Department of Civil, Construction, and Environmental Engineering
North Carolina State University

Module 2: Sensor Installation and Operation

Course, Curriculum, and Laboratory Improvement: Integration of Sensor Technologies in the Civil Engineering Curriculum, DUE0837612

Sensors in the CCEE Curriculum

- Sensors are increasingly used by practicing civil engineers to monitor, measure, and remotely observe the world around them. However, these technologies are not present in traditional CCEE curricula.
- A research team of T.M. Evans (PI), M.A. Gabr (co-PI), Z. Ning (GRA), and C. Markham (URA) received a grant from the National Science Foundation to address this issue by developing educational modules that will be incorporated in a series of CCEE courses.
- Each module will build on the content from previous models, providing both breadth and depth to your studies.

List of Educational Modules

- Module 1: Fundamentals of Geotechnical Sensing and Instrumentation (CE 342)
- Module 2: Sensor Installation and Operation (CE 440)
- Module 3: Data Analysis and Interpretation (CE 443)
- Module 4: Frequency Domain Signal Processing and Analysis (CE 548)

Motivation

- As you have seen this semester, laboratory measurement of soil properties is nontrivial. It is also often necessary (or, at least desirable) to monitor the response of the natural (pre-construction) or built (post-construction) environment to external loadings. This requires an understanding of sensors, transducers, subsurface measurements, in-situ characterization, remote sensing, and data collection.
- This module (the second in a series of four) provides a description of the process of selecting, siting, installing, and monitoring sensors.
- Sensor installations on the NCSU Centennial Campus will serve as a case study.

Module 2: Learning Objectives

- At the completion of this module, you will be able to:
  - Predict the response of sensors to various inputs;
  - Construct a conceptual instrumentation and monitoring program;
  - Describe the order and methodology for sensor installation; and
  - Differentiate between types of sensors and their modes of operation and measurement.
- In addition, this knowledge will prepare you to proceed with Module 3.

Overview

- Approach to Planning Monitoring Programs
  - Define target
  - Sensor selection
  - Sensor siting
- Sensor Installation & Configuration
- Advanced topic
  - Sensor design
  - Measurement uncertainty

Basic Questions

- Sensor Selection
  - What quantities need to be measured/monitored?
  - What levels of accuracy and precision are required?
  - Are measurements and monitoring requirements short- or long-term?
- Sensor Siting
  - What are the best locations for measuring the required data?
  - Where can sensors feasibly be placed?
  - Will installations interfere with the quantities being measured (Heisenberg)?

Basic Questions

- Sensor Installations
  - Which installation method will result in the highest quality data?
  - What is the least obtrusive method for installation?
  - What is the most economical method for installation?
  - Are measurements and monitoring requirements short- or long-term?
- Sensor Monitoring
  - Is a wireless or hard-wired connection more appropriate?
  - How will data be stored and archived?

Planning of Monitoring Programs

- Define project conditions
- Predict mechanisms that control or describe behavior
- Define the engineering questions that need to be answered
- These inputs determine the purpose of the instrumentation

Sensor Selection

- Parameters to be Monitored
- Required Accuracy
- Required Precision
- Cost
- Installation Requirements
- Special Requirements

Example: Sensor Design

- Electrical resistance strain gages
  - Quarter bridge network
  - Half bridge network
  - Full bridge network
- Linear variable differential transformer (LVDT)
- Vibrating Wire Transducer

Sensor Siting

- Measuring Location
- Access
- Security (for field sensors)
- Obtrusiveness
- Special Requirements

Case Study: NCSU Centennial Campus

Three instrumentation targets were selected:

- Lake Raleigh Dam
  - Piezometer
- Farm Pond Earth Dam
  - Piezometer
  - Inclinometer
- Load Frame in CFL
  - Strain gauges

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Sensor Selection

The sensors we select are commonly used in infrastructure instrumentation, and thus, fundamentally important for undergraduate civil engineering students to learn:

- **Inclinometer:**

  to measure ground tilt or horizontal displacement;

- **Piezometer:**

  to measure pore water pressure;

- **Strain gauge:**

  to measure strain in selected structures components.

Each of these selected sensors are expected to be robust and stable for long-term monitoring and can be monitored remotely.

Sensor Selection

Piezometer

Geokon Model 4500 VW piezometer

It has outstanding long-term stability and reliability, and low thermal zero shift.

Standard Ranges	350kPa
Resolution	0.025%F.S.
Accuracy	±0.1% F.S.
Temperature Range	-20°C to +80°C
Thermistor Operating Accuracy	±0.5°C

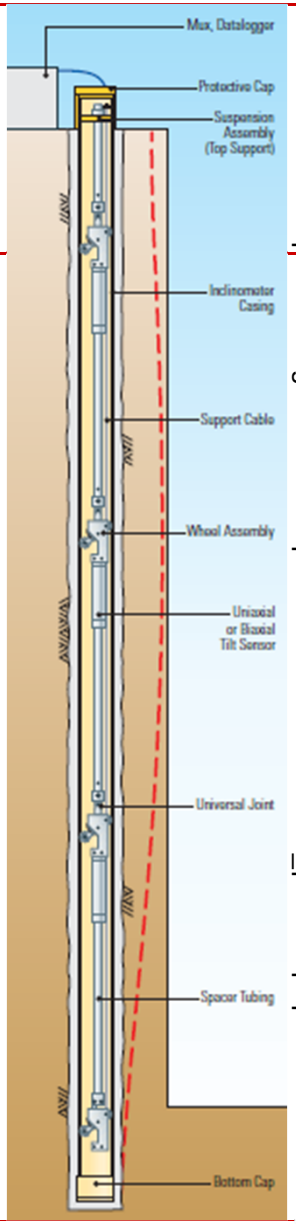
Sensor Selection

Inclinometer

Geokon Model 6300 VW in-place inclinometer

It is designed to be left in place inside the casing to permit automatic or continuous monitoring. Strings of sensors are joined together to obtain deflection profiles.

