Electromagnetic Non-destructive Testing of Ultra-High Performance Concrete (UHPC)

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ACI Convention – Orlando 2022

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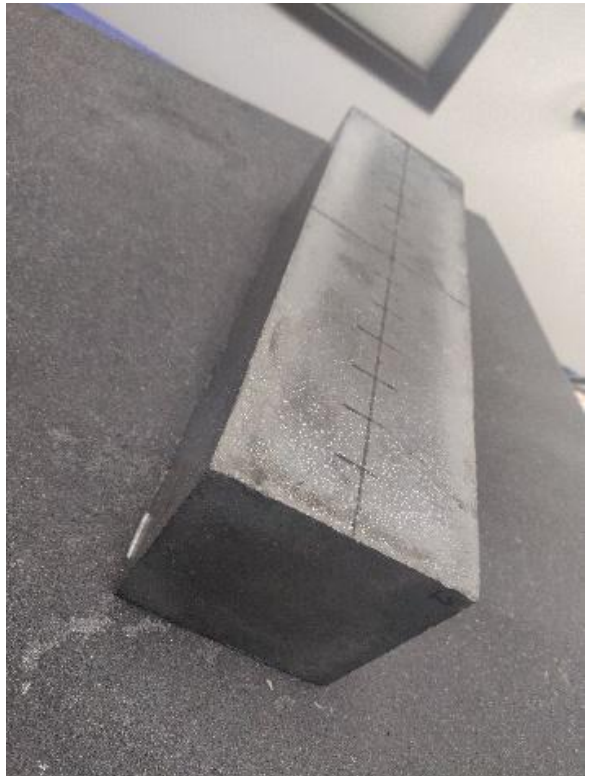
Outline

- Introduction
- Methodology
- Experimental Setup
- Results
- Conclusions
- Further work

Introduction

- UHPC is becoming ubiquitous within the building industry
- The orientation and quantity of fibers play an important role in tensile strength, structural adequacy and safety
- This work focuses on the quantification of fiber content and fiber orientation within UHPC



Introduction

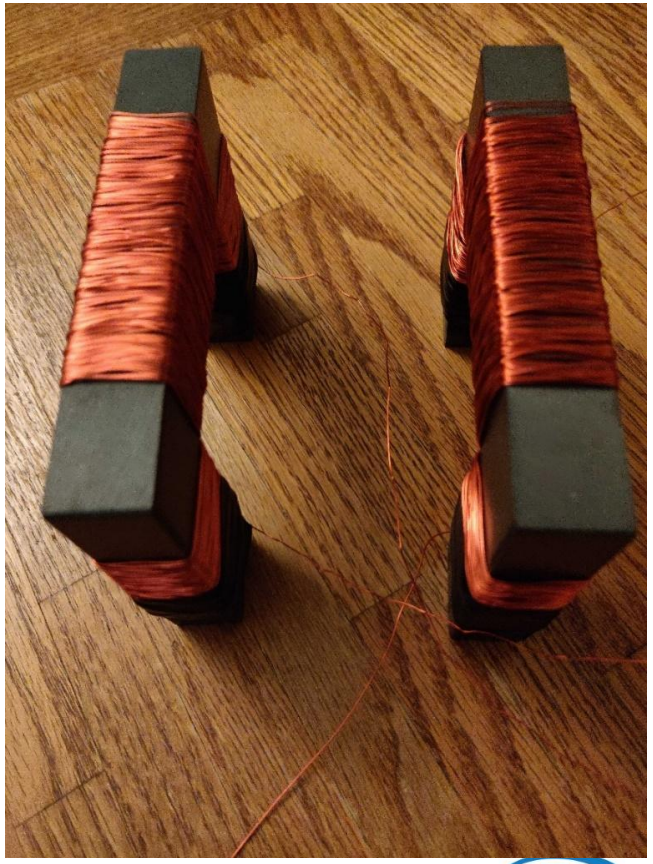
- CT scanning is the most effective method for determining fiber quantity and orientation
  - Requires the use of cores – destructive testing
  - Not portable
  - Can be slow
- Ultrasonic methods not reliable
  - Signal scattering
- Magnetic methods have shown promise
  - Steel fibers are ferromagnetic while cementitious materials are paramagnetic

Theory

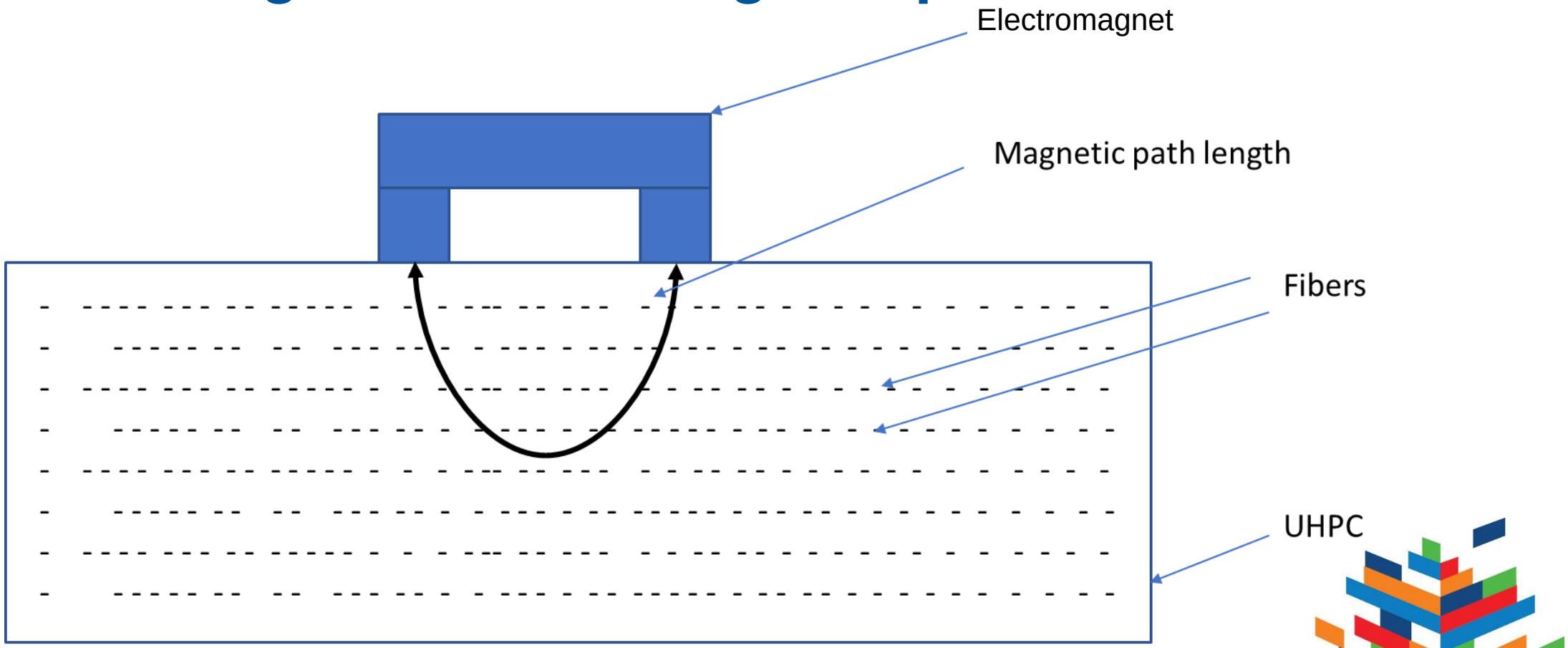
- Inductive sensing
  - When a magnetic field from a sensor interacts with a ferromagnetic material inducing a field in the material which is picked up by the sensor
- Electromagnetic theory
  - The magnetic path length of the field determines how much fibers we can sense at once

Electromagnet design

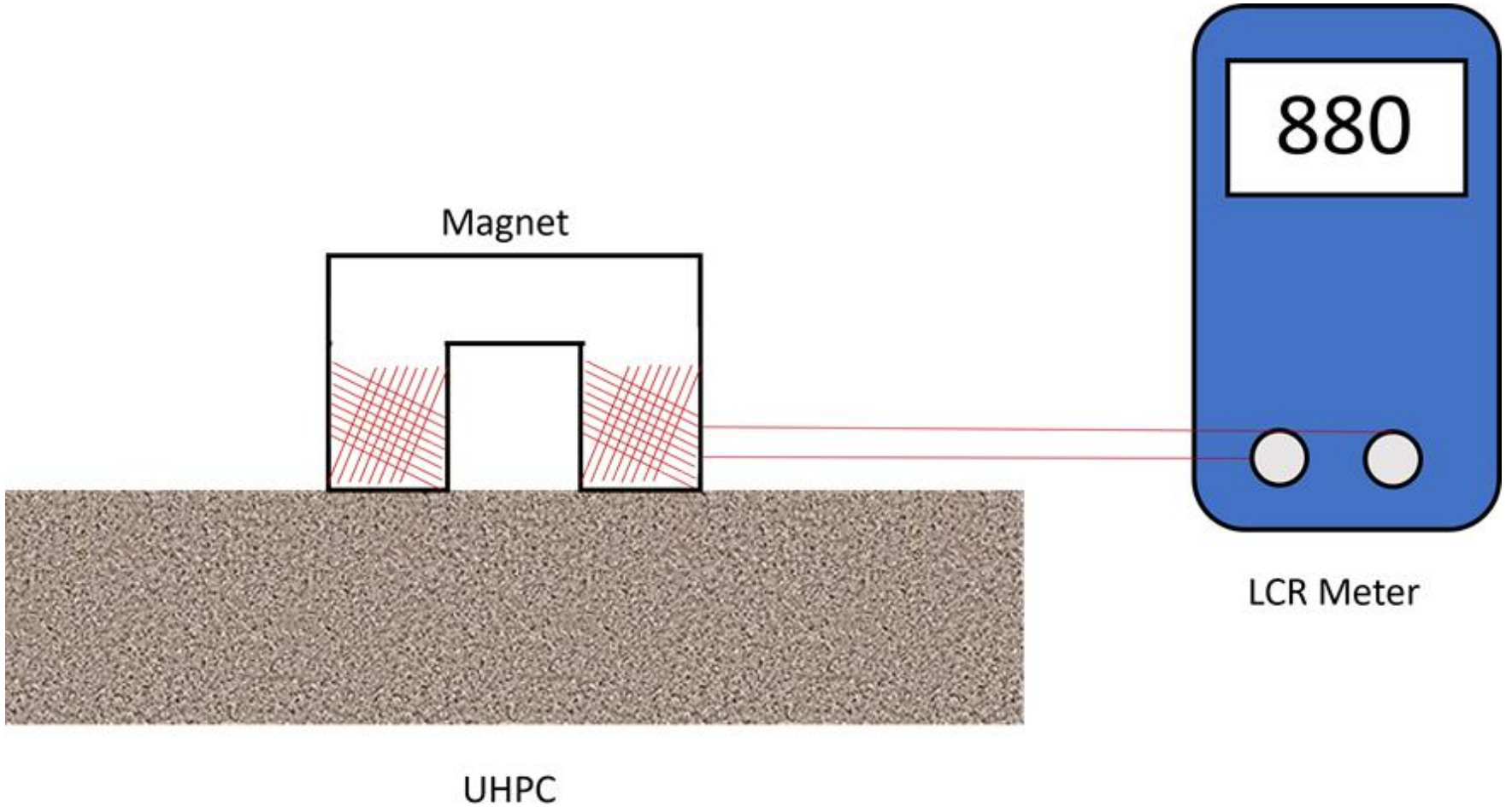
- The two electromagnets used in our sensor setup.
- The electromagnet consists of
  - gauge 25 magnetic wire
  - inductance of 7.5 mH
  - 210 turns



Magnetic Path Length explanation



Laboratory equipment setup



Laboratory equipment setup

Optimization

- To get the best design, we optimized some parameters
- Some of the important parameters to optimize
  - –Frequency
  - –Shape
  - –Size
  - –Number of electromagnets

