Overview

It’s more than just dots…Geotechnical Explorations
Geotechnical Definitions
Reading a Soil Boring Log
In-Situ Testing
Deep Foundations
Ground Improvement Options
Summary
Geotechnical Explorations

Where to start with the dots

Understanding Risk

Contractor

Owner

Design Professionals

Plans & Specs (Spearin Doctrine)

Limited Risk

Life Safety
Industry Standard of Care
The project team’s greatest risk is underground.

When do you need a Geotechnical Engineering Report?

IBC 2012-2018 section 1803
Local Codes

What should be included?

1803.6 indicates minimum requirements
boring location plan, boring logs,
expected settlement (more on that later), water levels, etc

Only 0.001% of the soil on a typical site is explored
Geotechnical Explorations

How many soil borings do you need?

IBC is the default. However… some jurisdictions have their own requirements

PA - Geotechnical Engineer of Record has authority over design of exploration

NJ - IBC NJ says 1 boring every 2,500 sqft of built area (can petition local code officials to modify)
Geotechnical Explorations

Roles of the Structural Design Professionals

Structural Engineers
- should require a Geotechnical Engineering Report
- provide loading & performance criteria
  - unfactored “actual” loads* used for settlement calcs
  - bearing capacity is based on soil properties
* reduced or not (ASCE 7 re: live load reductions)

Should the Structural Engineer design the Geotechnical Exploration?

IBC 1803.3.1- scope by a registered design professional

IBC 1804- registered design professional shall have a qualified individual on-site during all soil boring or sampling operations

Liability?
Geotechnical Explorations

Designing the Geotechnical Investigation

Based on past experience
Geologic maps
Soil maps *(USDA is not just for farmers)*
Presence of FILL and/or organics
Expected loading
Performance criteria
Geotechnical Explorations

Designing the Geotechnical Investigation

Sanborn map: % libraries.psu.edu
Geotechnical Explorations

Designing the Geotechnical Investigation
Geotechnical Explorations

Roles of the Structural Design Professionals

What to do when someone asks for “dots on a plan?”

1) Convince the owner that they have a risk
2) Explain the risk
3) Develop a robust Scope of Work for RFP
4) Review geotechnical proposals with owner
   - What are the advantages and risk management of each?
Geotechnical Explorations

Typical Scope

1) Plot of sampling and boring locations
2) Record of soil profiles
3) Water tables
4) Soil properties
5) Recommendations for allowable bearing pressure and/or deep foundations
6) Seismic site class
Geotechnical Explorations

Special Scope

Scopes should always be tailored to your specific project

1) Slope stability
2) Test pits for FILL sites
3) Support of excavation and retaining structures
   ○ typical parameters for permanent and temporary conditions (soil density and phi angle)
4) Deep foundation recommendations
   ○ If your experience tells you that you will have lateral loads include the lateral analysis for deep foundations
Geotechnical Explorations

When you don’t need a Geotechnical Engineering Report?

Where new ground will not be disturbed …

Example: small building renovation where existing structural drawings and soils report is available

Even more important to explain risk to owner
  - Financial
  - Schedule
  - Performance
Geotechnical Explorations

Seismic Site Class

Can be determined using:

- SPT N values (requires one 100 ft soil boring or known depth to rock)
- CPT correlations
- Seismic CPT
- Refraction Microtremor (ReMi), Multi-channel Analysis of Surface Waves (MASW), Cross-hole Seismic, and Down-hole Seismic
Geotechnical Definitions

- **Design Bearing Pressure:**
  - Maximum contact pressure that limits settlement and provides sufficient FS against bearing capacity failure

- **Bearing capacity:**
  - Based on soil strength
  - Considers all Loads (i.e., DL, LL, and Transient)

- **Settlement:**
  - Based on soil compressibility
  - Limiting deflection, so load dependent
  - Considers Sustained Loads Only (i.e., no Wind/EQ)
  - Total settlement = settlement during construction + long term settlement
  - Differential settlement is deflection over a certain distance
Geotechnical Definitions

More on differential settlement

- Settlement between two adjacent points
- Must include the distance between the points
Geotechnical Definitions

$q_{settle} = q_{ult} / FS$

$q_{ult} = \text{Bearing Pressure at Bearing Capacity Failure}$

$q_{settle} = \text{Bearing Pressure at } x'' \text{ of settlement}$

$q_{settle} = q_{all} < q_{ult} / FS$
Settlement depends on:

- Soil Stiffness/Compressibility
- Compressible Zone Thickness
- Load Size
- Load Magnitude
- Load Shape
Which Footing has greater settlement potential?