Standard Ranges	±10°
Resolution	±0.05 mm/m
Accuracy	±0.1% F.S.
Operating Frequency Range	1200-3500 Hz
Temperature Range	-20°C to +80°C
Thermistor Operating Accuracy	±0.5°C



http://www.geokon.com/products/inclinometers_probes.php

Sensor Selection

- Inclinometer

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Sensor Selection

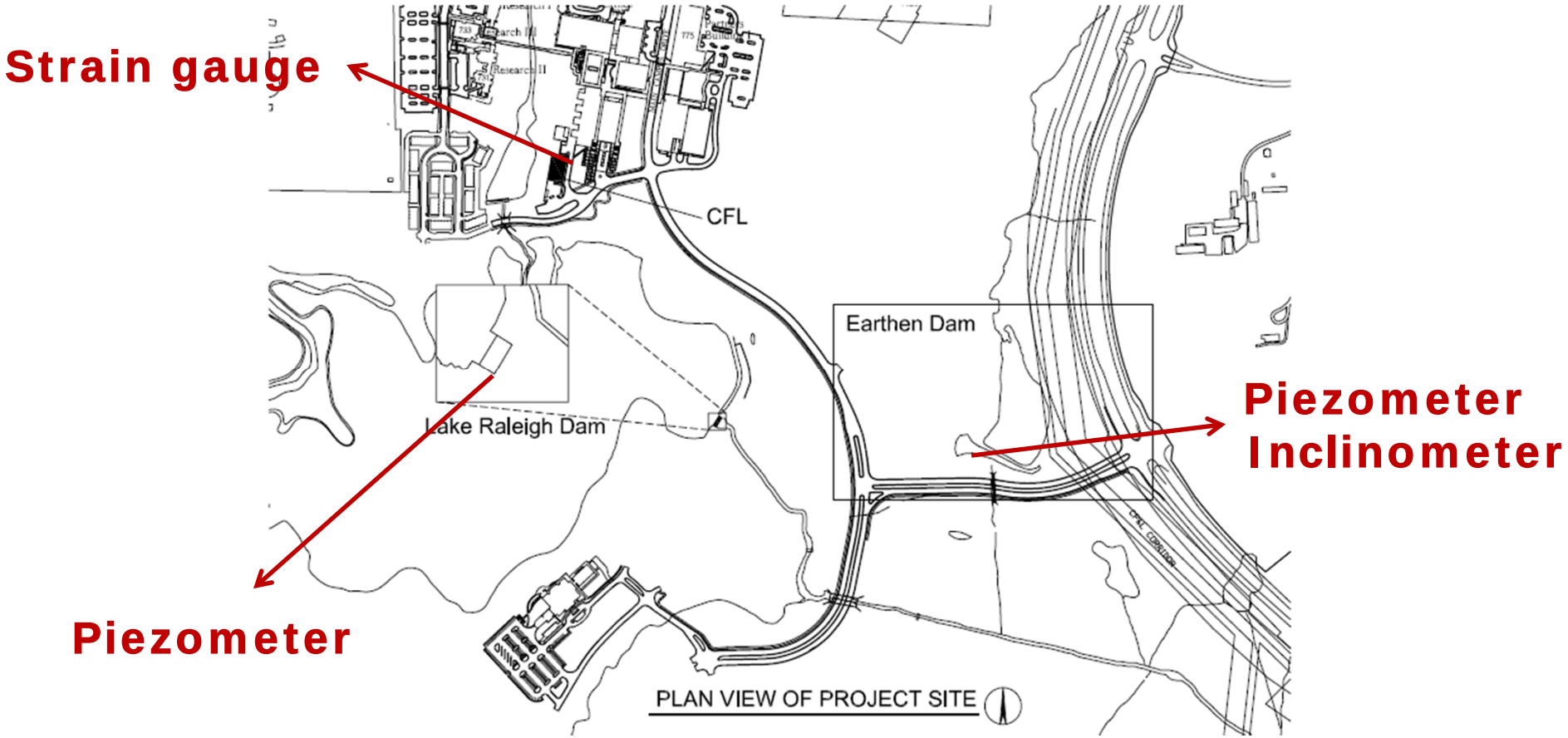
- Strain gauge
  - Capable of capturing structure responds to short-term live-load
  - Mount to various structural members as steel, concrete, timber
  - Easy and quick to install in any weather, entirely reusable

http://www.bridgetest.com/strain/bdi-strain-transducers

Sensor Siting

- Sites for instrumentation in NCSU Centennial Campus were selected as follows:
  - to accommodate the desired sensor types;
  - to allow easy access for installation, maintenance, and future class field trips;
  - for their ability to provide interesting data that are interpretable by undergraduate engineering students;
  - to allow for centralized remote data collection, logging, and storage.