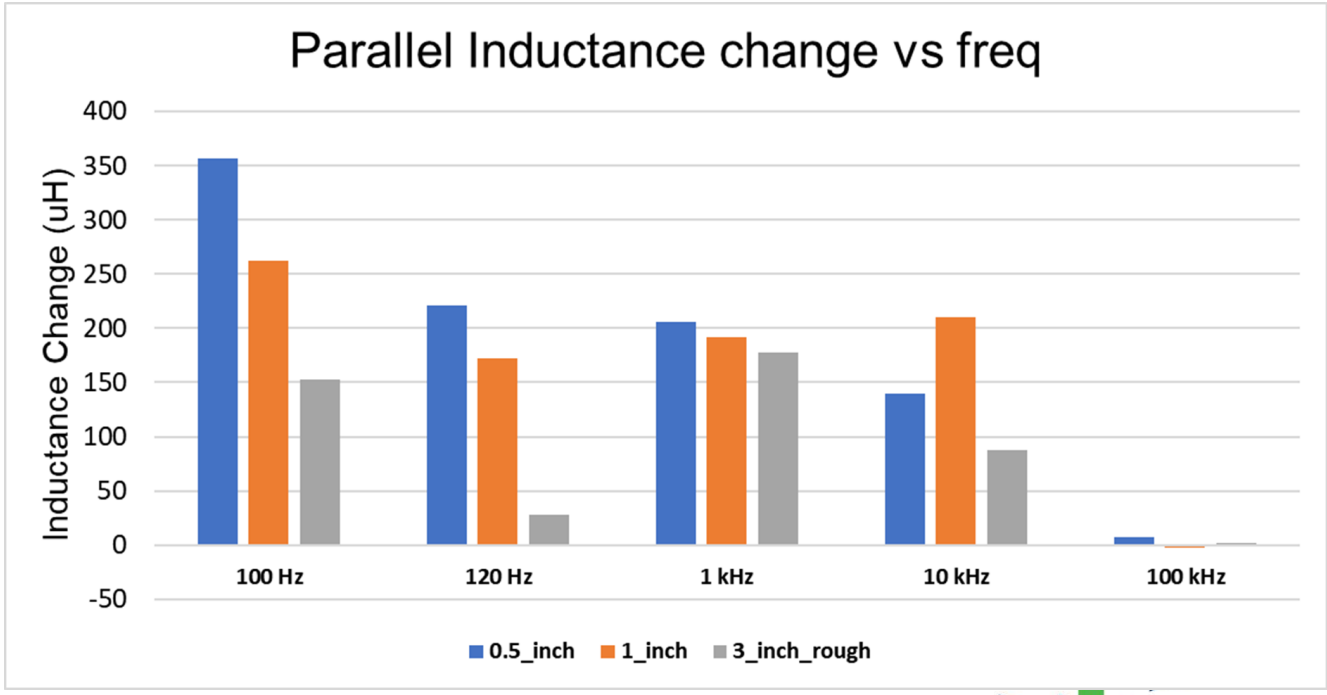
Optimization

Parameters to optimize

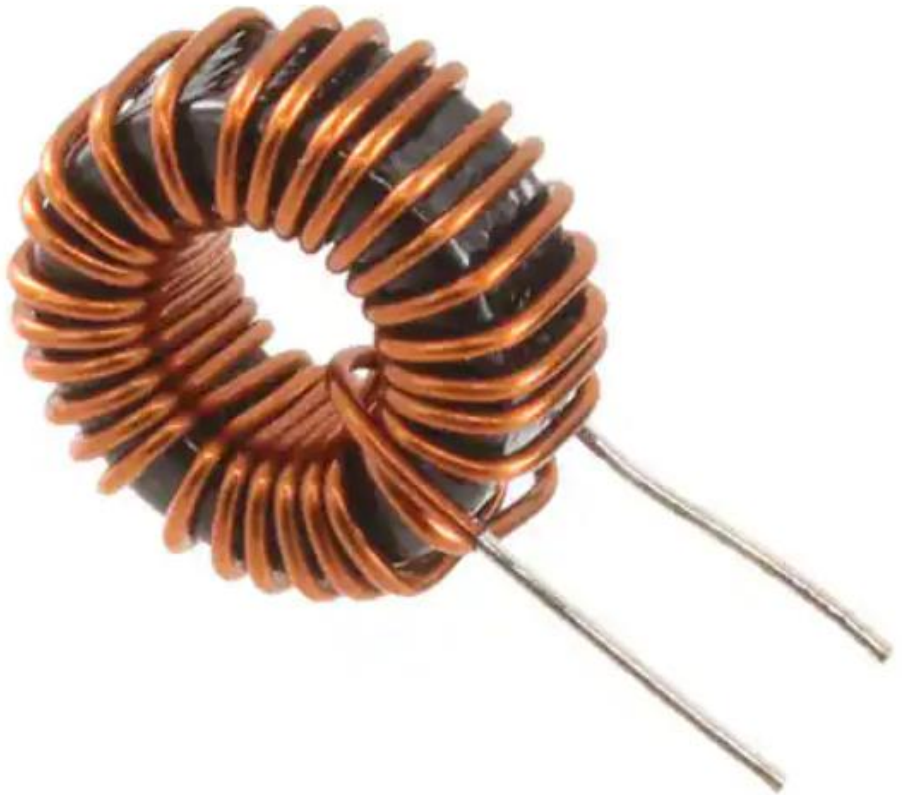
- **Frequency**
- **Shape**
- Size
- Number of electromagnets

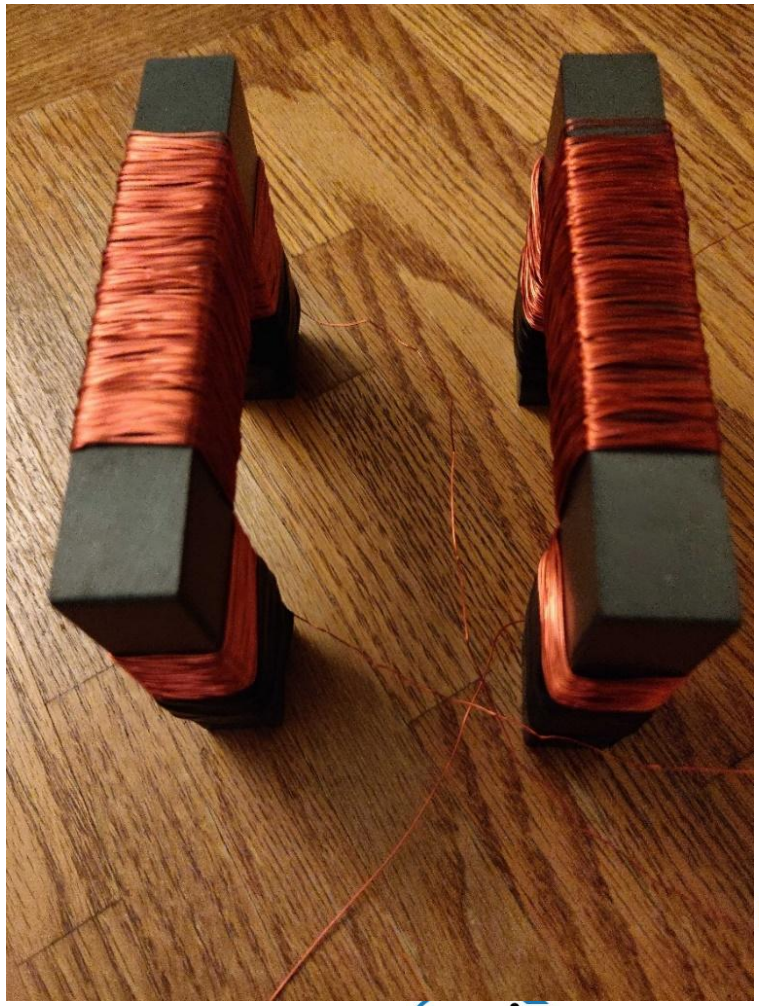
Frequency selection

- Need to stay below the resonant frequency
  - Where the inductance flips and changes to capacitor
  - At this frequency, the resistance is very high compared with the inductance
  - Optimal frequency was determined to be 1000Hz (10kHz)



