53:139 Foundation Engineering
The University of Iowa

Subsurface Soil Exploration

Motivation: The analysis and design of a structure's foundation is only as good as the engineer's knowledge of the subsurface soil properties.

- The geotechnical or foundation engineer must use all tools available to determine:
  a. What soils are present below the ground surface?
  b. How are they arranged: i.e. layer thicknesses; orientation of the layers; etc.
  c. Mechanical and transport properties of the soil: ϕ, c, E, ν, μ, p_c, C_s, C_c, k.
  d. Physical properties of the soil: e, n, w, S, D_r, G_s, GSD, classification, etc.
  e. Location of the water table, and its likely variations.
- Typical Cost of a Site Survey or Subsurface Exploration
  - Rule of thumb cost is approximately 0.1 – 0.5% of total project cost.
  - Locating a structure on an inappropriate site can jeopardize a whole project.
  - Overdesigning foundations due to uncertainties can be extremely wasteful.
  - Therefore, the moderate funds devoted to subsurface exploration are well spent.
- **Point of Departure:**
  - Your goal is form a three-dimensional picture or distribution of soil/rock types below the site of interest.
  - If you have some knowledge of what the picture already looks like, this can help. Therefore it may be useful to consult with people who already know.

- Geotechnical companies that have a history of experience in a given region usually have extensive boring logs and maps telling where the borings were taken.

In rural areas, well drillers also tend to have a fair idea of subsurface soil conditions.

State, university, and/or USGS geologists often have a pretty good idea about local subsurface geology and can tell you about local formations. Also, they can be of **extreme value** in interpreting any information that is generated during an engineering subsurface exploration. See the attached quote taken from the book: Application of Geology to Engineering Practice (this timeless old book is on reserve in the Engineering Library so that you can peruse it.)

> The attitude he maintains in his relation to the engineer is very well stated in his own words:
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> "It is the writers' belief, based on a great many years of observation, that neglect of geologic factors or inadequate study of them is a common fault in a majority of engineering undertakings. Many serious blunders may be traced to this as a fundamental cause." Again: "The writers do not assume to claim that a geological study is the cure for all difficulties. Neither do they assume to suggest that geologic opinion is to take the place of properly organized exploration. This is a mistake commonly made. It is just as extreme and unreasonable as the attempt to ignore the geologic factors. It is not unusual to hear engineers say that even if a geologist is employed explorations must still be made, as if that was some sort of legitimate reflection on the geologist and sufficient excuse for the engineer. Yet, that is exactly what should be done in the average engineering case. If he is properly competent, the geologist can indicate not only what kinds of explorations should be made, but also where they must be made to accomplish the most useful result in the most economical way. He should be able, also, if he is familiar with the needs of the engineer, to interpret the data observable in the field and obtained by exploration, more logically and more reliably than one who is not thus trained. The geologist, therefore, should not be regarded as a substitute for exploration, or an excuse for loose methods, but as an interpreter of geologic conditions, an aid in successful investigations, and a critical advisor in the matter of design, methods, and contracts that have to do with construction in the ground.
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> "The ideal situation is one in which the engineer, already comparatively well grounded in all the major features of the problem to be encountered, is still able to appreciate that a fuller or more critical study might materially improve the chances of success, or allow the design to be modified, secure more economical treatment or conduct the work on safer lines. Wherever this broad view is taken, and adequate consultation privileges are conferred on a competent, experienced geologist who appreciates the point of view and purpose of the engineer and will confine himself to the practical questions of the case, material service can be rendered in phases of the undertaking that cannot be reached in any other way."

Rules of Thumb for Conducting SSE's

- Rule of Thumb #1:

1) Estimate the maximum increase of vertical stress under a foundation with depth $\Delta\sigma_v(z)$.
2) Estimate the pre-existing vertical stress distribution $\sigma_v(z)$.
3) D_1 is the depth at which $\Delta\sigma_v = \frac{1}{10}q$, where q is the bearing stress directly under the foundation.
4) D_2 is the depth at which $\Delta\sigma'_v = 0.05\sigma'_v$
5) Choose $D_b = min\{D_1, D_2, z_{\text{bedrock}}\}$, where D_b is the depth of the borings to be performed.

- Rule of Thumb #2:

$$D_b = C \cdot S^{0.7}$$

D_b is the depth of boring in meters;
S is the number of stories in the structure being considered;
C is a coefficient:
  0.3 for light structures – 0.6 for heavy structures;

- Rule of Thumb #3:
  - If bedrock is encountered in a boring survey, you should usually bore to a depth of at least 3m into the layer to make sure of its integrity.