- 2,000 psf
- 5,000 psf
Should provide geometry to geotechnical engineer to re-evaluate settlement after foundation geometry is set.
## Reading a Soil Boring Log

### LOG OF BORING NO. B-4

**PROJECT:** Proposed Sports Complex
**PROJECT LOCATION:** Wilmington, Delaware
**DATE STARTED:** 6-30-17
**DATE COMPLETED:** 7-30-17
**DRILLING CONTRACTOR:** Walton Corporation
**DRILLER:** J. Truver
**DRILLING METHOD:** Hollow Stem Auger
**SAMPLING METHOD:** Soil Scope

### WATER LEVEL
- **Elevation (ft):** 18.5, 7.9, 3.6
- **Ground Surface Elevation:** 4.0
- **Datum:** Topo
- **Equipment:** CME800

### WATER ENCOUNTERED DURING DRILLING (ft)
- **Depth:** 10.3

### DESCRIPTION

<table>
<thead>
<tr>
<th>SAMPLE NUMBER</th>
<th>SAMPLE DEPTH (ft)</th>
<th>SAMPLE RECOVERY (in.)</th>
<th>SAMPLE BLOWS/6 inches</th>
<th>N (blows/ft)</th>
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<th>REMARKS</th>
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<tbody>
<tr>
<td>S-1</td>
<td>0.0</td>
<td>20</td>
<td>4-15-12-8</td>
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</table>

**NOTED:** Elevation and location should be considered approximate.
Reading a Soil Boring Log

Types of Soils

Gravel

Sand

<table>
<thead>
<tr>
<th>CLEAN GRAVELS (Less than 5% passes No. 200 sieve)</th>
<th>GW</th>
<th>Well graded gravels, gravel-sand mixtures, or sand-gravel-cobble mixtures</th>
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<tbody>
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<td>GRAVELS WITH FINES (More than 12% passes No. 200 sieve)</td>
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<td>Poorly graded gravels, gravel-sand mixtures, or sand-gravel-cobble mixtures</td>
</tr>
<tr>
<td></td>
<td>GM</td>
<td>Silty gravels, gravel-sand-silt mixtures</td>
</tr>
<tr>
<td></td>
<td>GC</td>
<td>Clayey gravels, gravel-sand-clay mixtures</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CLEAN SANDS (Less than 5% passes No. 200 sieve)</th>
<th>SW</th>
<th>Well graded sands, gravelly sands</th>
</tr>
</thead>
<tbody>
<tr>
<td>SANDS WITH FINES (More than 12% passes No. 200 sieve)</td>
<td>SP</td>
<td>Poorly graded sands, gravelly sands</td>
</tr>
<tr>
<td></td>
<td>SM</td>
<td>Silty sands, sand-silt mixtures</td>
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<td></td>
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# Reading a Soil Boring Log

## Types of Soils

<table>
<thead>
<tr>
<th>Silts of Low Plasticity (Liquid Limit less than 50)</th>
<th>ML</th>
<th>Inorganic silts, clayey silts of low to medium plasticity</th>
</tr>
</thead>
<tbody>
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<td>Silts of High Plasticity (Liquid Limit 50 or more)</td>
<td>MH</td>
<td>Inorganic silts, micaceous or diatomaceous silty soils, elastic silts</td>
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<tr>
<th>Clays of Low Plasticity (Liquid Limit less than 50)</th>
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<th>Inorganic clays of low to medium plasticity, gravelly, sandy, and silty clays</th>
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<td>Inorganic clays of high plasticity, fat clays, sandy clays of high plasticity</td>
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</table>

- **Silt**
- **Clay**
Reading a Soil Boring Log

Types of Soils

FILL

Organic Soils

| ORGANIC SILTS AND CLAYS OF LOW PLASTICITY (Liquid Limit less than 50) | OL | Organic silts and clays of low to medium plasticity, sandy organic silts and clays |
| ORGANIC SILTS AND CLAYS OF HIGH PLASTICITY (Liquid Limit 50 or more) | OH | Organic silts and clays of high plasticity, sandy organic silts and clays |
| PRIMARILY ORGANIC MATTER (dark in color and organic odor) | PT | Peat |
What’s the big deal about FILL?

