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

Module 1: Fundamentals of Geotechnical Sensing and Instrumentation

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 342)
- 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 first in a series of four) will provide an overview of these technologies and lay the foundation for ongoing studies of the use of sensors in civil engineering practice and research.

Module 1: Learning Objectives

- At the completion of this module, you will be able to:
  - List at least five common types of sensors;
  - Describe the function of these sensors;
  - Use appropriate terminology to discuss sensor applications; and
  - Qualitatively interpret signals from a known sensor type.
- In addition, this knowledge will prepare you to proceed with Module 2

Overview

- Introduction
- Case Study:
  - Central Artery/Tunnel Project
- Sensor Specifics
  - Permanent installations
  - Temporary installations

Basic Definitions

- Sensor
  - a device that responds to a physical stimulus and transmits a resulting impulse
- Transducer
  - a device that is actuated by power from one system and supplies power usually in another form to a second system
- Data Acquisition (DAQ) System
  - System of electronics used to collect signals from sensors/transducers

after Merriam-Webster, 2009

Types of Sensors

- Piezometer – measure pore water pressure
  - Open standpipe
  - Vibrating wire (push in)
  - Pneumatic
- Inclinometers – measure tilt
- Strain gauges
  - Full bridge
  - Half bridge
  - Quarter bridge
- Linear Variable Differential Transformer, LVDT (aka, Linear Variable Displacement Transducer)
- Load Cells

Case Study: Central Artery/Tunnel Project

- Recognized as the largest, most complex, and technologically challenging highway project in the history of the United States, the Central Artery/Tunnel project significantly reduced traffic congestion and improved mobility in Boston.

- The project replaced Boston's deteriorating six-lane elevated Central Artery (I-93) with an eight-to-ten lane state-of-the-art underground highway, two new bridges over the Charles River.

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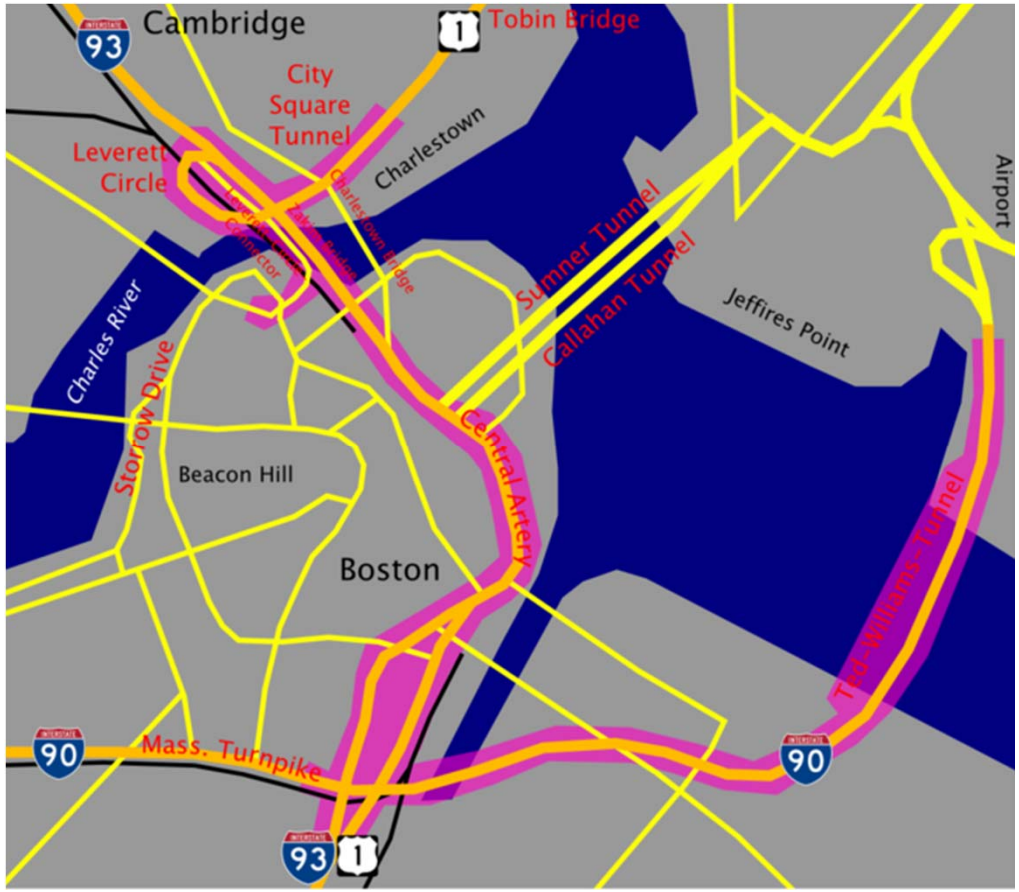
Case Study: Central Artery/Tunnel Project