Sensor Siting

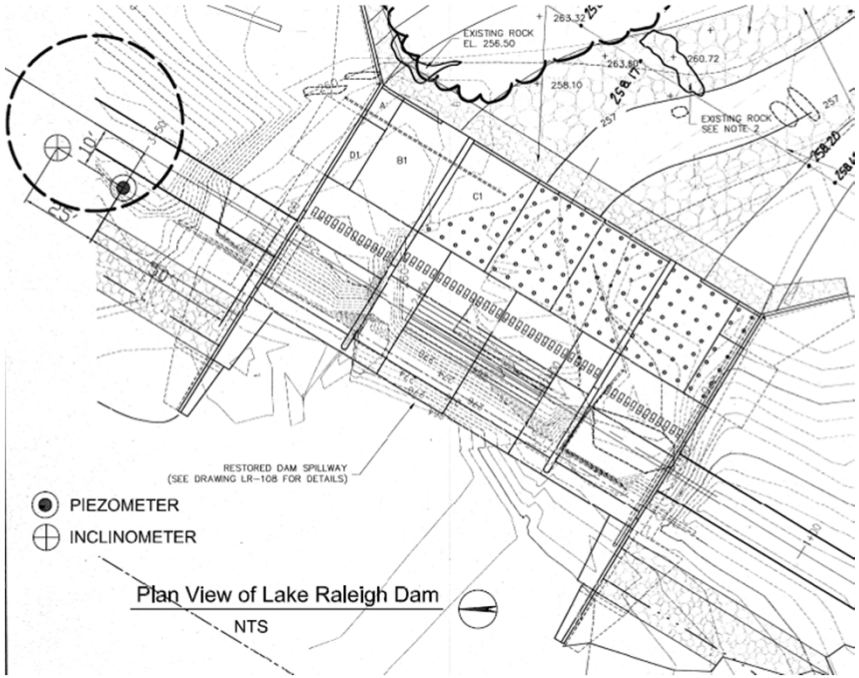


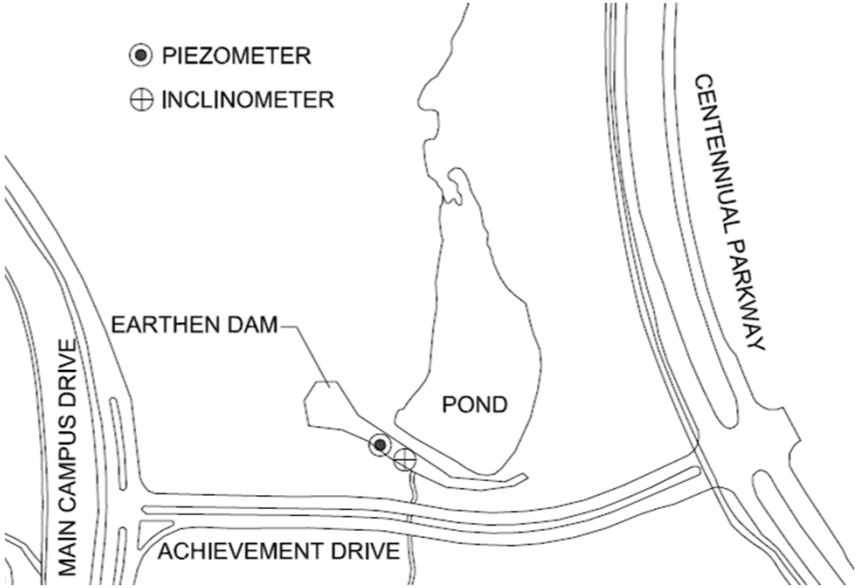
Sensor Siting

Aerial View

Sensor Siting

- Lake Raleigh
- Farm Pond





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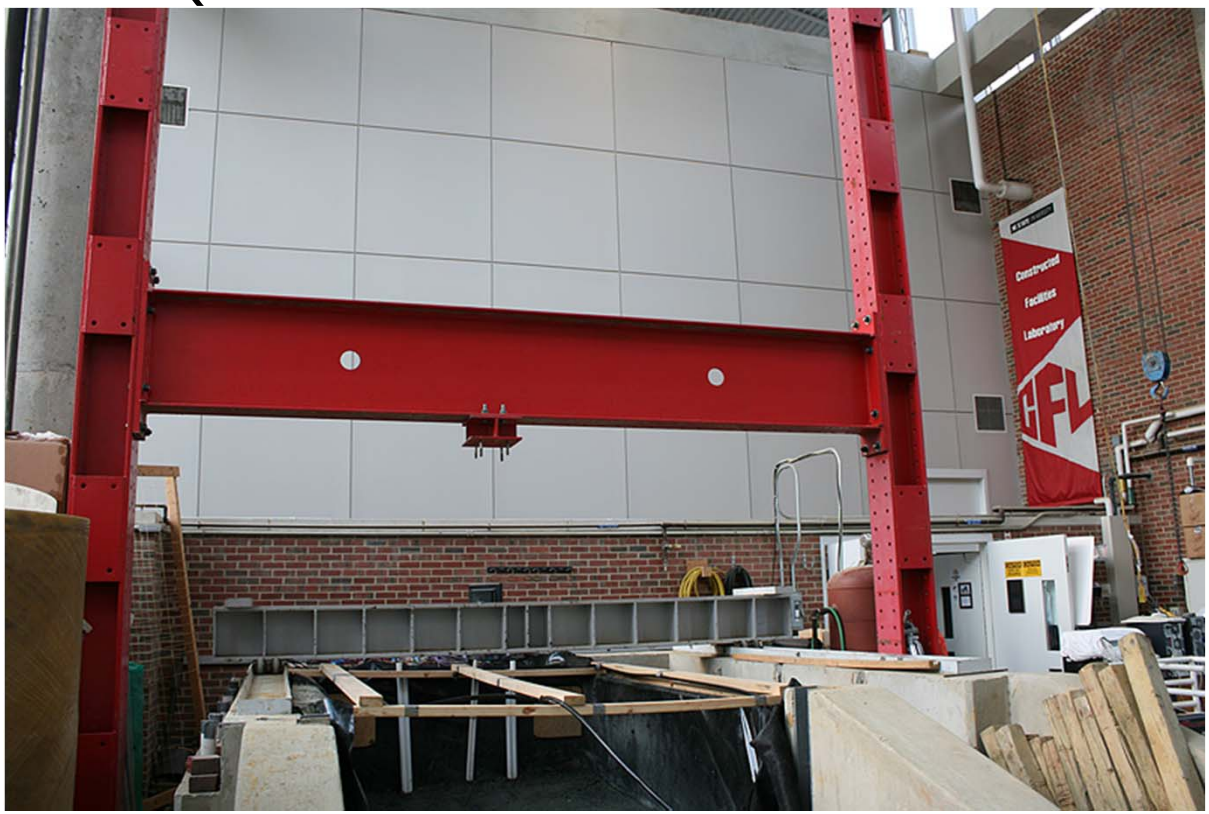
Sensor Siting

