Advancement in Geotechnical Instrumentation for Monitoring Field Performance

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Outline of Presentation

• Introduction

• Benefits of Geotechnical Instrumentation and Monitoring

• Types of Geotechnical Instrumentation

• Systematic Approach to planning a monitoring program

• Applications of Geotechnical Instrumentation – Case Study
Soil and Geologic Profile (Sta 265+00 to Sta 345+00) --- New Orleans, LA

• Geotechnical engineering is the branch of Civil Engineering that involves evaluation of engineering properties of soil and rock and their interaction with the structures they support.

• Geotechnical Engineers of design are often challenged with a wide variety of naturally occurring heterogeneous materials below ground.
Geotechnical Engineers account for several unknown parameters that need to be incorporated in their analysis and design recommendations.
Benefits of Geotechnical Instrumentation and Monitoring

- Design verification and evaluate critical design assumptions
- In-service Performance monitoring
- Minimize damage to adjacent structures
- Safety -- Provide a warning and indicate impending failure
- Devise remedial methods to fix problems
- Reduce litigation -- Document performance for assessing damages
- Improve performance and advance state-of-knowledge
**Geotechnical Instrumentation**

**During design** (Instruments used to measure in-situ soil and rock properties)

-- Soil boring and sampling  
-- Cone Penetration Testing (CPT)  
-- Field Vane Shear Test

**During construction** (Instruments used to monitor field performance)

-- Provide a warning and Indicate impending failure  
-- Reveal unknowns and aid use of the observational method  
-- minimize damage to adjacent structures  
-- Quality control construction or operations  
-- Reduce litigation  
-- Design verification  
-- Safety

**After construction** (Instruments used to monitor field performance)

-- In-service performance monitoring  
-- Improve performance and advance state-of-knowledge  
-- inform stakeholders  
-- provide warning and indicate impending failure
Instruments used to measure in-situ soil and rock properties
(during Design)
Drilling Boring Soil Sampling, Laboratory Testing
Cone Penetration Testing (CPT)
Instruments used to evaluate and monitor field performance
(during and after construction)
Engineering Parameters to measure and monitor

- Pore water pressure
- Stresses in Soil
- Lateral Deformation
- Vertical Deformation
Pore water pressure
Pore-Water Pressure

Pore-water measurements help engineers to:

- Establish initial site conditions.
- Determine safe rates for placement of fill.
- Predict slope stability.
- Design and build for lateral earth pressures.
- Design and build for uplift pressures.
- Monitor the effectiveness of drainage schemes.
Pore Water Pressure

Embankments
- Control placement of fill.
- Monitor consolidation.

Landslides
1. Calculate the shear strength of soil.
2. Calculate the soil mass.
Pore Water Pressure

Retaining Wall

- Monitor pore-water pressure to calculated load applied to wall.

Diaphragm Wall or Sheet Pile Wall

1. Monitor load applied to wall.

2. Monitor draw-down due to seepage or dewatering to predict settlement of adjacent structures.

3. Monitor uplift pressures in floor of excavation.
Pore Water Pressure

**Dynamic Compaction**
Monitor pore-water pressure to help evaluate consolidation of soil.

**Pile Test**
Monitor excess pore-water pressures generated by pile driving. Loading of pile can begin after excess pressure has dissipated.
Pore Water Pressure

Standpipe Piezometer

Riser Pipe
Bentonite-Cement Grout
Water Level produced by pore-water pressure at the filter tip
Bentonite Seal
Sand Intake Zone
Filter Tip

Vibrating wire Piezometer

Pneumatic Piezometer

Tubing to readout
Bentonite-cement grout
Grout plug
Sand filter
Stresses in Soil
Total Stress in Soil

Total Stress measurements in soil:
1. Measurements within a soil mass
2. Measurements at the face of a structural element

Provides direct measurement of Total Pressure in or on:
- Bridge abutments
- Diaphragm walls
- Fills and embankments
- Retaining wall surfaces
- Sheet piling
- Slurry walls
- Tunnel linings
- Earth bearing pressure on foundation slabs and footings