General Role of Geotechnical Instrumentation in **CA/T**

- Geotechnical instrumentation generally plays multiple roles on a project . It must be considered in the planning and design stages, then carried through construction and even operation phases.
- The following four roles constitutes a minimum for most projects, including the Central Artery project
  - Early Warning System
  - Record of Events
  - Construction Control
  - Evaluating Design Uncertainty

Key Issues

- **Environment Protection Issues:** Project construction is adjacent to old subway tunnels and stations, water and sewer mains, historic buildings. Instrumentation can be thought of as "insurance" to protect these facilities.
- **Long-Term Issues:** Project construction will include excavation in clay which will potentially alter groundwater levels temporarily. The project was carried out over a 12-year period. Certain issues, e.g., consolidation of clay, will require monitoring long after construction is complete.

Type of instruments used in Central Artery/Tunnel Project

Instrumentation Type	What is measured	How measured
Inclinometer	Subsurface horizontal deformation	Electrical probe
Multi-point heave gage	Heave below bottom of excavation	Electrical probe
Convergence gage	Convergence across excavation or tunnel	Mechanical extensometer
Vibrating wire piezometer	Groundwater pressure	Electrical readout unit
Vibrating wire strain gage	Strain on surface of steel	Datalogger or readout unit
Load cell on tieback	Load in tieback	Electrical readout unit

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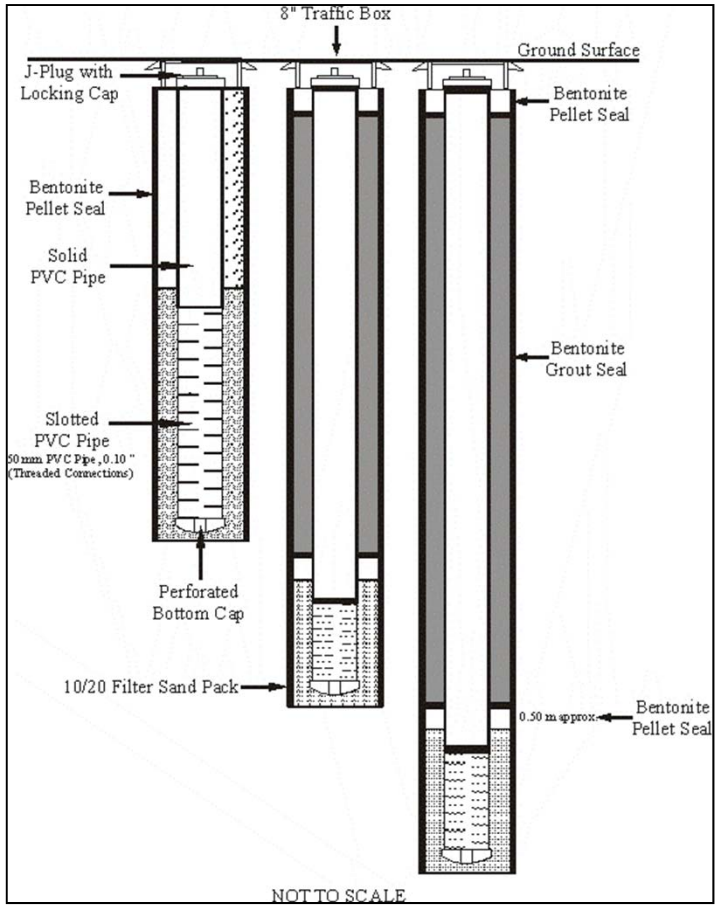
Piezometers