Shape Selection – U Magnet vs. Pancake Coil





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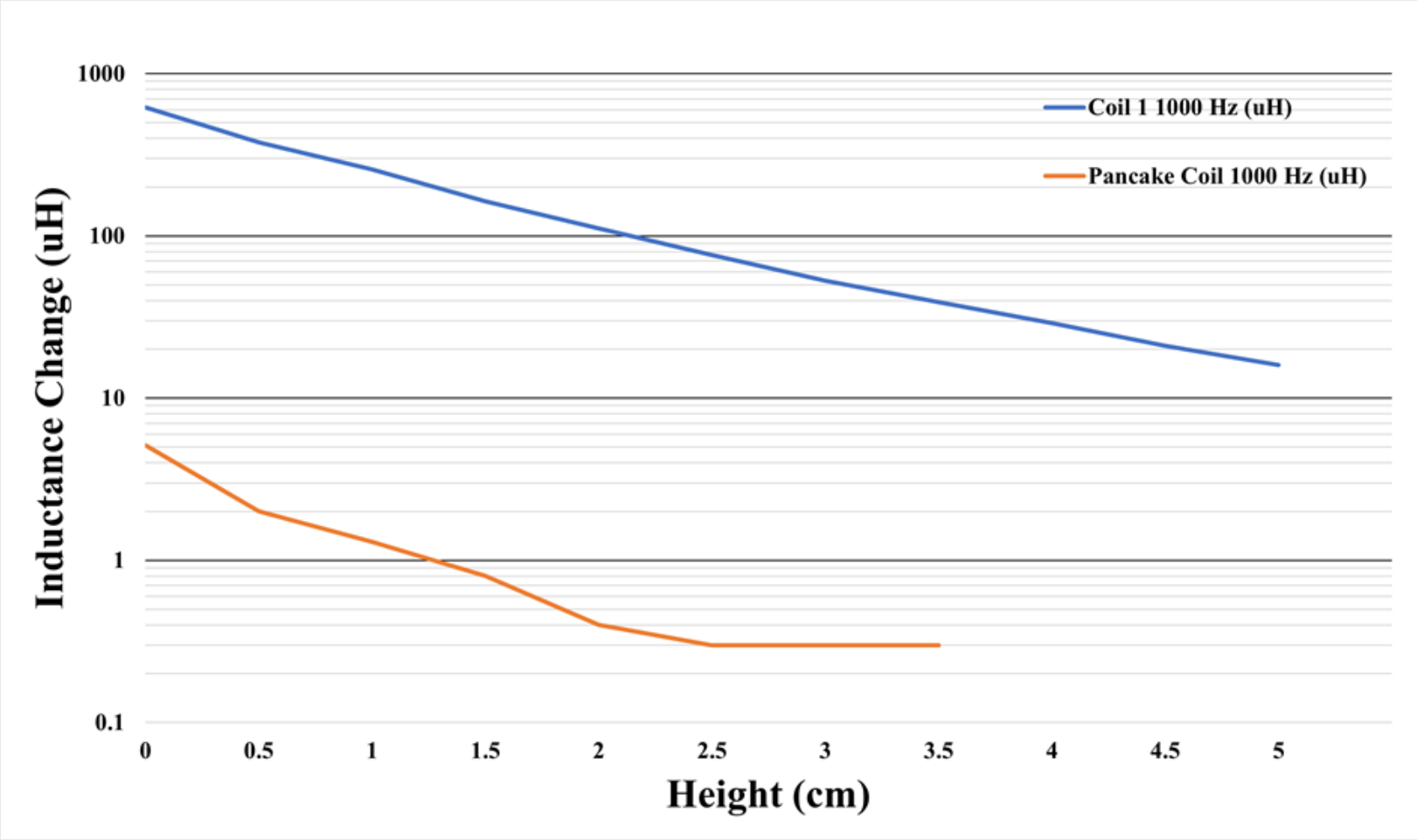
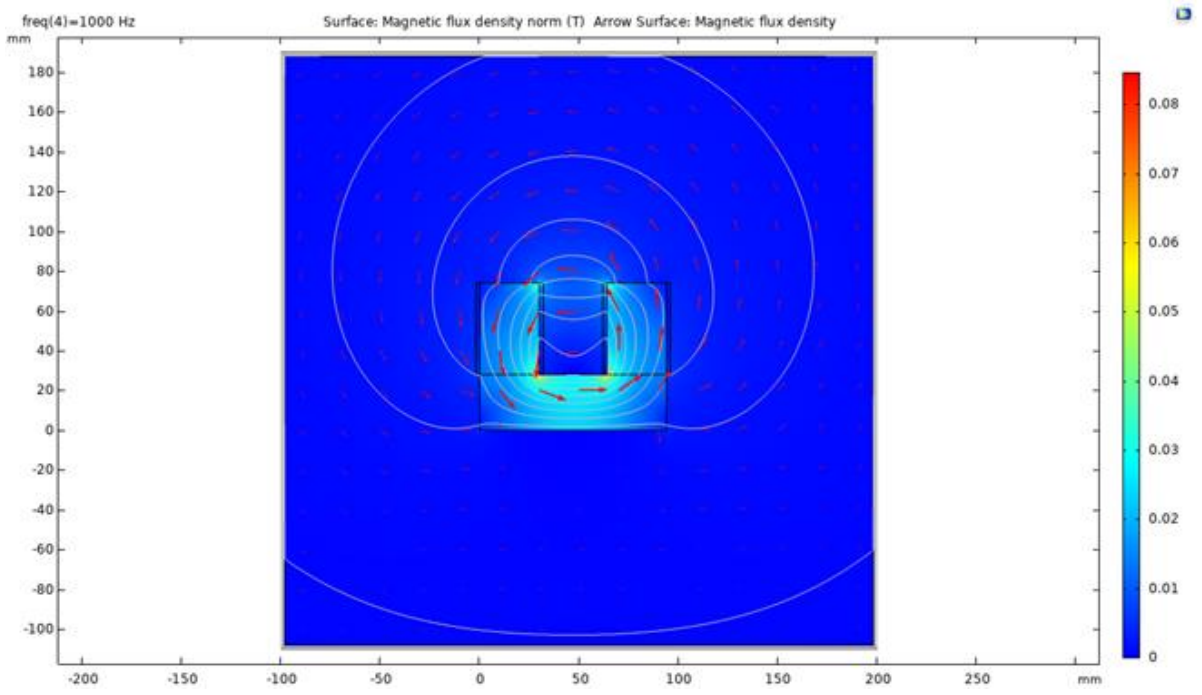
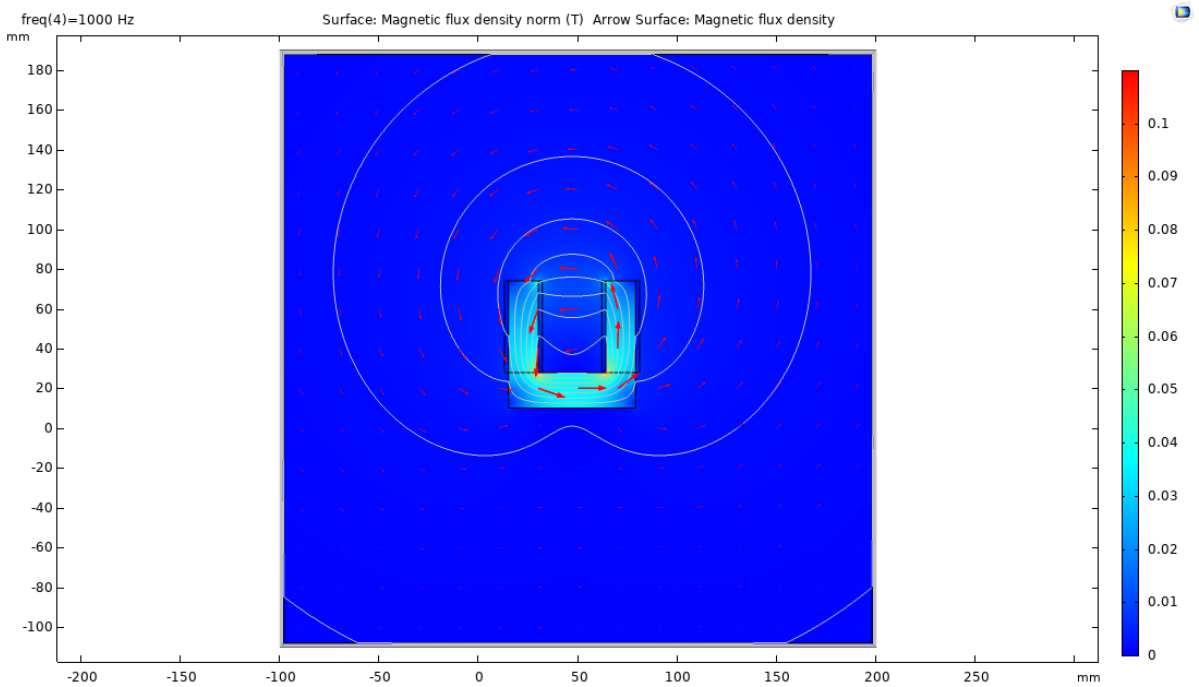


Optimization

- Frequency
- Shape
- **Size**
- Number of electromagnets

Size Selection





Left: large cross-sectional area (100 x 80mm) magnet with similar (75x75) field pattern with a smaller one.

Optimization

Parameters to optimize

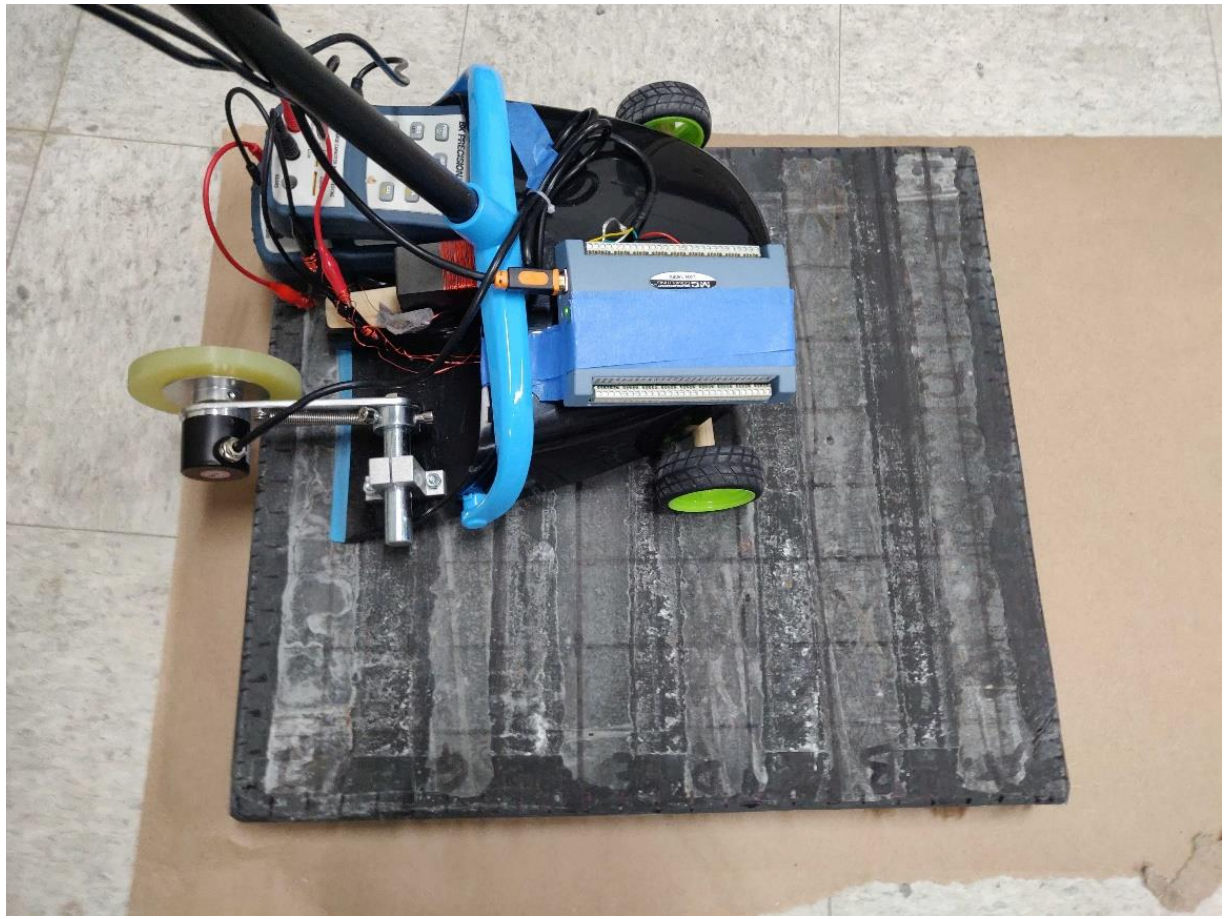
- Frequency
- Shape
- Size
- **Number of electromagnets**

Number of Electromagnets

- Fiber orientation detection
  - One scan the parallel direction to motion
  - The other scans the perpendicular direction to motion
- This helps us to be able to have a relative idea of the x-y orientation based on the ratio of the two directions (i.e., parallel/perpendicular)
  - If the ratio is greater than 1 then the fibers are more aligned relative to the parallel direction and vice versa