Instruments:
1. Earth pressure cells
2. Soil stress cells
3. Soil pressure cells
• The Earth Pressure Cells are designed to measure total pressure in earth fills and embankments.
• All cells consist of two circular stainless steel plates welded together around their periphery and spaced apart by a narrow cavity filled with de-aired oil.
• Changing earth pressure squeezes the two plates together causing a corresponding increase of fluid pressure inside the cell.
• A vibrating wire pressure transducer converts this pressure into an electrical signal which is transmitted to the readout location.
The Push-In Pressure Cell is designed to be pushed in place for the measurement of total pressures in soils and earth fills. Where effective stress is required, the cell is fitted with an integral piezometer. A thread is provided on the end of the cell to allow for installation using lengths of pipe or drill rods.
• The Tip Pressure Cell is used to measure pile-tip loads in cast-in-place concrete piles (caissons).
• The Pile Tip Pressure Cell has a thick upper plate. The cell is manufactured to be close to the diameter of the pile and the back plate is supplied with hooks or sections of rebar to allow the cell to be connected to the bottom of the reinforcement cage.
• Two vibrating wire pressure transducers are connected to the cell to provide some redundancy in the event that one transducer is damaged during installation.
• An added feature is a remote “crimping” mechanism to allow the cell to be inflated slightly so as to ensure good contact between the cell and the surrounding concrete.
Lateral Deformation
Lateral Deformation

Measurements of lateral deformation help engineers to:

- Evaluate the stability of slopes and embankments.
- Determine the need and timing for corrective measures.
- Verify the performance and safety of structures such as retaining walls and embankments.

Retaining Walls

- Monitor deformation of soil behind retaining wall.
- Check for rotation of retaining wall.
Lateral Deformation

Landslides, Cuttings, and Embankments

- Monitor stability of slope, cut, or embankment.
- Detect shear zones and help determine whether shear is planar or circular.
- Determine whether movement is constant, accelerating, or slowing.
Pile Tests

- Monitor deformation of laterally loaded pile.
- Warn of impending failure.
Inclinometers

Inclinometer casing

Lateral Deformation

Traversing Probe system

In place inclinometer

Inclinometer casing
Vertical Deformation
Vertical Deformation

Measurements of vertical deformation help engineers to:
- Verify that soil consolidation is proceeding as predicted.
- Predict and adjust the final elevation of an embankment.
- Verify the performance of engineered foundations.
- Determine the need and timing for corrective measures.

Embankment
- Monitor the progress of consolidation.
- Monitor the performance of foundation soil.
Vertical Deformation

Foundations
Monitor performance of foundation under structures such as storage tanks to warn of stresses that can cause leaks or ruptures.

Pile Test
- Monitor compression of pile.
- Monitor settlement below pile.
Vertical Deformation

Settlement Cells

Typical installation of settlement cell

- Reservoir
- Liquid-filled tubing

Height of the column of liquid increases as cell moves downward with settling ground.

Cell measures the pressure of the column of liquid.
The Settlement System is designed for the remote measurement of surface or subsurface settlement in fills, surcharges, dams, embankments, etc.

A borehole is drilled which allows a pressure transducer to be anchored to solid ground below the area of settlement.

A fluid filled tube extends upward connecting the transducer to a reservoir which is located in the moving strata or fill.

The measurement of fluid pressure indicates the elevation difference between the sensor and the reservoir. This design eliminates the need for long liquid filled tubes.
**Rod Extensometer**

- The Rod Extensometer consists of anchors set at specified depths, rods inside protective tubing, and a reference head.

- Measurements are taken at the reference head by micrometer or by an electric sensor.

- Advantages: Can be automated, can be read remotely, works in any orientation, can measure multiple points.

- Limitations: Limited measurement range (50 to 100 mm).
Sondex

- The Sondex system consists of a series of rings attached to a flexible corrugated pipe.

- Measurements are lowering a probe through an inner access pipe to detect the position of the rings.

- Advantages: Can monitor large settlements; works with inclinometer casing and can supplement inclinometer data, indicates incremental settlements, no limitation on number of measured rings.

Extensometer

- Limitations: Cannot be automated, vertical installation only.
3D Deformation – ShapeAccelArray (SAA)

- Measures 2D and 3D shape and 3D vibration
- Measures vertical and horizontal deformation
- Rigid segments connected by joints that bend in any direction
- Standard segment length is 305 mm --- 500 mm is also available
- Segments contain 3 orthogonal MEMS gravity/vibration sensors
- Every eighth segment included a microprocessor

- Prices by segment
  - Cost = $500/meter
  - Longest continual SAA available = 100m and cost $50,000
  - Manual data collection = $1000
  - Automated data logger (solar powered earth station) = $5000
  - All software is free
3D Deformation – ShapeAccelArray (SAA)
3D Deformation – ShapeAccelArray (SAA)

- Data concentrator (DC) useful for unattended field installations. DC is usually solar powered.

- DC stores data automatically, with up to 3-year capacity.

- Typical transfer: DC automatically connects to internet using cellnet or other wireless means. Data are served automatically to customer’s internet connection.

- Simplest transfer: PC periodically used to download data via serial port of DC.

- SAA3D Viewer software used to view/export data.

- DC can be configured remotely to change alarm levels, acquisition times, connection times, etc.