- Typically, a permanent installation in a borehole
- Used to measure *pressure* head at discrete intervals below the phreatic surface



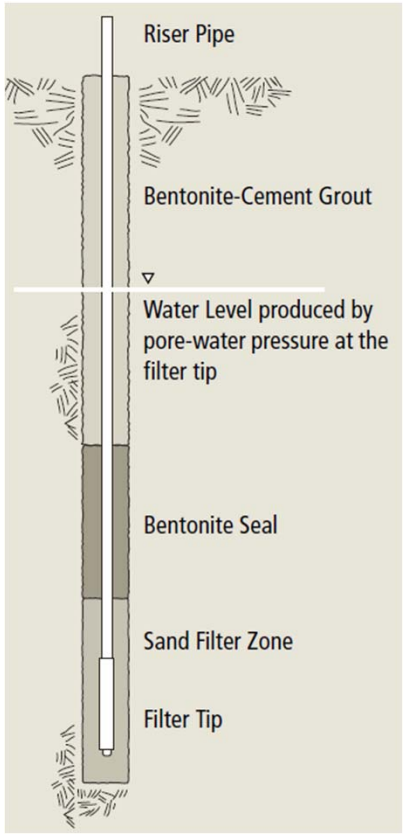
http://great-white-north.com/PhaseII%20CA.htm

Piezometers

- Three primary types
  - Standpipe
  - Pneumatic
  - Vibrating wire
- First two are simple, robust, and inexpensive, but require hands-on measurements
- Vibrating wire is more complicated, but accurate, operator independent, and amenable to remote monitoring