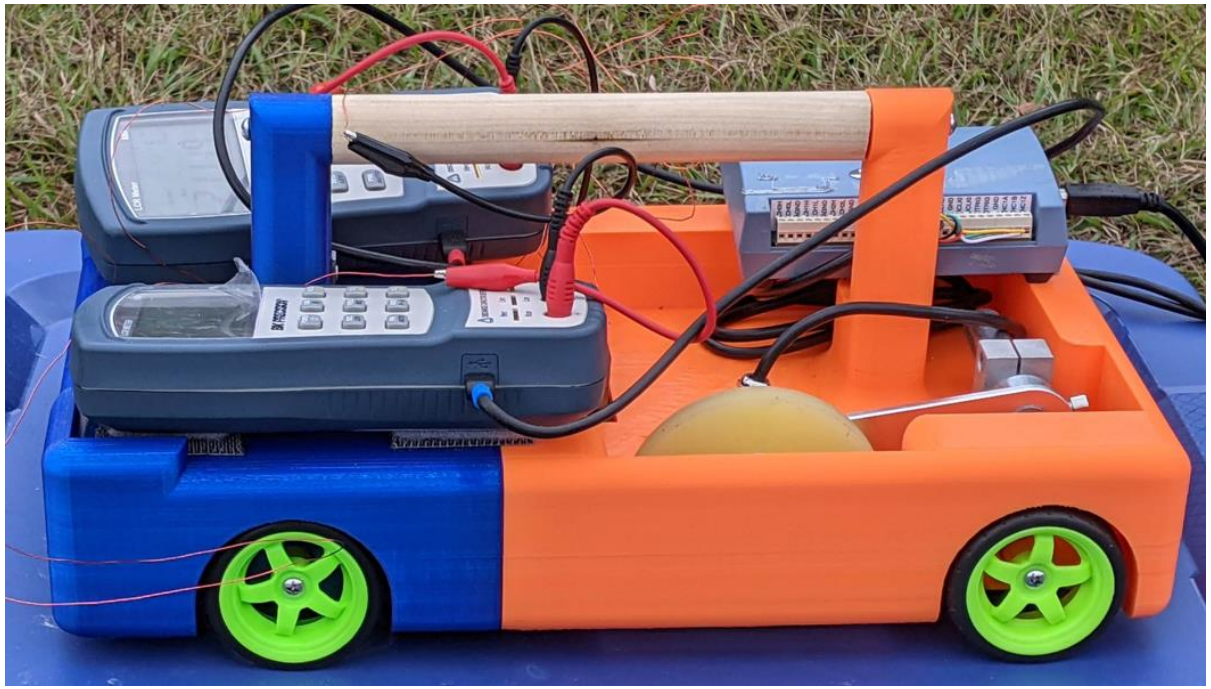
Device iterations

- Version 1



Device Iteration

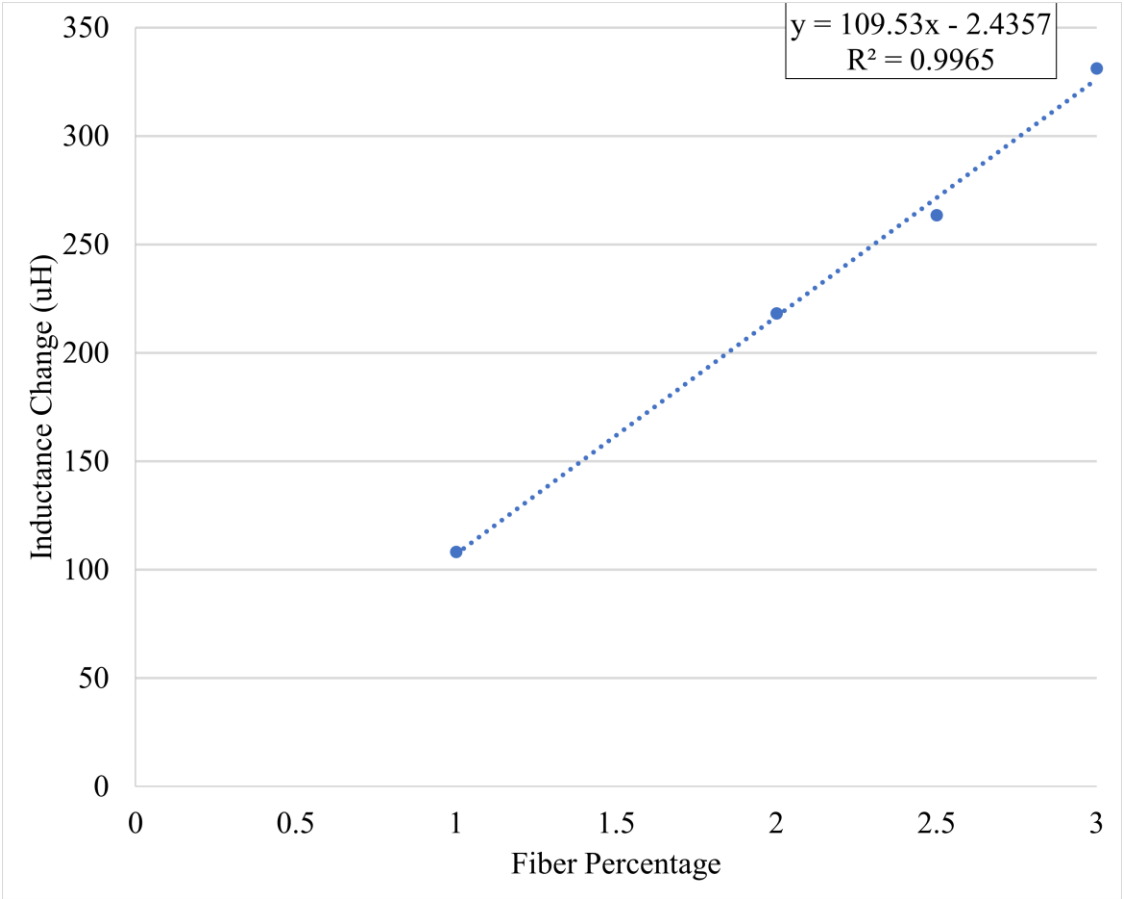
- Version 2



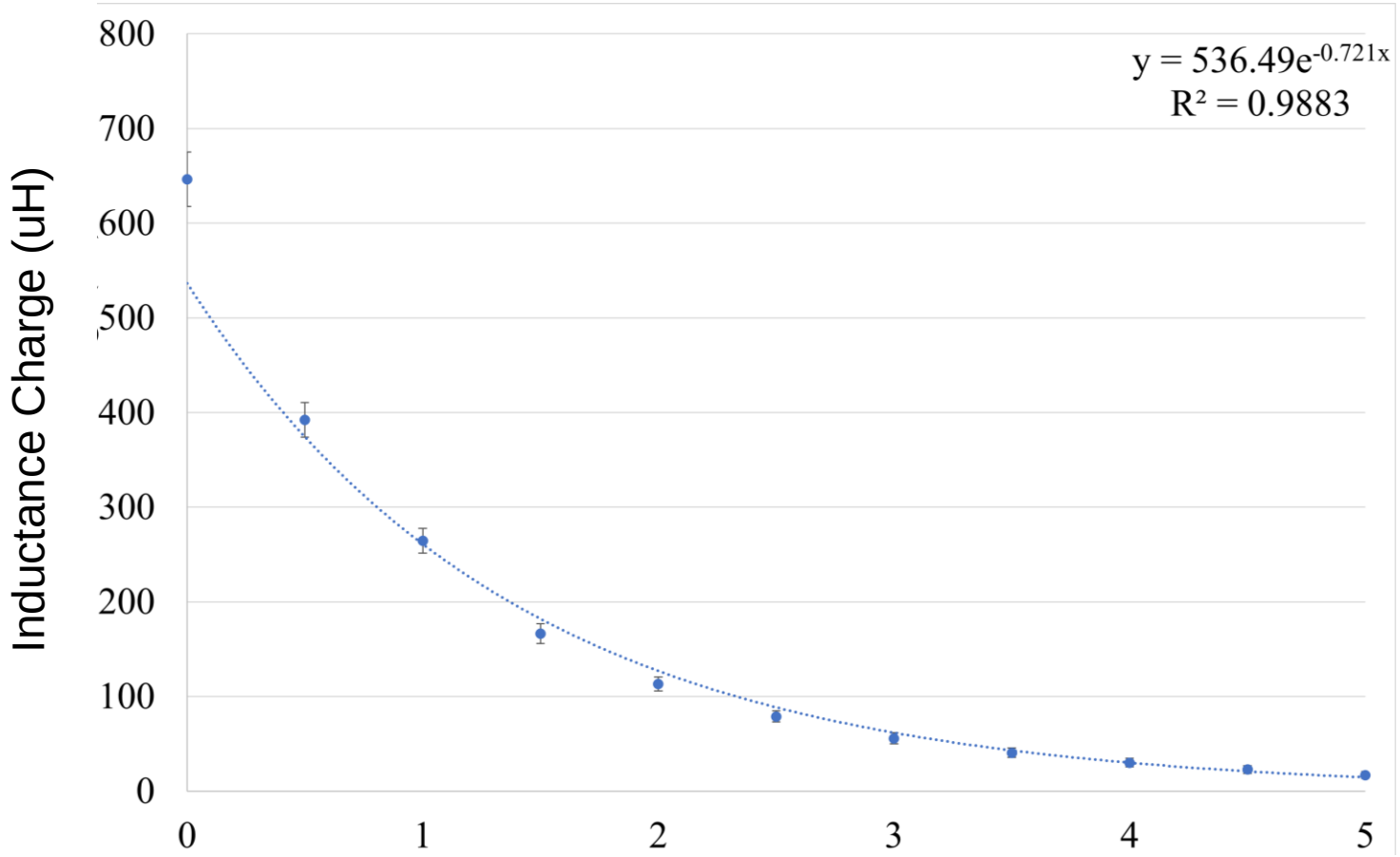
Calibrating the device

- The device was calibrated using lab specimens with fiber percentages ranging from 1 to 3 %
- Calibrated testing the inductance change versus the fiber percentage.
  - height/depth can be measured
  - Inductance measured in 0.5 cm increments
  - Height from 0 cm (touching the specimen) to 5 cm

Inductance Change for lab specimen



Laboratory specimen testing – 2% fibers

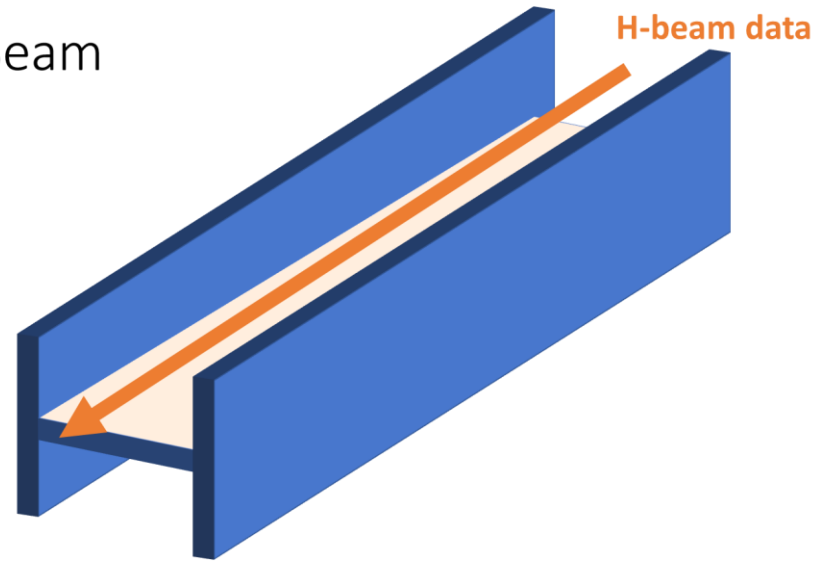


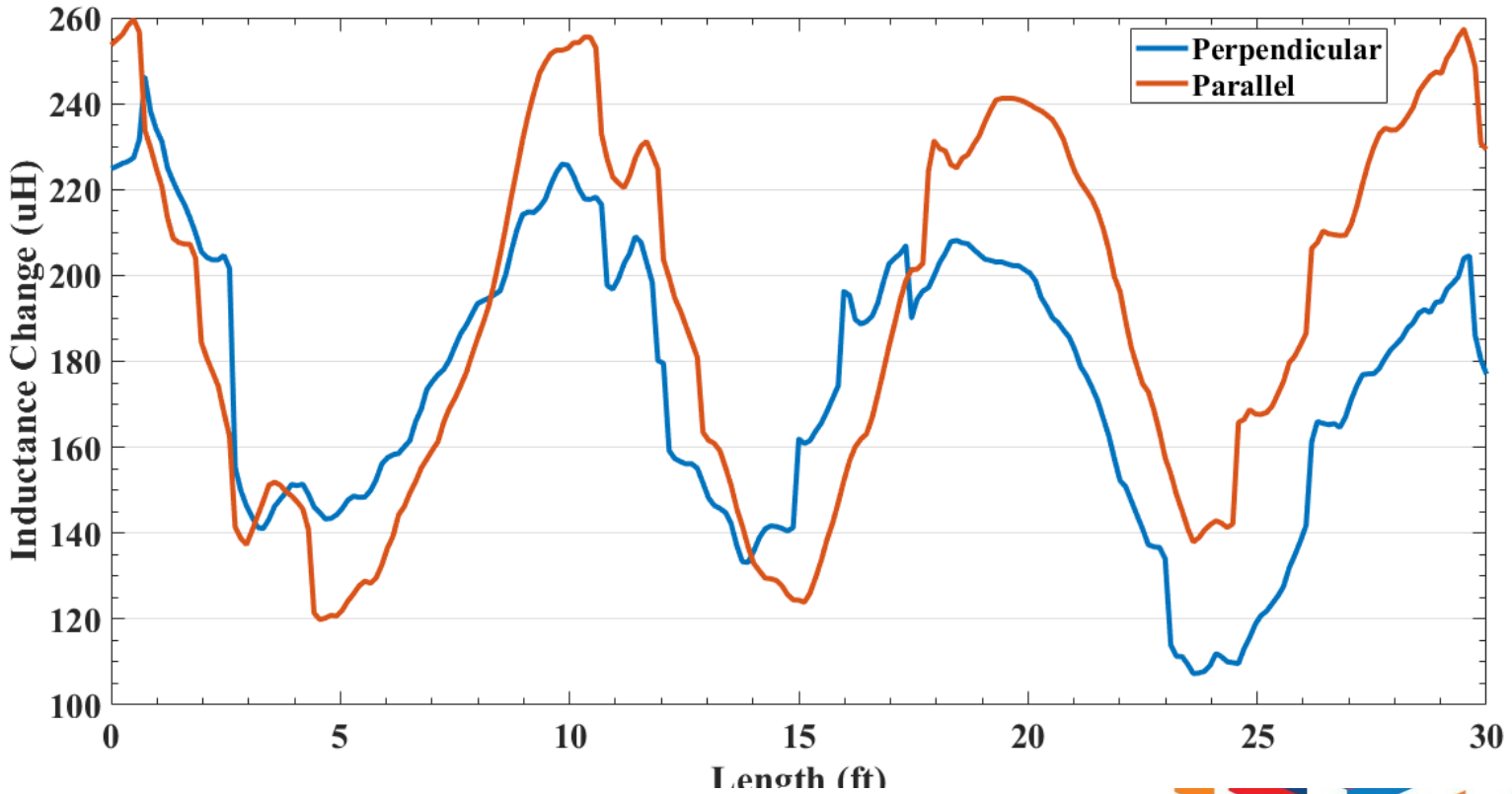
Field testing procedure

- Specimen preparation to be scanned by cleaning the surface and marking out straight paths
- Marked “interesting” spots for core removal
- Cores were removed from the marked portions using a 2-inch bit
- The cores taken are x-ray CT scanned
- Analyses and comparison of the CT result to the magnetic result

