Declining Lawn at Lychee Hills of SUSTech

Name:

Student ID:

1. Setup

The Landscaping Office of SUSTech has noticed the declining health status of the lawn at Lychee Hills. The president was mad about the undermaintained lawn that gradually turned yellow. So, the Landscaping Office has decided to repair. It was known the subsurface beneath the lawn is made of basically two layers - the topsoil that provides moisture and nutritions to the grass and a foundation of loose or consolidated Quaternary sediments. They doubt some yellow patches were caused by topsoils not thick enough, so an investigation on the **topsoil thickness** is necessary.

The Landscaping Office lacks expertise in such problems, so they reached out to the earth science department and asked if geophysics can help. The key information they would like to obtain is the thickness of the topsoil. If possible, they are also interested in the horizontal variability of the top soil layer. Here is a list of their wishes:

1. Estimate an average thickness of the topsoil and see if its overall quality meets the industrial standard
2. Evaluate the variability of thickness
3. Evaluate the uniformity of the topsoil layer
4. Be quick and cheap but with sufficient information for the follow-up repair

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Questions:

Those requirements are from the Landscaping Office. Do you think their expectations are realistic? Or how confident are you of solving those problems? Why? Provide your answers below. You may come back and revise your answers when you finish this worksheet.

Your answers:

1.
2.
3.
4.

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2. Properties

Geophysical methods only work if there is a contrast in physical properties.

Questions:

Please list at least three physical properties that you think may be used to distinguish a topsoil layer and the foundation. The topsoil is rich in organic matters and moisture, while the foundation is relatively less porous and less permeable. Also provide comments on whether these properties can be practically used in this project.

Your answers:

1.
2.
3.

In this worksheet, we concentrate on electrical conductivity, or its reciprocal electrical resistivity. Electrical conductivity is a bulk property of material that characterizes the ease that charge carriers flow through the material when an electrical force is applied. In conductive media, free charge carriers usually include ions and electrons. Pure water is resistive, but water in porous earth materials can dissolve salt in minerals and become ionically conductive. Naturally occuring free electrons are often found in metallic mineralizations.

Questions:

The following items are likely to be encountered at Lychee Hills. Please find their conductivity (or resistivity) values. Don't forget to attach the appropriate unit.

Your answers:

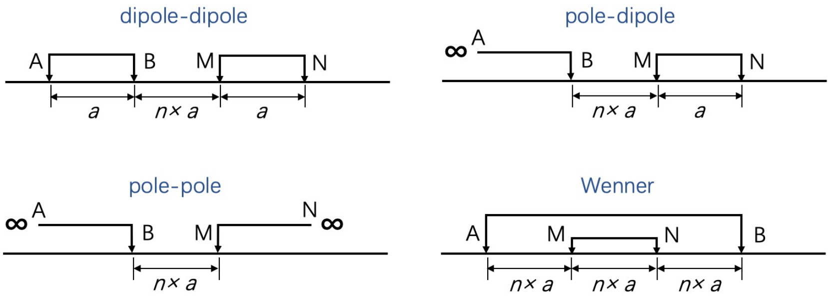
1. Air =
2. Water =
3. Soil =
4. Tills =
5. PVC pipes =

6. Steel pipes =
7. Concrete =

3. Survey

Electrical method, also known as dc resistivity, employs the similar procedure that measures the resistance using Ohm's law. An electrical survey system usually consists of four electrodes. Electrode A and B are current source electrodes, and M and N are potential measurement electrodes. During a survey, an electrical current is transmitted through A and B, and the potential difference between M and N is measured as data. Although it is possible to place the four electrodes at arbitrary locations, some typical inline electrode configurations are often used in practice to provide a sectional view of subsurface conductivity.

Below are four commonly used electrode arrays. All array types are specified by n-spacing and a-spacing. A small spacing has the advantage of higher lateral resolution near surface, while a large spacing can be used to reflect conductivity at depth. In a particular survey, the a-spacing can be fixed and n-spacing varies to achieve different depths of detection.



Questions

Modern electric survey instrumation installs a spread of electrodes in a constant spacing, then connects the electrodes to a switch box, where a computer program controls the electrodes to switch back and forth between the roles of the current electrode and the potential electrode. Suppose there are 10 electrodes (electrode number 1 ~ 10) along a line, please write an electrode scheduling table, in which each row represents one measurement datum and each column is the electrode number for A, B, M and N. You need to complete the electrode scheduling tables for the dipole-dipole, pole-dipole, pole-pole and Wenner arrays.

Your answers

Dipole-dipole data index	A	B	M	N
1				
2				
...				

Pole-dipole data index	A	B	M	N
1				
2				

Pole-dipole data index	A	B	M	N
...				

Pole-pole data index	A	B	M	N
1				
2				
...				

Wenner data index	A	B	M	N
1				
2				
...				

Questions

Electric survey shares a lot of similarities with the ideas in electronics and the circuit theory - think of a resistor circuit powered by a constant current source, your task is to infer the resistance of one or more resistors by measuring the potential difference between two juctions. Use this conceptual model to help you answer the questions below.

1. Is the potential difference measured by a dipole over a more conductive target higher or lower compared to the half-space reference? Why?
2. Is the potential difference measured by a dipole over a more resistive target higher or lower compared to the half-space reference? Why?
3. The same conclusions can also be obtained by the primary-secondary fields. Here, the primary field can be the status of a uniform halfspace, and the secondary field from the residual conductivity model. In the case of a more resistive anomalous object, is the direction of the secondary field the same as that of the primary or against?
4. The continuity condition of the current density implies additional electric charges can accumulate on the conductivity interface when electric currents cross the interface. Those charges are the source of the secondary field. If the currents enter a more resistive target from a more conductive background, which type of charges (positive or negative) can be generated on the interface?