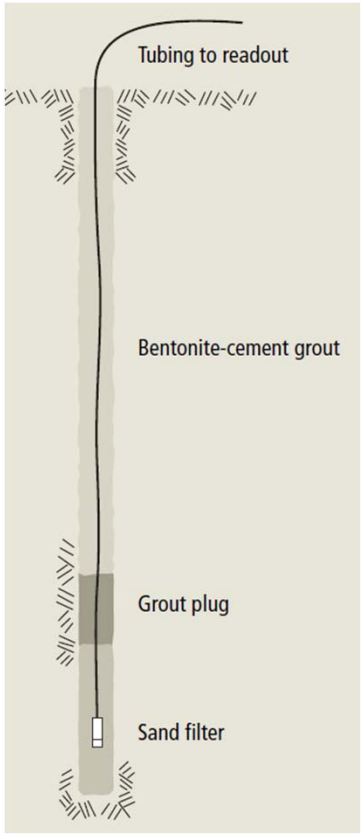
Piezometers

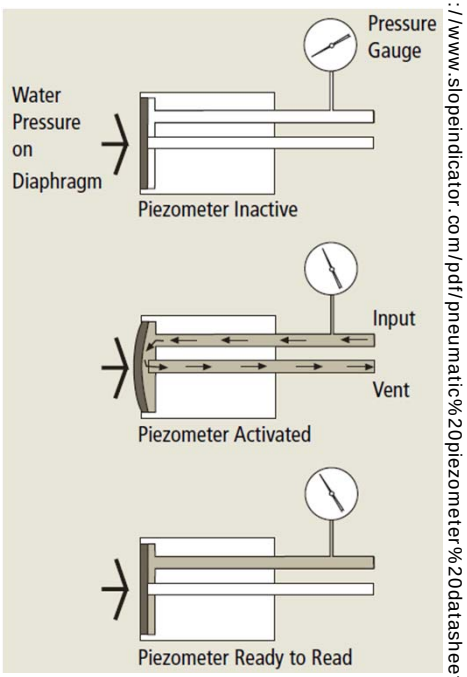
Standpipe



http://www.slopeindicator.com/pdf/standpipe%20piezo%20datasheet.pdf

Pneumatic





http://www.slopeindicator.com/pdf/pneumatic%20piezometer%20datasheet.pdf

Vibrating Wire Piezometers

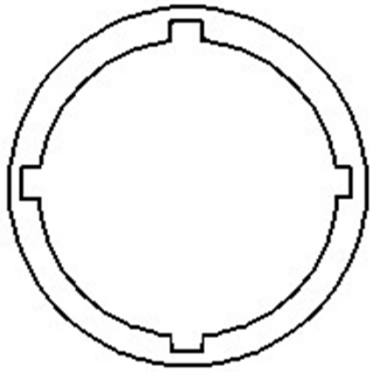
- Six main flavors of VW piezometers:
  - Standard
  - Heavy-Duty
  - Push-In
  - Multi-Level
  - Low-Pressure
  - Vented
- A tensioned steel wire is attached to a diaphragm which deforms in response to pressure changes
- The natural frequency of the wire is a function of tension, and in turn, pressure

http://www.slopeindicator.com/pdf/vw%20piezometer%20datasheet.pdf

Inclinometers

- Inclinometers are used to measure lateral movements in soil and rock
- Typical applications would be in an earth dam, behind a wall, in a slope, or adjacent to a tunnel or excavation
- Sensor probes are installed (temporary or permanent) down specially-grooved casing aligned with the direction of anticipated movement

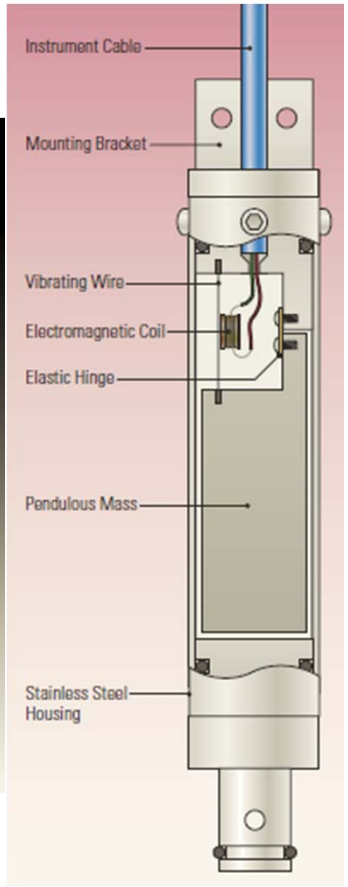
http://www.rstinstruments.com/Inclinometer%20Casing.html



http://www.canterbury.gov.uk/main.cfm?objectid=284

Inclinometers

- Each probe has wheels to keep the sensor aligned and centered within the casing
- The sensor consists of a vibrating wire connected to a pendulous mass
- Measurements are made similarly to VW piezometers
- Multiple sensors (a "stack") are installed in each borehole



http://www.geokon.com/products/datasheets/6300.pdf

Strain Gauges

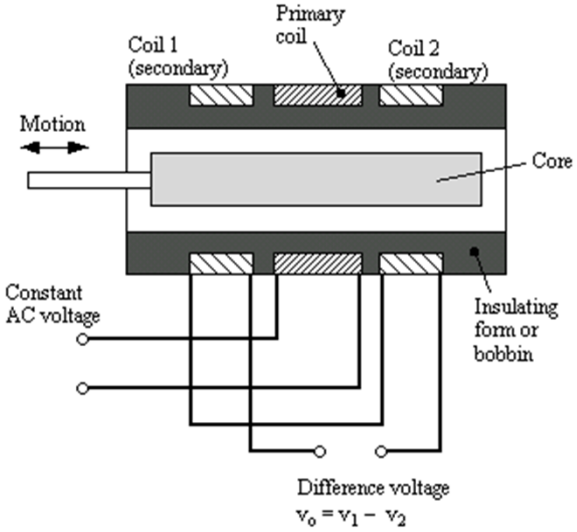
- A strain gauge is a device used to measure the strain of an object.