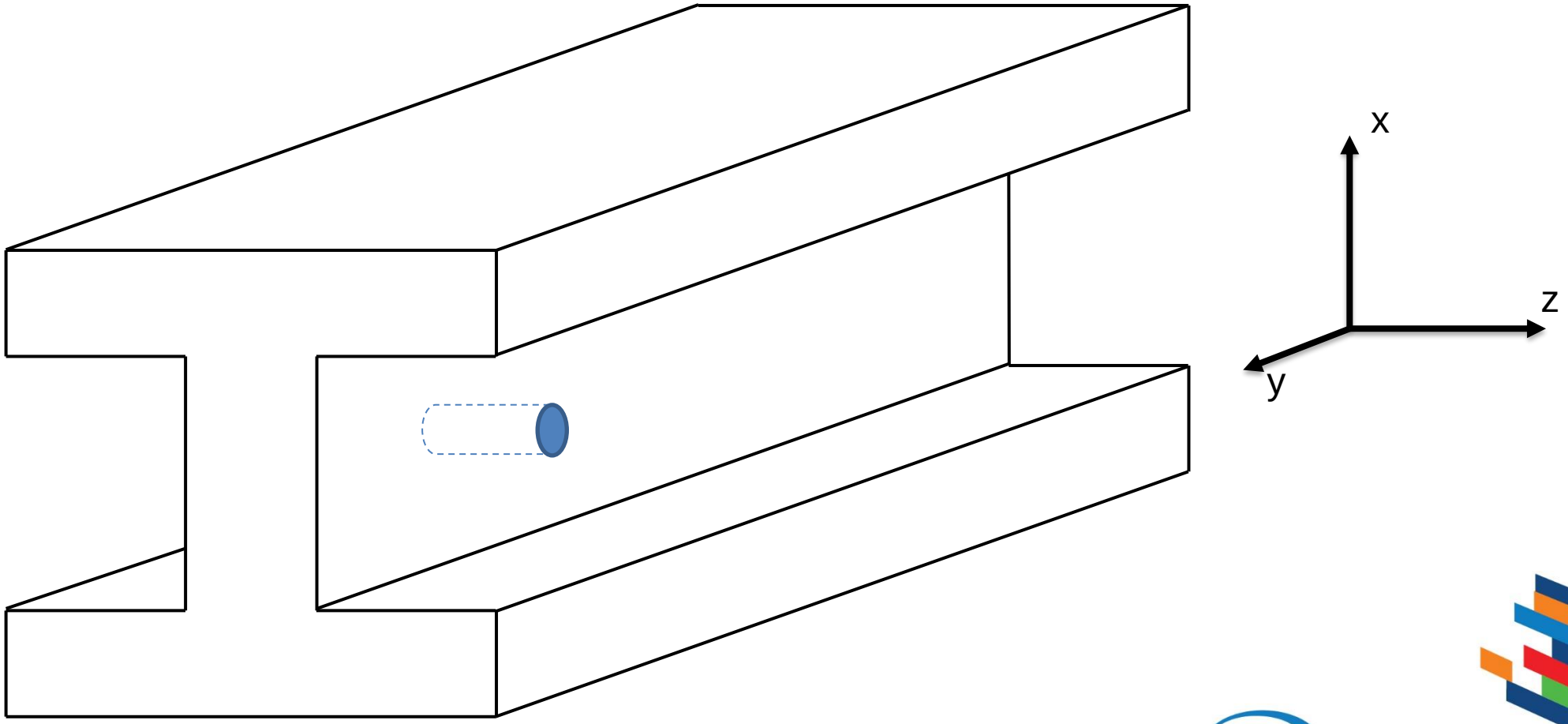
Scanning of H Pile with the electromagnetic device

H beam showing interesting highs and lows



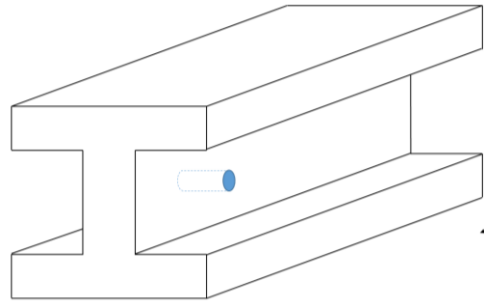


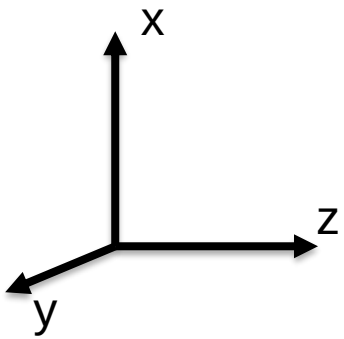
Core taken from H Pile

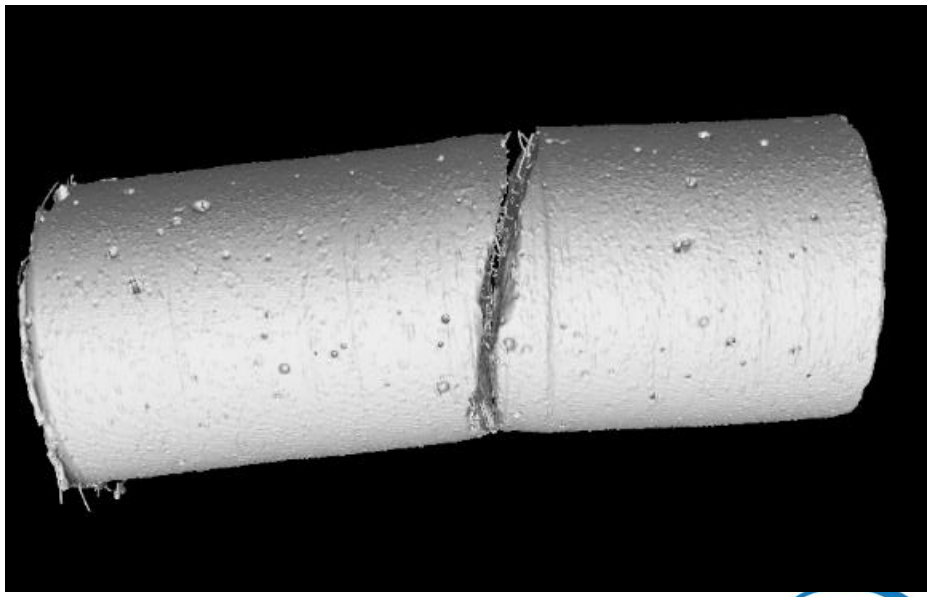


CT Scanning of H Pile Core for Fiber analysis

- Core was scanned and oriented as shown so the z axis is perpendicular to the cored surface and y axis is lengthwise for the H pile







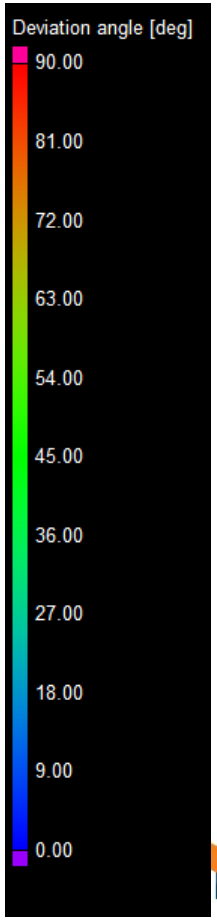
Fiber orientation analysis with CT Scanner

- Fiber orientation was analyzed in the three directions: x, y, and z.
- For each axis analysis image:

  BLUE=fibers aligned with axis

  RED=fibers roughly perpendicular with axis

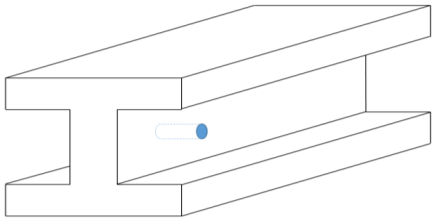
  GREEN=fibers in intermediate range

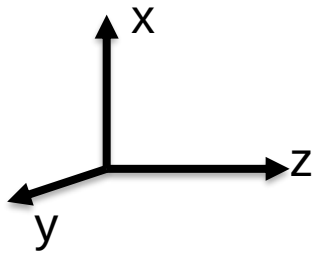


Core markings and labelling

- Made markings on the core before taking it out and the ones we made right after taking the cores.
- Aluminium strip held by tapes placed on the double-headed arrow signifying the direction of the magnetic scan.

CT Analysis



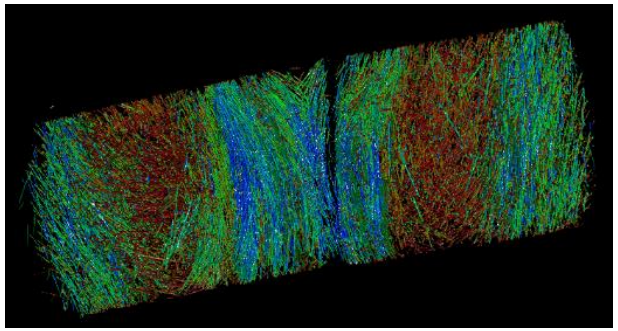


Scans with more blue fibers show more fibers in the direction of the axis

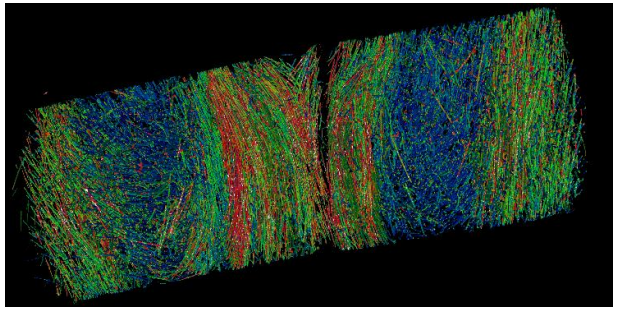
From these scans we can see that there are some distinct layers of concrete that have preferentially oriented fibers

Very few fibers are oriented in the z direction, which makes sense because this would be perpendicular to the formed surface