FILL is soil that:

● was not deposited naturally
● has been placed in an uncompacted manner
● has variable engineering properties
● presents significant risk to the owner and design team
# Reading a Soil Boring Log

## SPT Test

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![Diagram of SPT test setup](image)

- **Crown sheave(s) or pulleys(s)**
- **Typically 1 inch dia manila rope**
- **Rotating cathead**
- **Doughnut hammer**
- **Slip or guide pipe**
- **Anvil**
- **Drill rod**
- **Ground surface**
- **18 inch**
- **Borehole**
- **30 inch fall**

**REMARKS**
# Reading a Soil Boring Log

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# Reading a Soil Boring Log

## Elevations and Water Level

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Reading a Soil Boring Log

Things to Look for

- Soil types
  - FILL
  - Organics
  - Soft Soils
- Boring location plan
  - Are there enough borings in the building footprint?
  - Are the borings deep enough?
    - Do they terminate in uncontrolled fill?
- Soil stiffness
  - SPT N values
  - Caving
- Where are your footings founded in relation to the soil layers?
- Groundwater
In-Situ Tests

Beyond the SPT

- CPT
- DMT
- Pressuremeter
- Vane Shear Test

Thoughts on limitations & state of the practice
In-Situ Tests

CPT

Cone Penetration Test (CPT)

\( f_s = \text{sleeve friction} \)

\( u_b = \text{porewater pressure} \)

\( a_n = \text{net area ratio (from triaxial calibration)} \)

\( q_t = \text{measured tip stress or cone resistance} \)

\( q_c = \text{corrected tip stress} = q_t + (1-a_n)u_b \)

1. Saturation of Cone Tip Cavities and Placement of Pre-Saturated Porous Filter Element.
2. Obtain Baseline Readings for Tip, Sleeve, Porewater Transducer, & Inclinometer Channels.

Continuous Hydraulic Push at 20 m/min; Add rod every 1 m.

Readings taken every 10 to 50 mm

http://geosystems.ce.gatech.edu/Faculty/Mayne/Research/devices/cpt.htm
In-Situ Tests

CPT
In-Situ Tests

A word about SPT and CPT

- **SPT**
  - provides a physical sample for visual logging and lab testing
  - numerous correlations
  - requires less interpretation
  - can get through dense layers and FILL more easily

- **CPT**
  - continuous logging
  - general idea of soil classification
  - information about pore pressure, seismic data
  - in-situ dissipation testing

Ideally, both are used on-site with one CPT adjacent to an SPT for correlation purposes
In-Situ Tests

Flat Dialtometer Test (DMT)

- Accurate measurement of soil strength and compressibility
- Provides direct measurement of deep foundation soil values
- Direct measurement of ground improvement results.

Credit: http://insitusoil.com/dilatometer-test/
In-Situ Tests

Pressuremeter Test (PMT)
► In-situ stress-strain relationship testing.
► Determine elastic modulus.
► Accurately design shallow foundations for settlement.
► Accurately determine pile horizontal and vertical capacity.

Louis Menard (researcher and early adopter) guaranteed foundations designs based on PME with $10,000,000 of professional liability insurance from Lloyds of London (Hartmann, 2008)
Deep Foundation Options

- Precast Concrete Piles
- H-Piles
- Ductile Iron Piles
- Micropiles
- Drilled Shafts (Caissons)
- Auger Cast-in-Place Piles
- Helical Anchors
Deep Foundation Options

Precast Concrete Piles

► Advantages
  ► Displacement
  ► High capacities possible
  ► Most economical by cost per lineal foot
  ► Manufactured in controlled environment
  ► Driven - so each pile is tested for capacity
  ► Mechanical splices
  ► Speed

► Disadvantages
  ◦ Large equipment
  ◦ Large laydown areas
  ◦ Vibrations and noise
  ◦ Obstructions
Deep Foundation Options

H-Piles

- Advantages
  - Minimizes displacement of soils during installation
  - Driven, so each pile is tested during installation.
  - High availability
  - High capacity in soils that are difficult to drive in (high n-value)
  - Speed

- Disadvantages
  - Obstructions
  - Splicing - welding
  - Equipment size
  - Noise/vibrations
Deep Foundation Options