Field Borings:

- Quite simply, this is the drilling of shafts with power augers down into the soil. The soil at the changing bottom depth of the shaft is sampled.

- Records are made of each boring made, and these are called boring logs.
    - Often soil layer interfaces can be detected simply by noting a change in the auger's drilling rate, or sound.
- Soil samples obtained from borings are generally classified as either <u>disturbed</u> or <u>undisturbed</u>.
- Disturbed samples are usually obtained with Split Spoon Samplers. Tests performed on **disturbed** samples are:
    - GSD tests
    - Atterberg limit tests
    - Specific gravity measurements
    - Classification
    - others
    - If the soil can be realistically re-compacted or re-consolidated to its in-situ state, most all tests can be performed.
- Undisturbed soil samples are usually obtained with thin-walled Shelby Tube samplers. Tests performed on **undisturbed** samples are:
    - Triaxial compression tests
    - Unconfined compression tests
    - consolidation tests
    - permeability tests

The Split Spoon Sampler (SSS)

- Used to take disturbed soil samples from the base of a borehole, usually at 5 foot intervals

- Degree of disturbance of soil samples is quantified by:

$$A_r = \frac{D_o^2 - D_i^2}{D_i^2}$$

D_o is the outside diameter of the sampler (50.8mm)
D_i is the inside diameter fo the sampler (34.9mm)
For the split-spoon sampler, $A_R = 1.12$

- Soil samples are considered to be *undisturbed* when $A_R \leq 0.10$ Samples collected with the split-spoon sampler are thus *highly disturbed.*

The Standard Penetration Test (SPT)

- Since samples collected with the SSS are highly disturbed, soil testers usually do not perform strength tests on them directly.
- Nevertheless, the process of collecting the soil sample with a SSS can be used to estimate the soil strength.
- The Standard Penetration Test (SPT)

1. Drive the SSS 6 inches into the bottom of the borehole
2. Drive the SSS another 12 inches into the bottom of the hole and count N the number of blows required to drive the SSS the last 12 inches. [Each blow is a drop of a 623N (140lb) hammer a distance of 0.762m (30 inches).]
3. The N value can be correlated with the strength or consistency of the soil. In the following, q_u is the unconfined compression test of the clay.

Correlation of Clay Consistency with N

N	Clay Consistency	$q_u(kPa)$
0 – 2	very soft	0 – 25
2 – 5	soft	25 – 50
5 – 10	med. stiff	50 – 100
10 – 20	stiff	100 – 200
20 – 30	very stiff	200 – 400
30 –	hard	400 –

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- For frictional soils (sands, gravels, silty sands, etc), the strength of the soil increases with the effective overburden stresses σ'_v. The greater the depth of the soil, the greater σ'_v and the greater the strength of the soil will usually be (within some limits). Thus the greater the depth, the greater the N value usually is in the SPT. Thus the raw N value is not just a soil property, but also a depth property.
- Therefore we need to correct N for frictional soils.

$$N_{\text{corr}} = C_N \cdot N$$

N_{cor} is the corrected value of N for a σ'_v of 95.6kPa (2ksf).

N is the raw blow count value from the field.

- There are numerous possible formulae for computation of C_N:
  - The simplest is that of Liao and Whitman (1986):

$$C_N = [\sigma'_v]^{-\frac{1}{2}}$$

where σ'_v is in tons per square foot, or

$$C_N = 9.78[\sigma'_v]^{-\frac{1}{2}}$$

where σ'_v is in kPa

Correlation of Granular Soil Properties with N_{cor}

N_{cor}	Ave. ϕ	min ϕ	max ϕ	$\simeq D_r$ (%)
0	26	26	26	0
5	29	28	30	5
10	35	35	35	30
30	40	38	42	60
50	46	46	46	95

Undisturbed Sampling of Cohesive Soils

- Generally done with thin-walled Shelby Tubes
- Wall thickness ranges from 1.63mm to 3.25mm
  Length of tube, L, is typically 610mm.
- Outside diameter, D_o ranges from 51mm to 89mm.
- Example: Disturbed area ratio A_R for a thin-walled Shelby Tube:

$$A_R = \frac{51^2 - 49.3^2}{49.3^2} = 0.0702 \rightarrow \textbf{undisturbed}.$$

- Recovery Ratio:

$$L_r = \frac{\text{Actual length of recovered sample}}{\text{Theoretical length of recovered sample}}$$

  - $L_r = 1$ indicates a sample that is relatively undisturbed.
  - $L_r < 1$ indicates either: (1) that the sample compressed during pushing; or (2) that part of the sample fell out during extraction of the tube.
  - $L_r > 1$ suggests that the soil expanded or loosened.