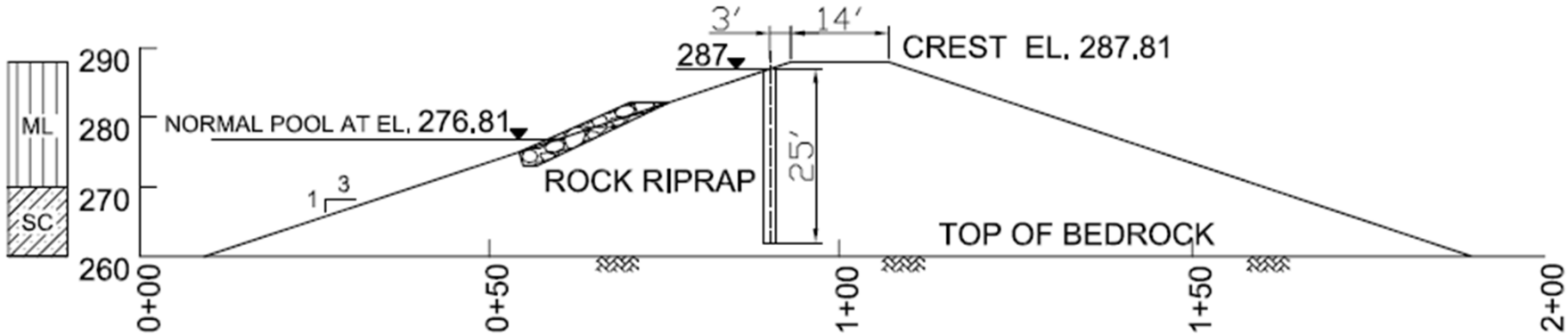
- CFL (Constructed Facilities Laboratory)



Sensor Installation-Piezometer

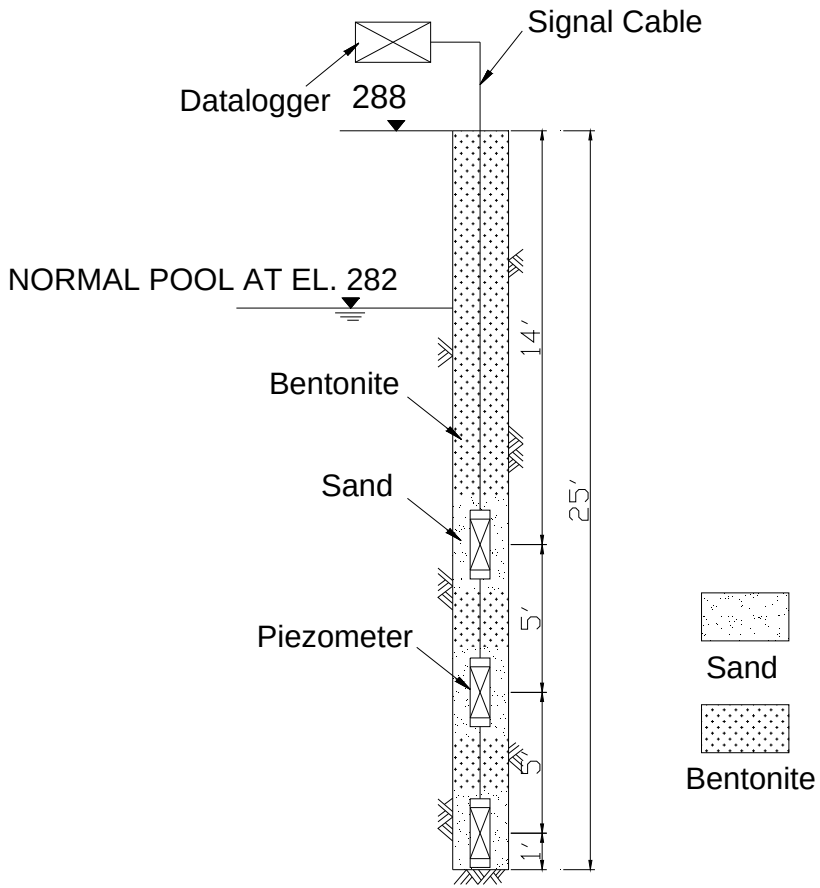
- Piezometer (in borehole)
  - Establish initial zero reading
  - Saturate the filter stone
  - Drill borehole and wash it clean of cuttings
  - Deliver the sensor down to expected level
  - Backfill with clean sand around sensor to form a collection zone
  - Fill with bentonite between collection zones up to the top of borehole

Sensor Installation-Piezometer



Section view of piezometer configuration in Lake Raleigh Dam

Sensor Installation-Piezometer



Details of piezometer configuration in Lake Raleigh Dam

Sensor Installation-Piezometer

Drilling Rig

Drilling

Auger

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Sensor Installation-Piezometer