Ductile Iron Piles

► Advantages
  ► Low vibration
  ► Close to adjacent structures
  ► Low headroom
  ► Fast (no splicing)

► Disadvantages
  ○ Obstructions
  ○ Lower capacity
Deep Foundation Options

Micropiles

Advantages
- High Capacities
- Obstruction avoidance
- Tight access
- Retrofit/repair
- Drill through weathered rock (karst)

Disadvantages
- Need casing for caving soils
- Slow
- Higher costs
Deep Foundation Options

Drilled Shafts

**Advantages**
- High Capacities
- High lateral capacities
- More likely to penetrate obstructions than driven piles
- Rock socket (local experience)

**Disadvantages**
- Need casing for caving soils/high groundwater
- Spoils (contaminated? )
- Slow
- No batter (lateral loads)
Deep Foundation Options

Auger Cast-in-place Piles

► Advantages
  ► High Capacities
  ► Low spoil generation
  ► Versatile for different applications.
  ► Lower vibration

► Disadvantages
  ○ Obstructions
  ○ Messy site
  ○ No batter (limited lateral)
  ○ Can “neck” in very soft soils
Deep Foundation Options

Helical Anchors

▶ Advantages
  ▶ High tension capacities
  ▶ Modular
  ▶ Ubiquitous
  ▶ Tight access
  ▶ Retrofit/repair

▶ Disadvantages
  ○ Capacity suspect
  ○ Too ubiquitous?
  ○ Plumbness
  ○ Obstructions are a concern
  ○ QC
  ○ Installation damage
Deep Foundations

Specifying Deep Foundations-

- Geotechnical Engineer can provide basic pile recommendations
  - diameter, range in depth, and capacity to be verified in load testing

- Design/Build Contractors can also provide value based on historic load test data

- Geotechnical Engineer should comment on
  - applicability for the site (obstructions, vibrations, adjacent structures, accessibility)
  - load testing (how many & type)
Ground Improvement Options

- Geopier Rammed Aggregate Piers
- Rigid Inclusions
- Rapid Impact Compaction
- Deep Dynamic Compaction
- Compaction Grouting
Ground Improvement Options

Geopier Rammed Aggregate Piers

▶ Advantages
  ▶ High stiffness
  ▶ Control settlement in soft or undocumented soils
  ▶ Increased/high bearing capacity
  ▶ Installed under the water table and in caving soils

▶ Disadvantages
  ○ Obstructions
  ○ Limited depths
  ○ Limited uplift & lateral
Ground Improvement Options

Rigid Inclusions

▶ Advantages
► High Capacities
► Address organic and very weak deposits
► Deep profiles
► Lower cost vs piles
► Low vibration
► Allows traditional spread footing and slabs

▶ Disadvantages
○ Higher cost than aggregate
○ Potentially messier
○ No batter (limited lateral)
○ Limited uplift
Ground Improvement Options

Rapid Impact Compaction

► Advantages
  ► Realtime data collection.
  ► Does not require the same size berth as Dynamic compaction
  ► Standard size equipment (e.g. no cranes)
  ► Can proof out large areas of site

► Disadvantages
  ○ Vibrations close to existing structures
  ○ Depth could be limited
Ground Improvement Options

Deep Dynamic Compaction

Advantages

- Deep improvement penetration
- Inexpensive
- Cover large areas in short periods of time.

Disadvantages

- Vibration and flying debris - 100 foot buffer
- Large equipment
- Large laydown areas
- Often requires post-treatment confirmation testing
Ground Improvement Options

Compaction Grouting

► Advantages
  ► High Capacities
  ► Increased depth range
  ► Can be completed in rock, tag into rock
  ► Compact equipment
  ► Can work in tight access areas

► Disadvantages
  ○ Construction risk - schedule and cost
  ○ Messy process
  ○ Slow process
Ground Improvement

Specifying Ground Improvement

- Most Geotechnical Engineers provide performance recommendations
  - Settlement limits, penetration of fill/organic layers are the most common
  - Geotechnical Engineer should review all design/build calculations for agreement with intent of the Geotechnical Engineering Report
  - Testing recommendations (how many tests, and pre- or post construction?)
Thank you.
Questions?

We would like to acknowledge Dave Kozera, PE (DW Kozera) and Stephanie Slocum, PE (Engineers Rising) for their help in preparing the introduction slides.