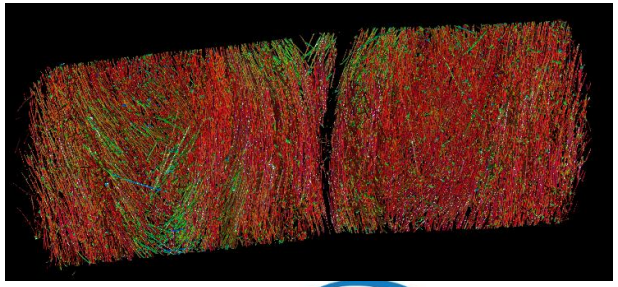
x axis

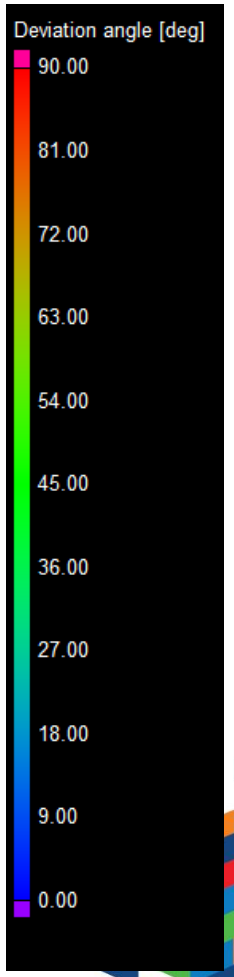


y axis

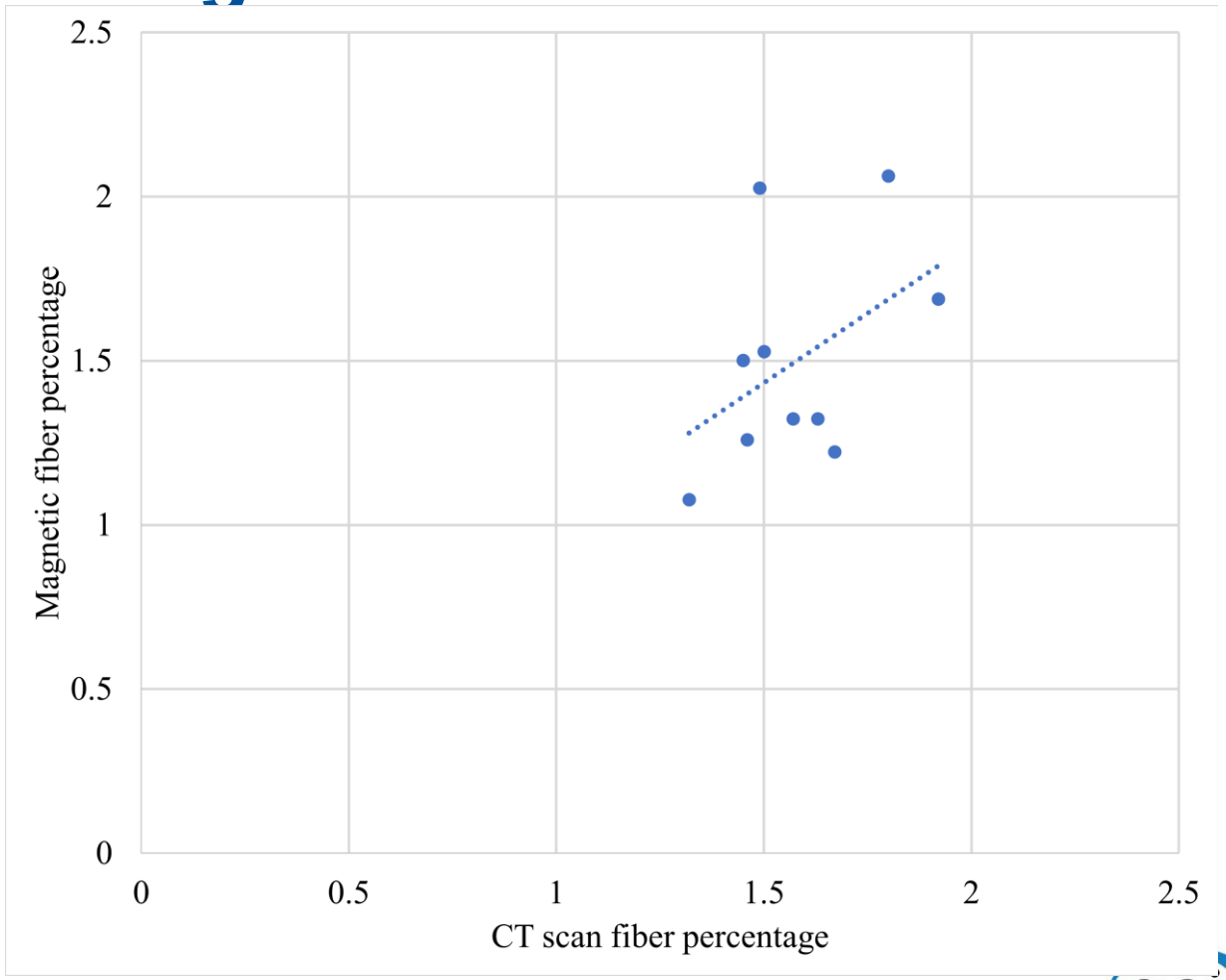


z axis

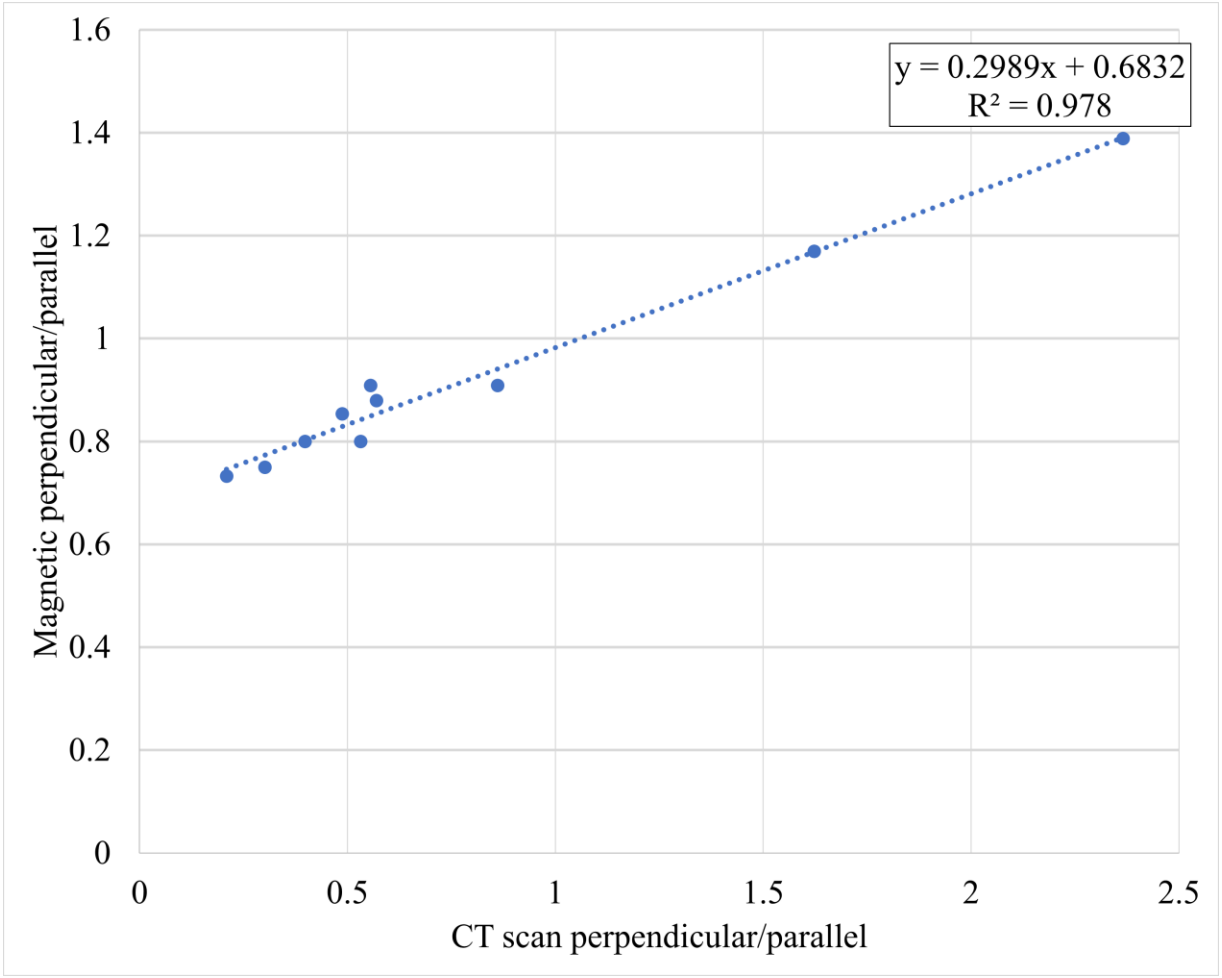




Fiber percentage result vs CT scan – Field Data



Orientation test result vs CT scan – Field Data



Conclusions

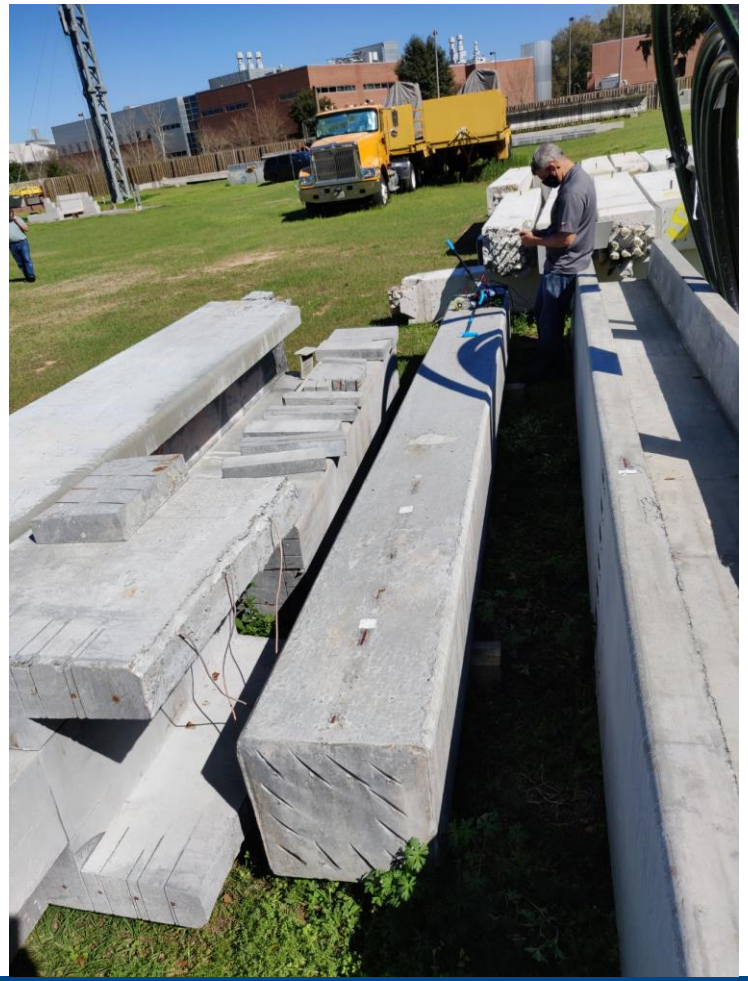
- The use of the NDT testing and validation of the results using CT scanning – the newly developed device can be used to detect:
  - Volume of fibers for UHPC created in laboratory
  - Relative volume of fibers UHPC created in the field
  - Orientation of fibers
- The results are promising for further development of the device for implementing

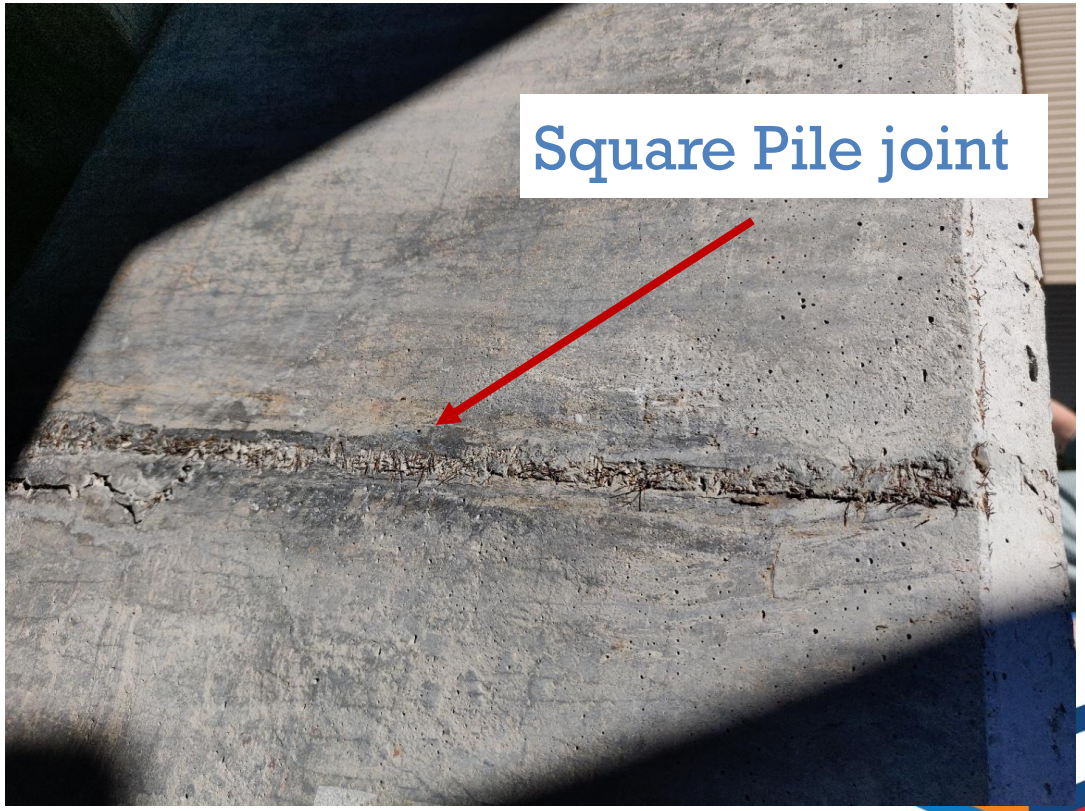
Thank You!