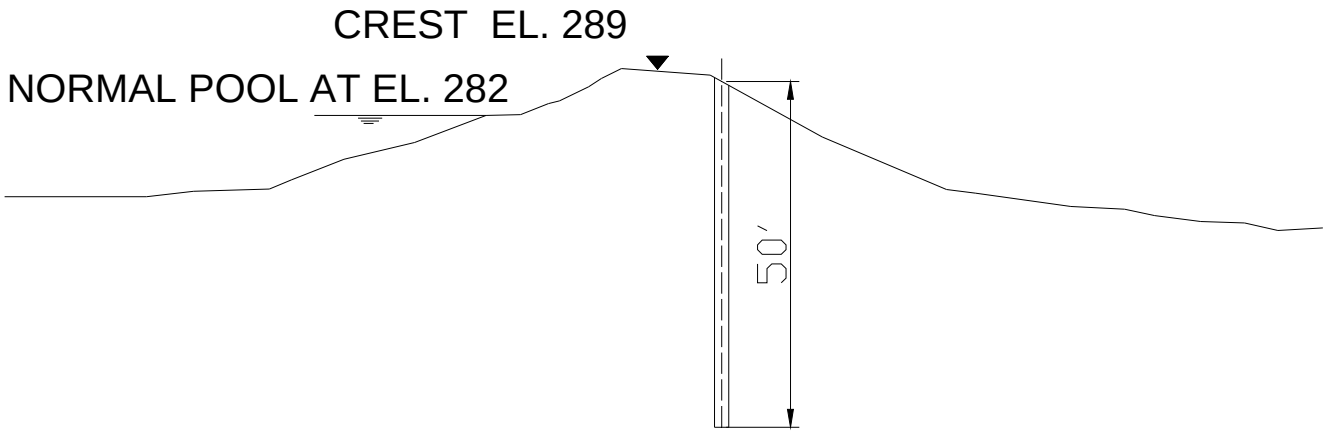
Lowering sensor

Filling with Bentonite

Sensor Installation-Inclinometer

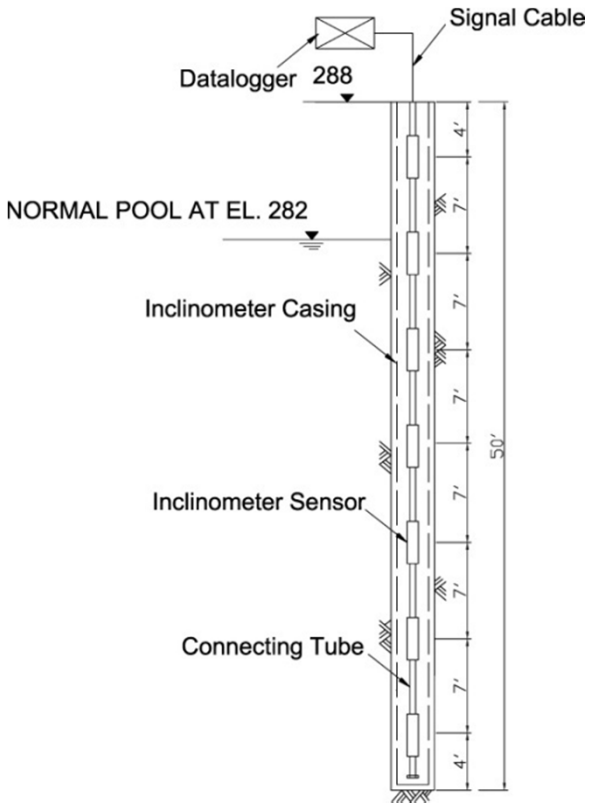
- Inclinometer
  - Drill borehole
  - Install casing
  - Connect sensor, wheel, and tubing
  - Lower the assembly into borehole with safety cable attached to the bottom wheel
  - Continue to add tubing, sensors and wheel assemblies until the last sensors has been installed
  - Record zero conditions after stabilizing

Sensor Installation-Inclinometer



Section view of inclinometer configuration in Farm Pond Dam

Sensor Installation-Inclinometer



Details of inclinometer configuration in Farm Pond Dam

Sensor Installation-Inclinometer

Tilt Sensor

Wheel Assembly

Installation of in-place piezometer

Sensor Installation

- Lake Raleigh Dam

Sensor Installation

- Farm Pond Dam

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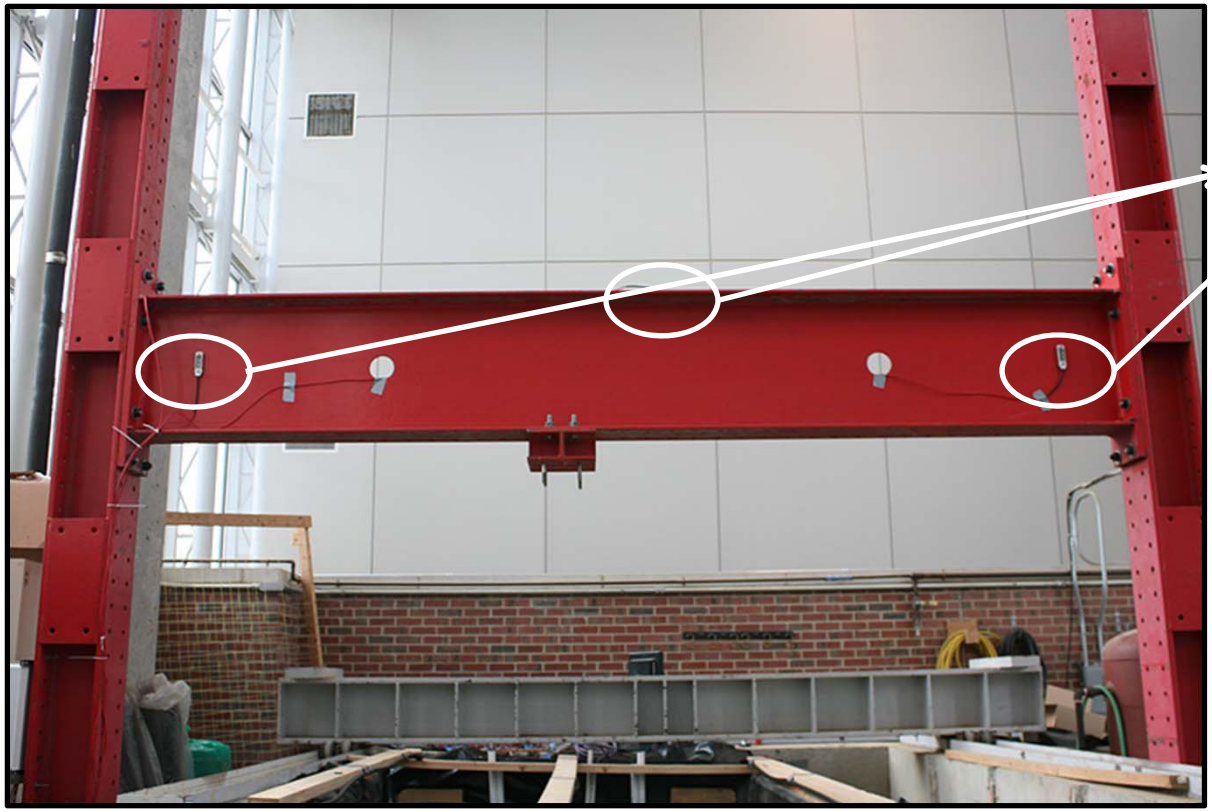
Sensor Installation