4/27/2008
Systematic Approach to planning monitoring program using Geotechnical Instrumentation
1. Predict mechanisms that control behavior

- Prior to developing a monitoring program, one or more working hypothesis must be developed for mechanisms that are likely to control behavior.

- The hypothesis should be based on a comprehensive knowledge of project conditions.
2. Define the Geotechnical questions that need to be answered

- Every instrument on a project should be selected and placed to assist in answering a specific question
- If there is no question, there should be no instrumentation -- First Golden Rule
- A listing should be made of geotechnical questions that are likely to arise during the design, construction, or operation phases

- What are the initial site conditions?
- What information can be provided by instrumenting a full-scale test of the complete excavation and support system?
- What is a suitable design for tieback anchors?
- Is the bracing being installed correctly?
- Is the excavation stable and are nearby structures being affected adversely by ground movements?
- What is the magnitude and distribution of load in a support system?
- Is the groundwater table being lowered?
- Is excessive bottom heave occurring?
3. Identify, analyze, allocate, and plan for control of risks

• All risks associated with construction should be identified
• Responsibility for each risk may be allocated to a single party or to more than one party
• Risk analysis should be performed
  -- Identify potential sources of risk
  -- Determine the probability of occurrence for each source
  -- Estimate consequences from each source of risk
4. Select parameters to be monitored

Typical geotechnical parameters that are monitored are:
• Pore water pressure
• Deformation
• Tilt
• Total stress
• Load and strain in structural members
• Temperature
5. Predict magnitudes of change

• Manufacturers of geotechnical instruments will define their range and accuracy
• In order that appropriate instruments are selected, there must be a prediction of the maximum change that might occur.
• If measurements are for construction control or safety purposes, a predetermination should be made of numerical values that indicate the need for decisive mitigation measures. --- trigger levels (green, amber, red)
  -- **Green** indicates that all is well
  -- **Amber** indicates the need for cautionary measures including an increasing in monitoring frequency
  -- **Red** indicates the need for timely remedial actions and being prepared to implement them quickly
6. Device remedial action

- If the observations should demonstrate that remedial action is needed, that action must be based on appropriate, previously anticipated plans.

- Planning should ensure that required labor and materials will be available so that remedial action can proceed with minimum and acceptable delay.

- An open communication channel should be maintained between design and construction personnel, so that remedial action can be discussed at any time.
7. Select instruments

- When selecting instruments, the overriding desirable feature is **Reliability**

- In evaluating the economics of alternative instruments, the overall cost of procuring, calibration, installation, maintenance, monitoring, and data processing should be compared.

- Instruments should have a good past performance record and should always have maximum durability in the installed environment.
8. Select instrument locations

- Zones of particular concern should be identified – structurally weak zones, most heavily loaded zones, zones where highest pore water pressures are anticipated

- Representatives variations in geology and construction procedures should be considered
  --- Primary Instrumented Sections – provide comprehensive performance data
  --- Secondary Instrumented Sections – indices of comparative behavior

- Locations should be selected so that data can be obtained as early as possible during the construction process
9. Plan regular calibration and maintenance

- Regular calibration of the instruments should be performed
  -- Factory calibration
  -- Acceptance tests (laboratory conditions)
  -- Calibration during service life

- Regular maintenance of the instruments should be performed
  -- shield from construction activities
  -- manufacturer’s instruction manual – troubleshooting guide
  -- cleaning, drying, lubricating, battery life
10. Plan data collection and data management

- Written procedures for data collection, processing, presentation, and interpretation should be prepared
- Staff training should be planned
Case Study
Soils generally consists of granular sediments, clays, and tills.

Hout formation near ground surface – extremely clayey, has high natural moisture content, very low shear strength, and flows when subjected to stress.

Responsible for bank and stability problems.
SAA Installation: Late May – Early June 2008
SAA #5

19 Sep  
24 Sep  
26 Sep  
27 Sep
Summary

- Geotechnical Engineers of design are often challenged with a wide variety of naturally occurring heterogeneous materials below ground and several unknown parameters that needs to be accounted for in their analysis and design recommendations.

- Adequate instrumentation of Geotechnical features can provide engineers will valuable performance benchmarks during every stage of a project.

- Data from strategically installed instruments can be used to characterize initial subsurface site conditions, verify design assumptions, provide data for use in quality control during construction, minimize damage to adjacent structures, monitor field performance of critical project features, and early warning of impending failures.

- Recent advancements made in design and manufacturing of Geotechnical Instrumentation has increased accuracy of data gathered.

- Data from Geotechnical instruments can be gathered, monitored, and transmitted in real time using wireless capabilities.
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“The legitimate uses of instrumentation are so many, and the questions that instruments and observation can answer so vital, that we should not risk discrediting their value by using them improperly or unnecessarily” – Ralph Peck (1984)
Thank You!