bridge in New Haven, Connecticut. It was a shaft of 8-ft diameter and 71-ft length.

The CSL test was conducted by PileTest following ASTM specifications. Eight 2" diameter PVC tubes (one tube per foot of shaft diameter) were used, and ultrasonic waves were collected using a transmitter and a receiver placed in a pair of access tubes.

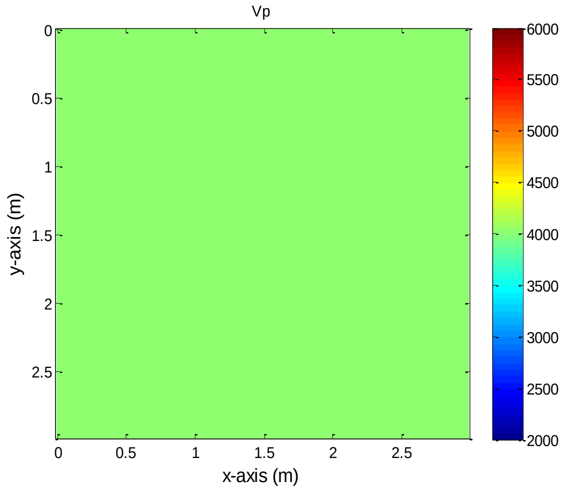
Data was recorded for each pair of tubes (28 pairs in total) at depths of 4-cm intervals from the top to tip of the shaft for a total of 530 depths.

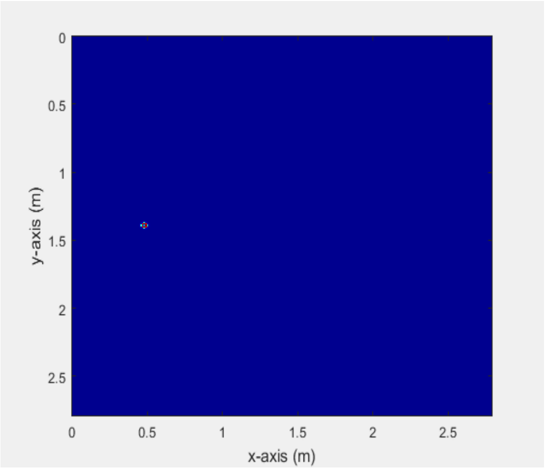


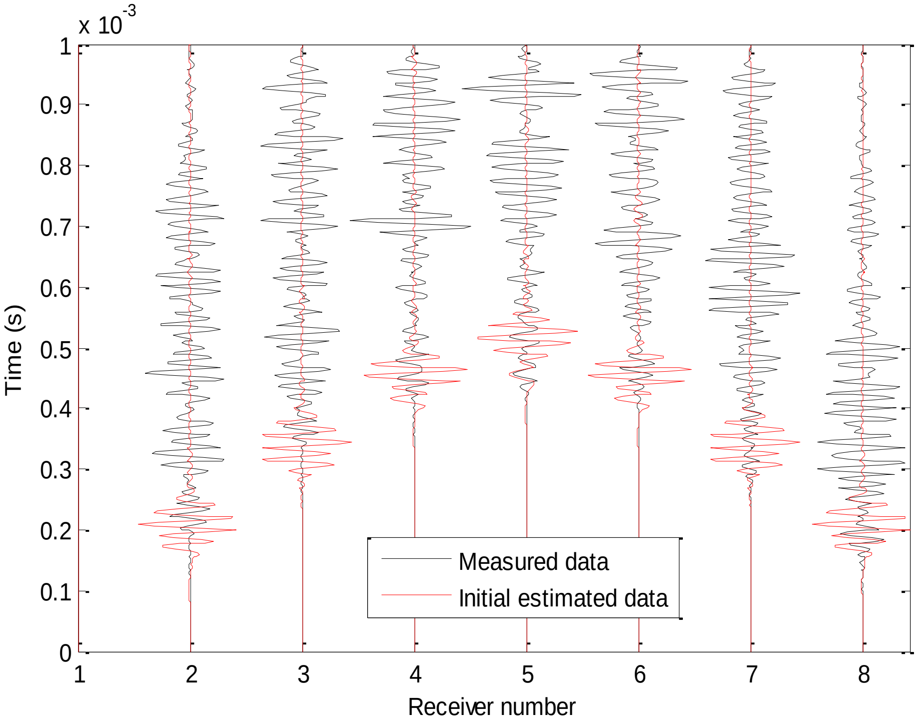
Actual CSL data for 7-channel shot gather at 50 ft depth