- Loading Frame in CFL



Sensor Measurements

Data measurement for the sensors is accomplished with a data acquisition system with wireless data transmission capability and solar power supply.

- Datalogger & support software
- Vibrating-wire-interface
- Multiplexer
- Radio & antenna
- Power supply

Datalogger

Radio

VW interface

Solar panel

Multiplexer

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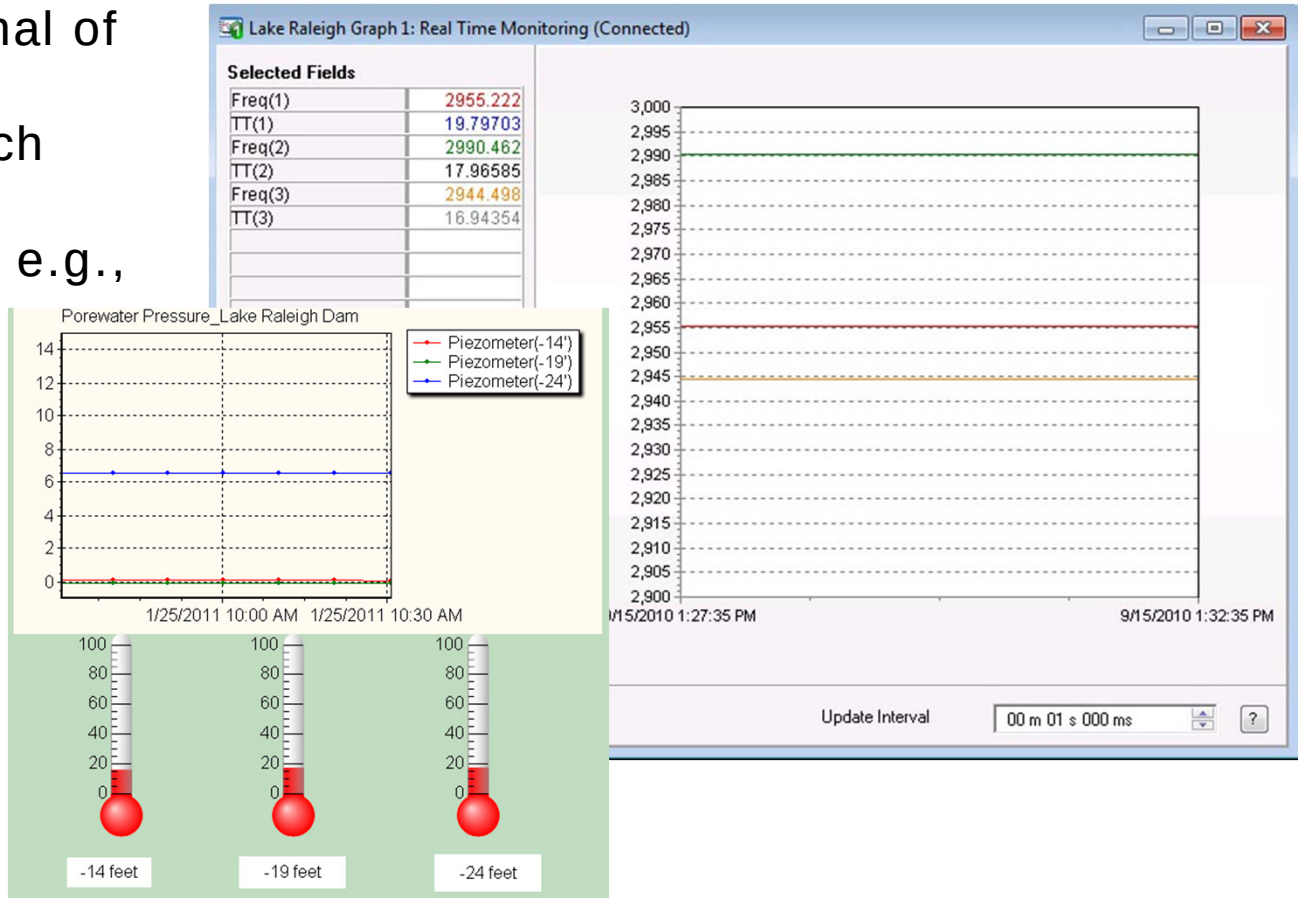
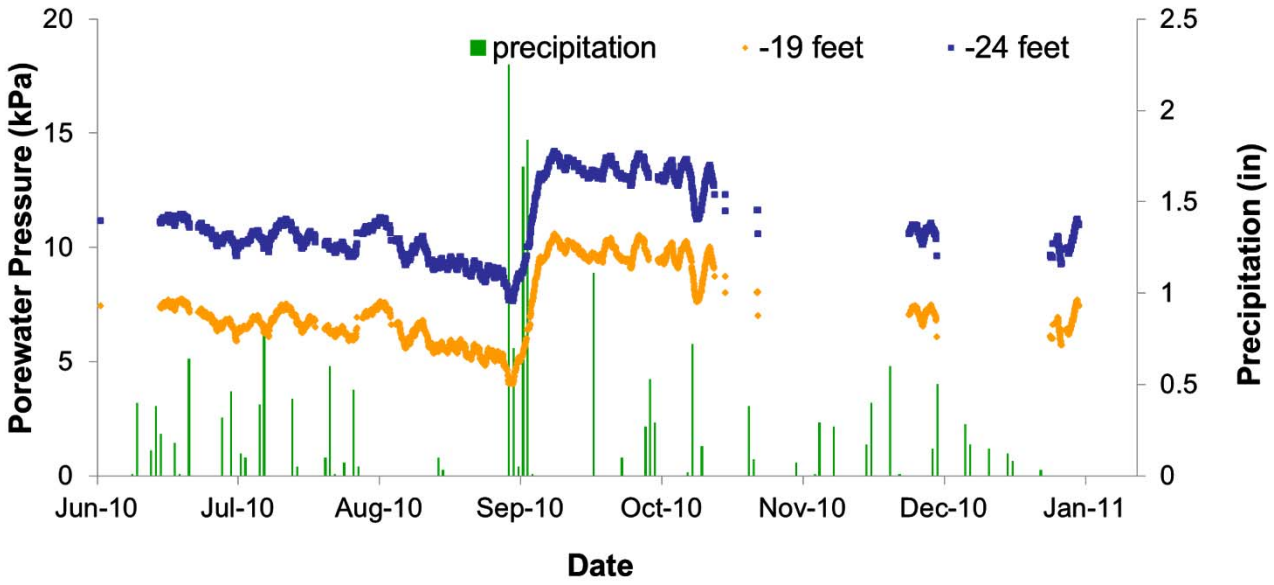
Sensor Measurements