- Main applications in civil engineering
  - Monitoring stresses in structural members during and after construction
  - Measuring strains in reinforced concrete
  - Monitoring loads in strutting systems for deep excavation
  - Measuring strain in tunnel linings and supports
- Types of Strain Gages
  - Embedment strain gages
  - Weldable strain gages
  - Fiber optic strain gages
  - Dynamic Strain Transducers

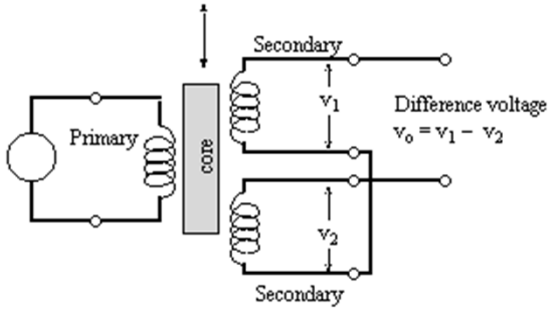
http://www.slopeindicator.com/instruments/sg-intro.html

Linear Variable Differential Transformers

- The **linear variable differential transformer** (LVDT) is a type of electrical transformer used for measuring linear displacement. The transformer has three solenoidal coils placed end-to-end around a tube. A cylindrical ferromagnetic core, attached to the object whose position is to be measured, slides along the axis of the tube.



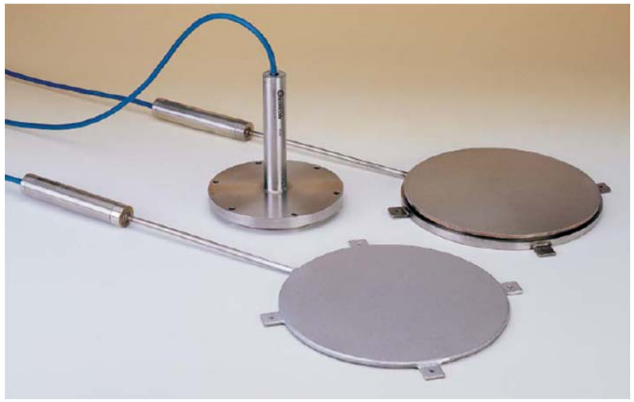
http://www.me.utexas.edu/~dsclab/labs/forcemotion/lvdt.html



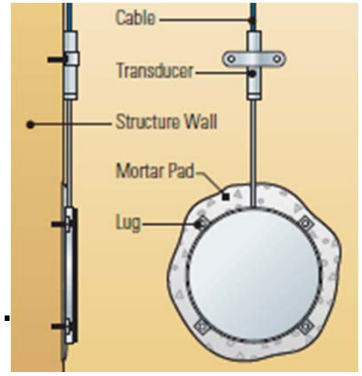
http://www.rdpelectrosense.com/displacement/lvdt/general/dcth-configuration.htm

Load Cells

- (Earth) load cell provide a direct means of measuring total pressure, in or on
  - Diaphragm walls
  - Retaining walls surfaces
  - Sheet piling
  - Slurry walls
  - Tunnel linings



- Load cells are constructed from two stainless steel plates welded together and separated by a narrow gap filled with hydraulic fluid. A steel tubing connects the fluid filled cavity to a pressure transducer that coverts the fluid pressure into a electrical signal.



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

Summary

This Module is a brief yet fundamental introduction to the concept of sensors, their applicability and example of their use.

Will you be able to answer these questions now?

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