Proof of concept

Initial model

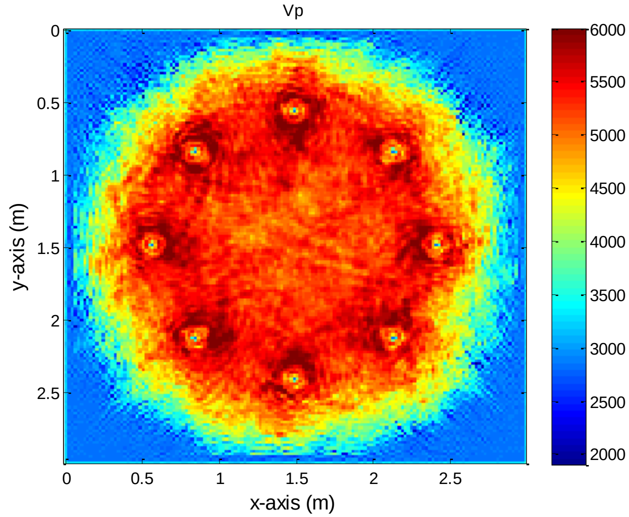




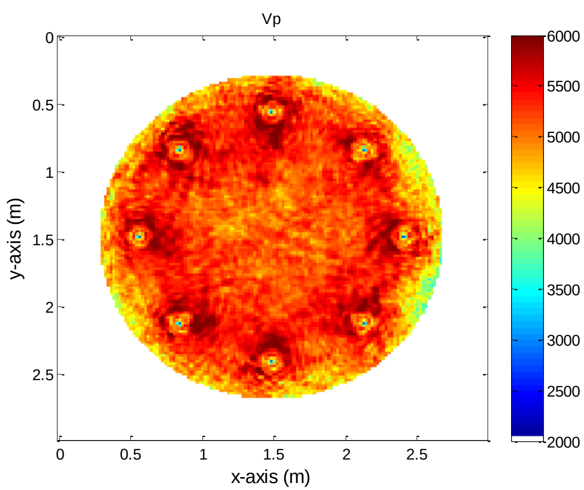


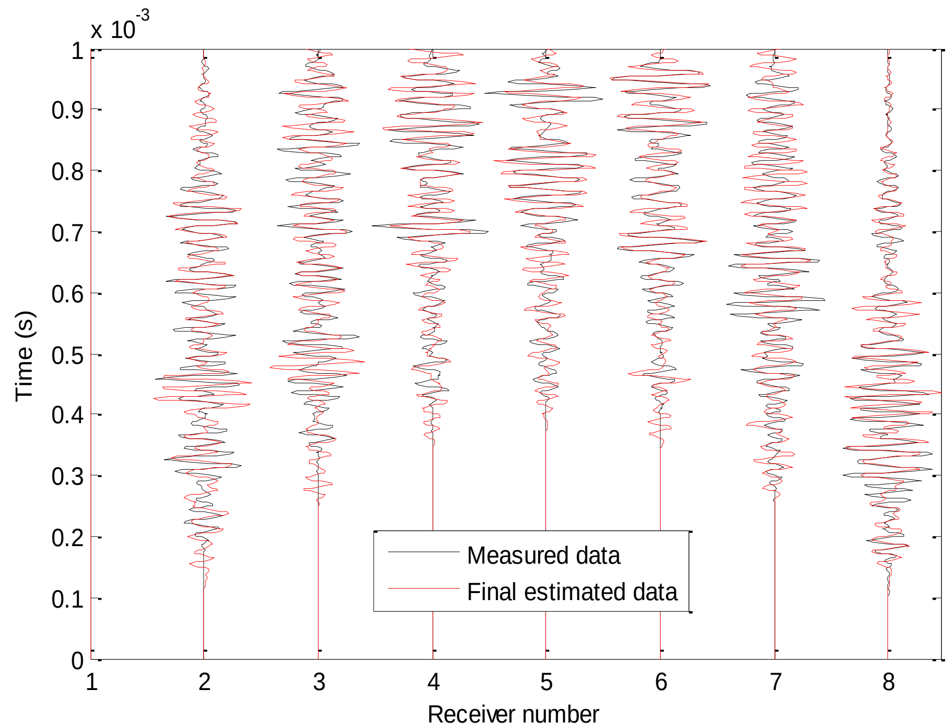
Proof of concept

Result at 50-ft depth



Result within borehole





Task 1: Develop 2D AFWI algorithm

Task 2: Optimize test configurations and wavefield characteristics

Task 3: Verify the 2D AFWI algorithm on actual drilled shafts with defects

Thank You!