- The output signal of a VW sensor is frequency, which can later be converted into, e.g., pressure and displacement



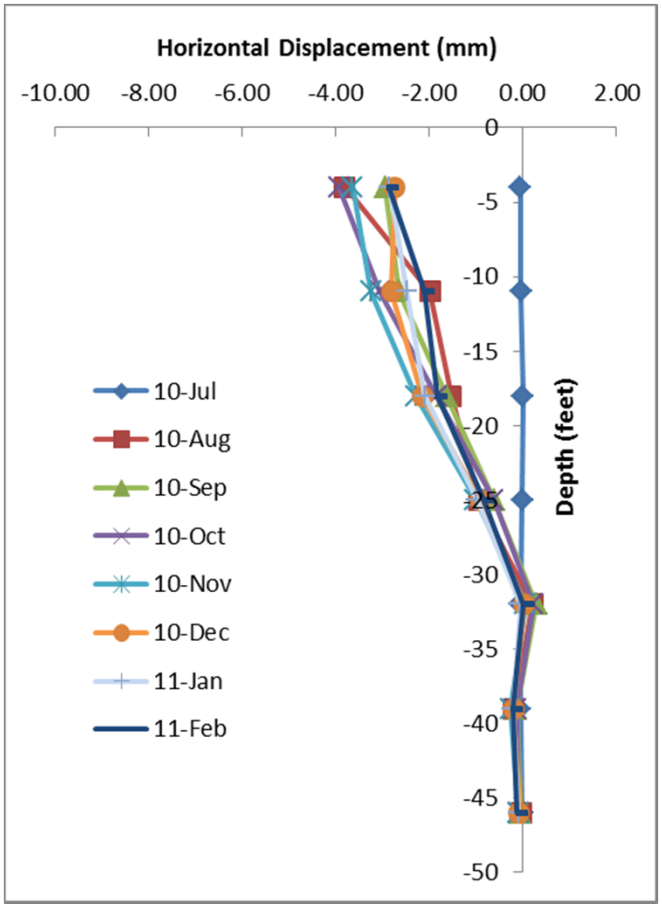
Sensor Measurements

- Pore Water Pressure (Farm pond dam)



Sensor Measurements

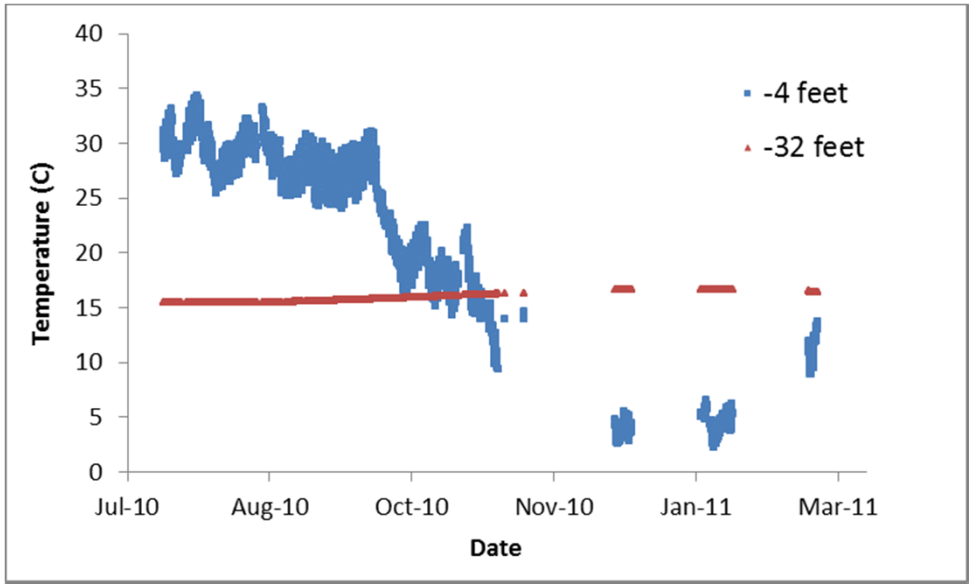
- Horizontal Displacement (Farm Pond Dam)