Questions?

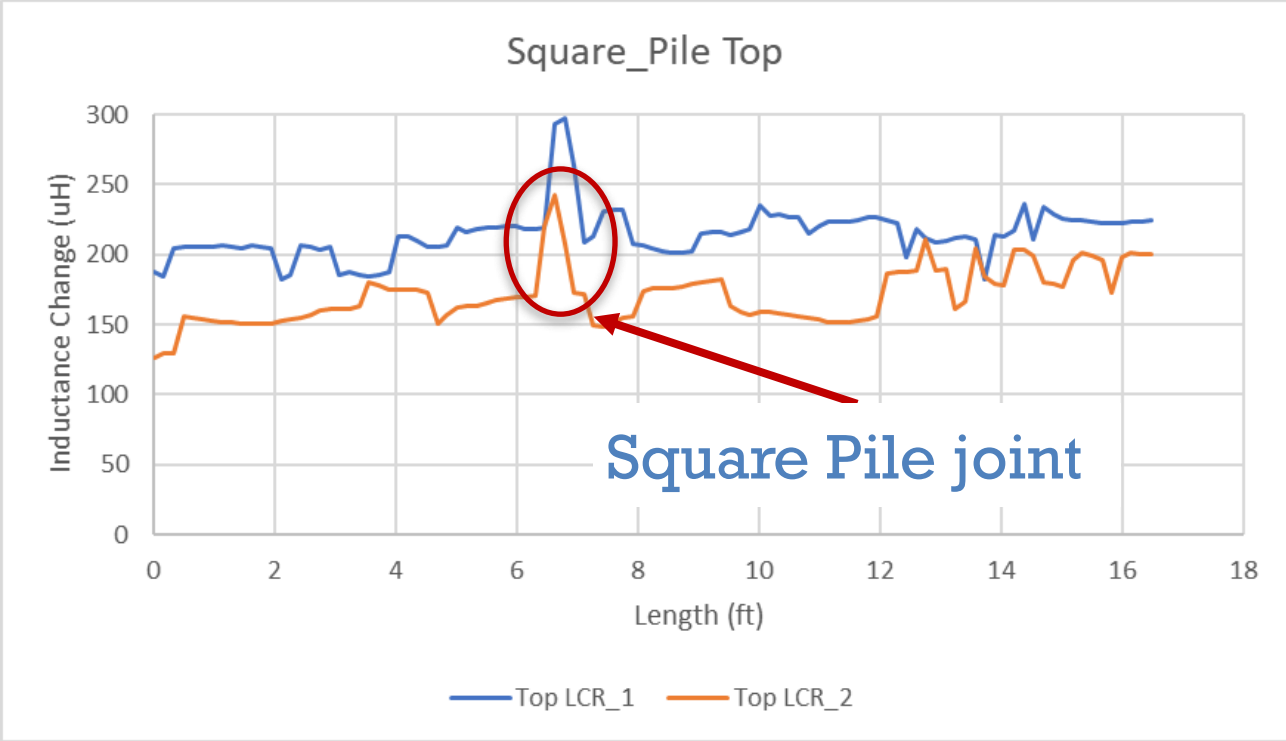
Additional Results

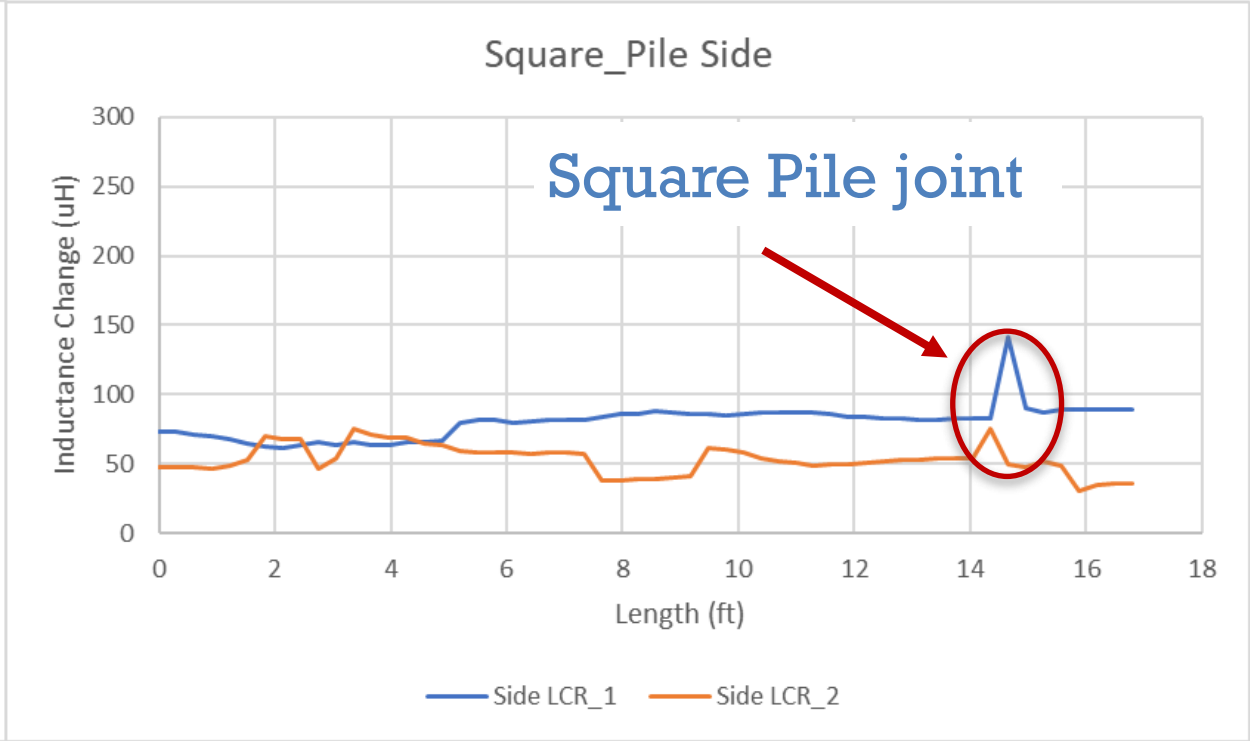
Square pile showing a joint





Result of square pile showing effect of the joint

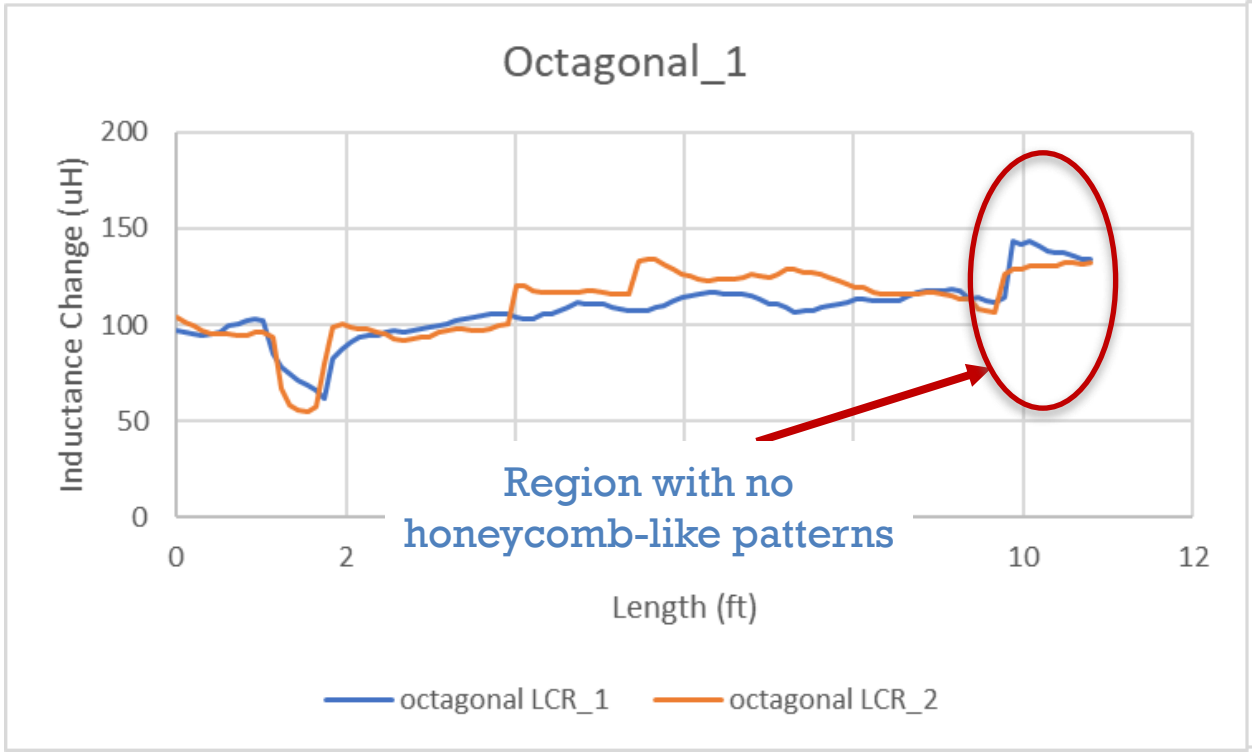


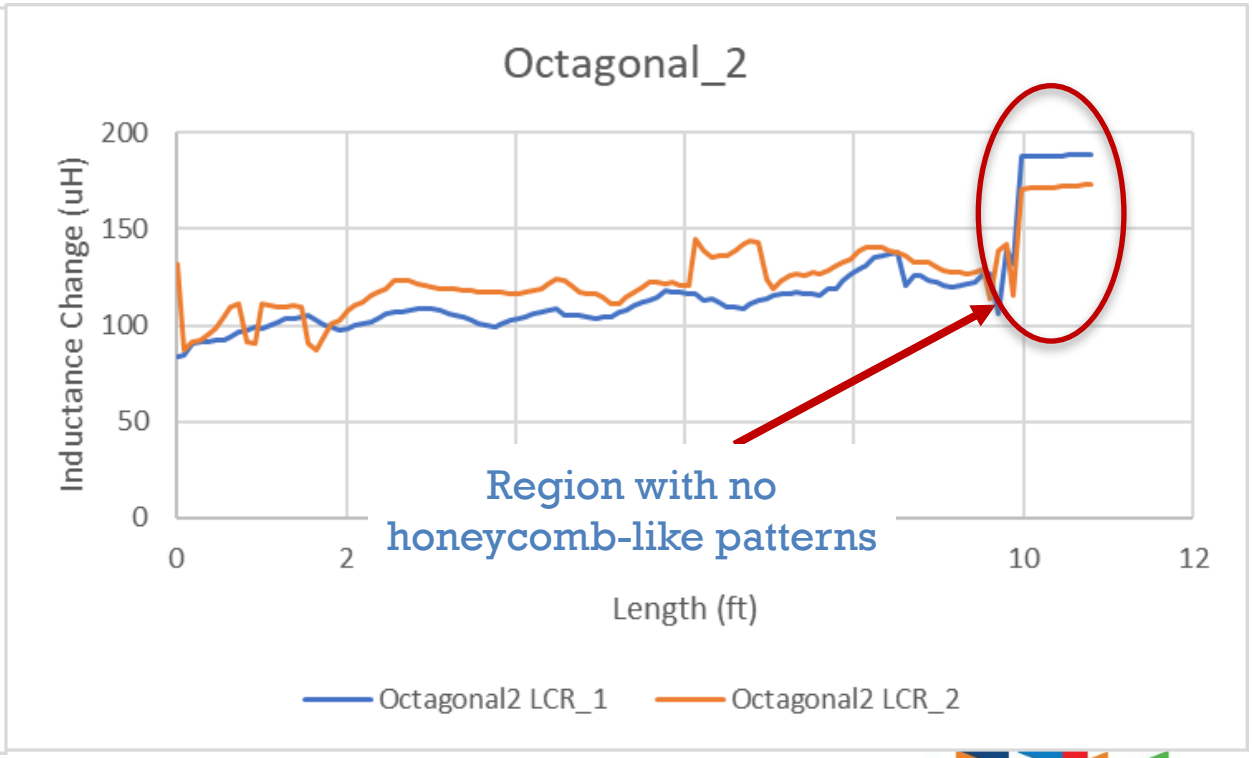


Octagonal Pile showing two sides marked

Region with no honeycomb-like patterns

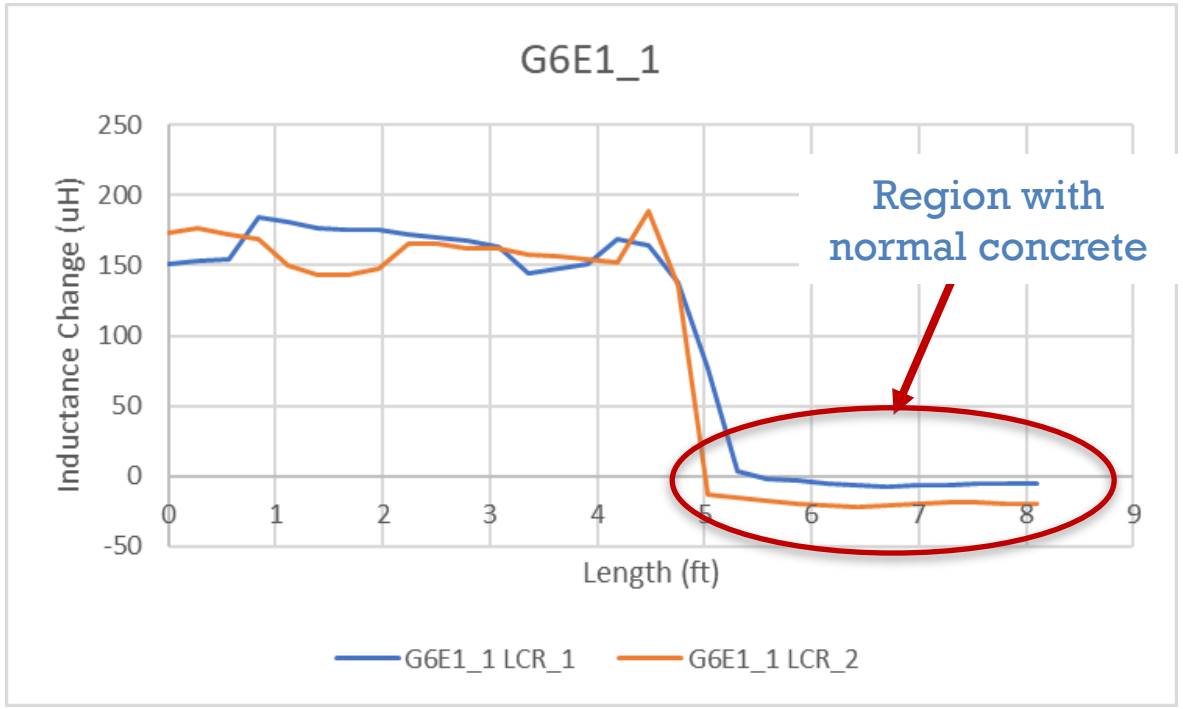
Results for two sides of an Octagonal pile

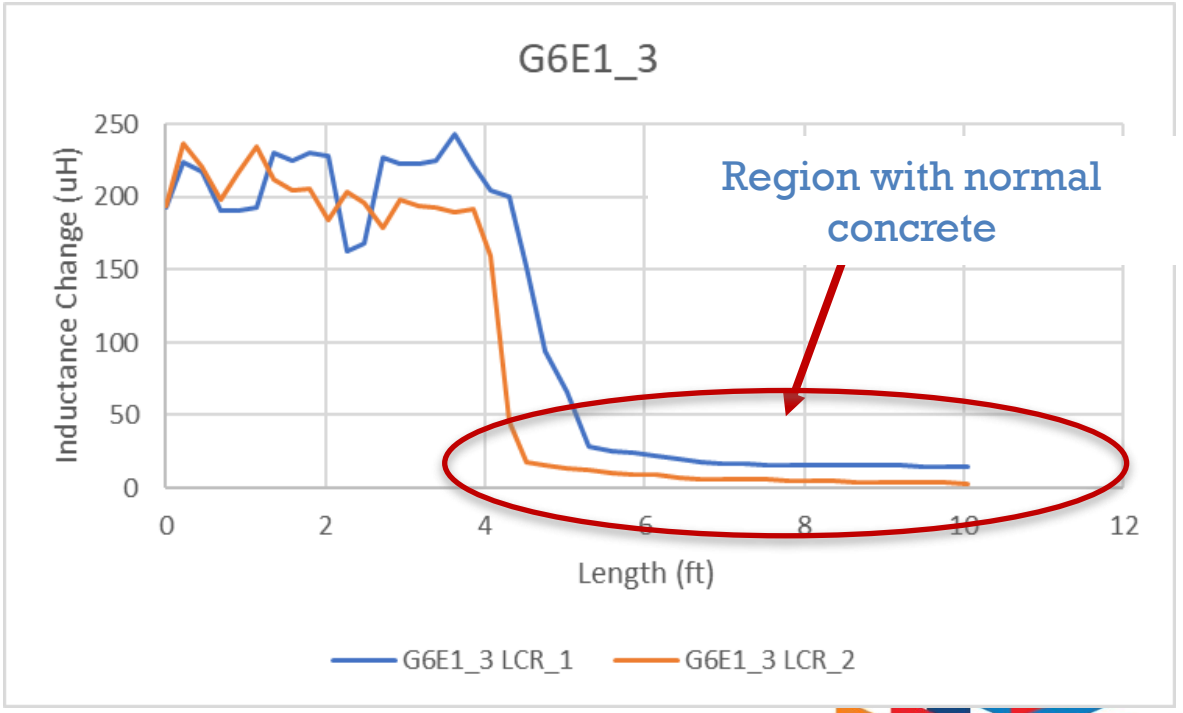




Bridge member with UHPC and normal concrete

Results for a UHPC & normal concrete bridge member





Further work

- We would like to model this using CIVA
- We would like to use CT scan for validation and comparison using some of the samples we made in Florida against some samples here at CEA

Lab setup

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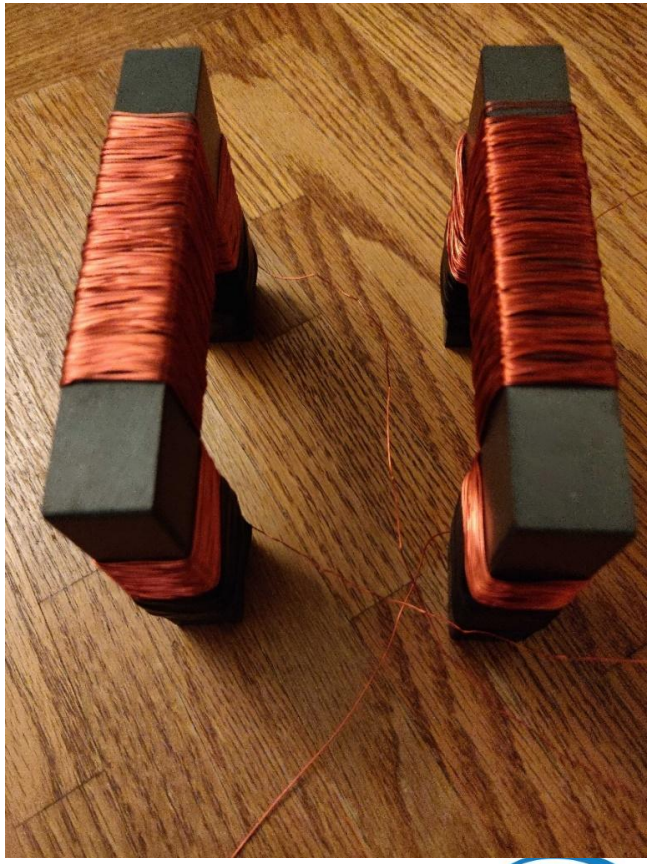

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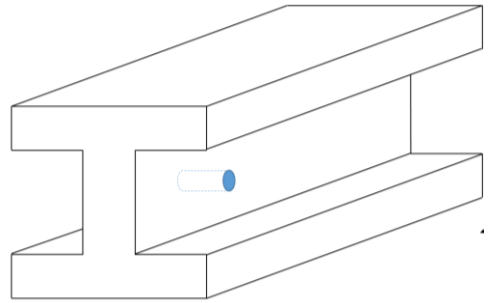

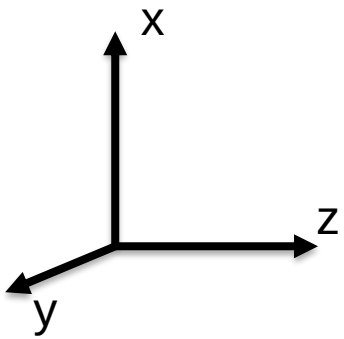

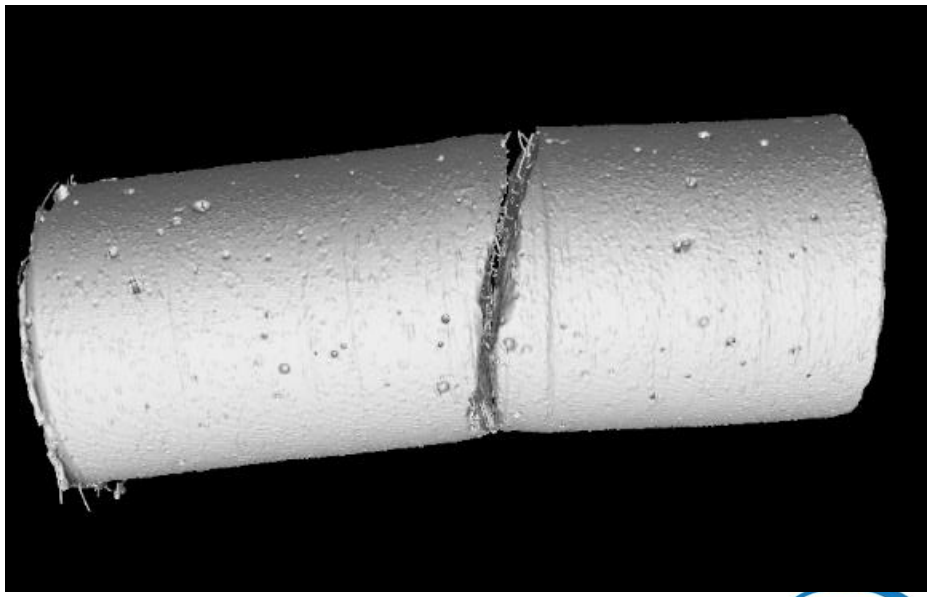

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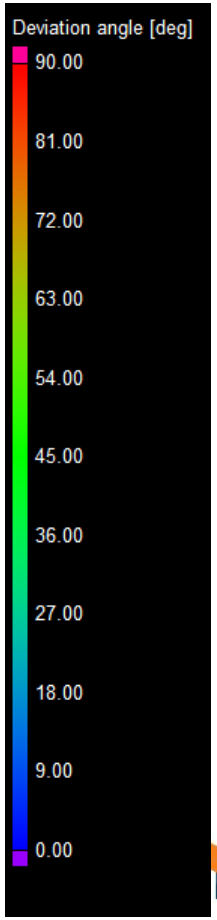

Quantitative Analysis

- We used trigonometry to calculate the amount of fiber projected in each direction:

$$\sum_{\theta=0}^{\theta=90} \frac{n}{\sin(\theta)}$$

  Where *n* is the amount of fiber with the deviation angle θ.

- For example, if the projection ratios were found to be:

  x/y: 0.59 y/x: 1.70

- This will show that there is roughly 70% more fiber alignment in the y direction when compared with the x direction in this location.

Quantitative Analysis

- For the fiber volume
  - We get a raw percentage from the fiber analysis we run during the postprocessing of the CT scans
  - This raw percentage represents what volume of fiber the analysis software thinks is fiber compared to the rest of the volume
  - We compare this to the magnetic percentage we obtain from comparing inductance changes