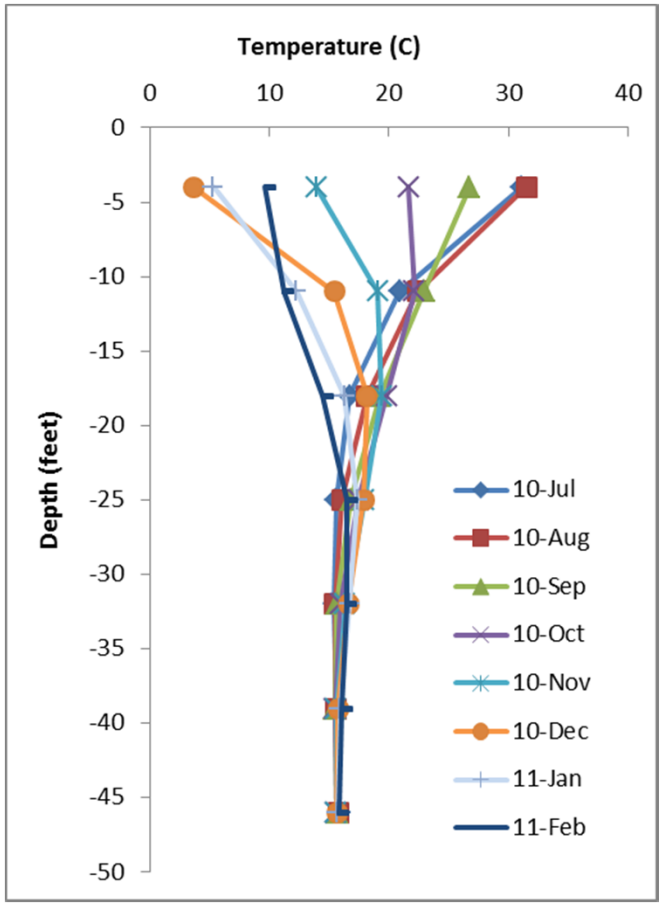


Sensor Measurements

- Temperature

(Farm Pond Dam)





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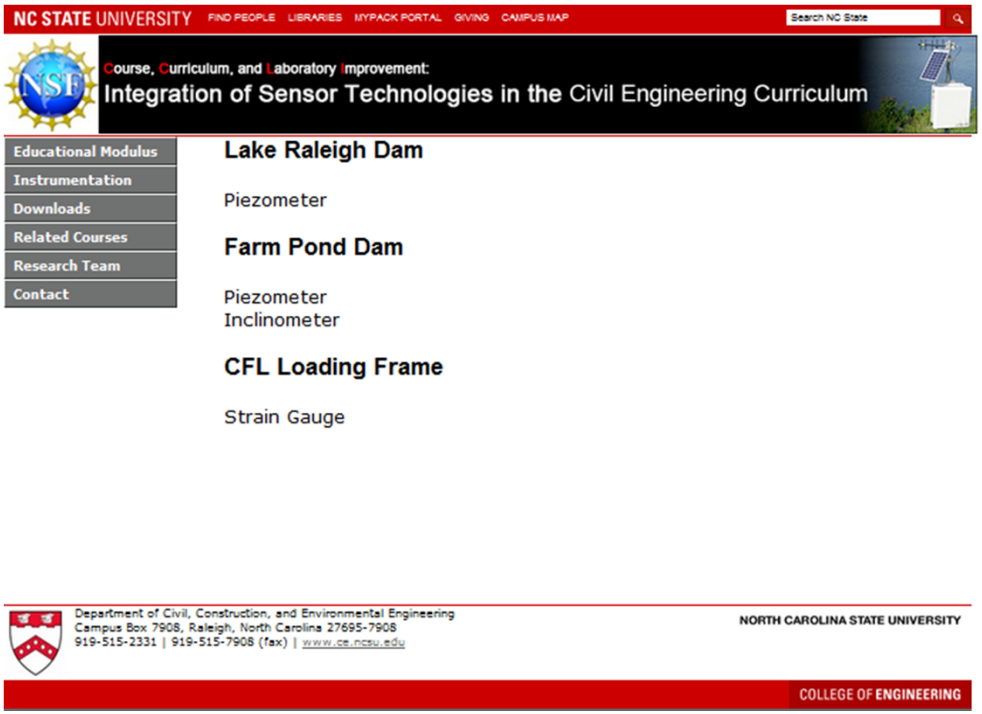
Project Website

A website was built-up to provide access to the monitoring data and information about the related courses.



http://www.ce.ncsu.edu/ccli-sensors/

Files Available

- pond_piezometer_1-1-2011_0-0.xls
- pond_piezometer_1-10-2011_0-0.xls
- pond_piezometer_1-11-2011_0-0.xls
- pond_piezometer_1-12-2011_0-0.xls
- pond_piezometer_1-13-2011_0-0.xls
- pond_piezometer_1-14-2011_0-0.xls
- pond_piezometer_1-15-2011_0-9.xls
- pond_piezometer_1-16-2011_0-0.xls
- pond_piezometer_1-17-2011_0-0.xls
- pond_piezometer_1-18-2011_0-0.xls
- pond_piezometer_1-19-2011_0-0.xls
- pond_piezometer_1-2-2011_0-0.xls
- pond_piezometer_1-20-2011_0-0.xls
- pond_piezometer_1-21-2011_0-0.xls
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- pond_piezometer_1-5-2011_0-0.xls
- pond_piezometer_1-6-2011_0-0.xls
- pond_piezometer_1-7-2011_0-0.xls

Summary and Conclusions

- This module is about sensor installation and operation. A case study is provided in detail based on the instrumentation network set up on the NCSU Centennial Campus.
- Are you now able to answer these questions?