Your answers

1.
2.
3.
4.

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4. Data

Apparent Resistivity

In practice we cannot measure the potentials everywhere, we are limited to those locations where we place electrodes. For each source (current electrode pair) many potential differences are measured between M and N electrode pairs to characterize the overall distribution of potentials. In a uniform halfspace the potential differences can be computed by summing up the potentials at each measurement point from the different current sources based on the following equations:

$$V_M = \frac{\rho I}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB}\right]$$
$$V_N = \frac{\rho I}{2\pi}\left[\frac{1}{AN} - \frac{1}{NB}\right]$$

where AM, MB, AN, and NB are the distances between the corresponding electrodes.

The potential difference ΔV_{MN} in a dipole-dipole survey can therefore be expressed as follows,

$$\Delta V_{MN} = V_M - V_N = \rho I \underbrace{\frac{1}{2\pi}\left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right]}_{G}$$

and the resistivity of the halfspace ρ is equal to,

$$\rho = \frac{\Delta V_{MN}}{IG}$$

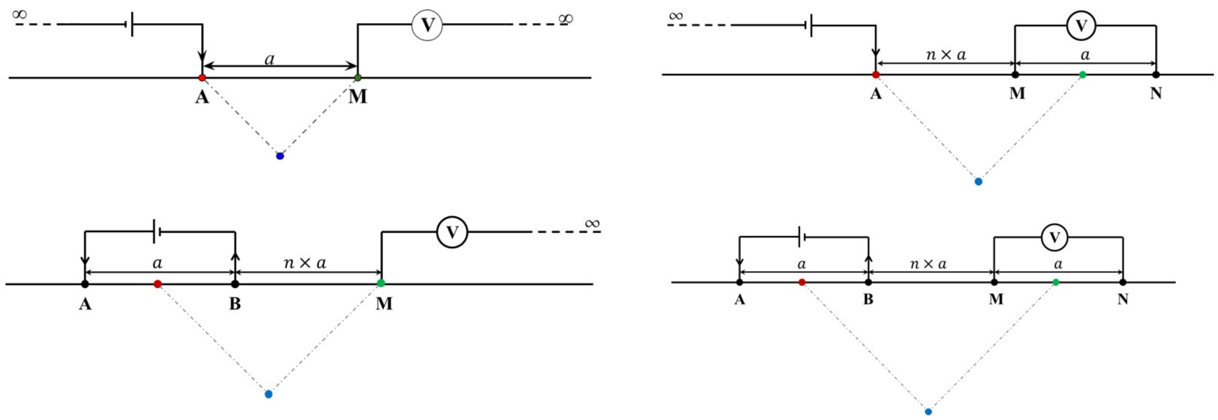
In this equation G is often referred to as the geometric factor.

In the case where we are not in a uniform halfspace the above equation is used to compute the apparent resistivity (ρ_a) which is the resistivity of the uniform halfspace which best reproduces the measured potential difference.

Pseudo-section

2D profiles are often plotted as pseudo-sections by extending 45° lines downwards from the A-B and M-N midpoints and plotting the corresponding ρ_a value at the intersection of these lines as shown below. For pole-dipole or dipole-pole surveys the 45° line is simply extended from the location of the pole. By using this method of plotting, the long offset electrodes plot deeper than those with short offsets. This provides a rough idea of the region sampled by each data point, but the vertical axis of a pseudo-section is not a true depth.

In the widget below the red dot marks the midpoint of the current dipole or the location of the A electrode location in a pole-dipole array while the green dots mark the midpoints of the potential dipoles or M electrode locations in a dipole-pole array. The blue dots then mark the location in the pseudo-section where the lines from Tx and Rx midpoints intersect and the data is plotted. By stepping through the Tx (current electrode pairs) using the slider you can see how the pseudo-section is built up. The figures below show how the points in a pseudo-section are plotted for pole-dipole, dipole-pole, and dipole-dipole arrays.



Water tank experiments

We have a water tank with a spread of electrodes on the wate surface. The electrodes are connected to a dc resistivity instrumrnt. There are predefined electrode scheduling tabls in the instrument. Learn the basic operation of the instrument and explore the pseudo-section data as responses to resistive and conductive anomnalous objects in the water.

Questions

Experiment with dipole-dipole and Wenner arrays.

1. How do you design experiments to answer the questions below?
2. Which survey type is more suitable for deep exploration?
3. Which survey type is good at resolving small features?

Your answers

1.
2.
3.

Lychee Hills data

Two datasets were acquired at the same location on the Lychee Hills lawn using dipole-dipole and Wenner arrays respectively. Specify the files you export from the instrument.

- __.xlsx : data file of the dipole-dipole array
- __.xlsx : data file of the Wenner array

Questions

Open the data files and understand the survey specifications. Write your own code to import the data and plot apparent resistivity pseudo-sections. You can use the template below, but remember to change the file names.

Your answers

In [ ]:

```
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
%matplotlib inline

# dipole-dipole array
df = pd.read_excel('T190424009.xlsx', sheet_name='DAT', header=0) # specify file na
df.describe() # show contents of data frame

# plot apparent resistivity pseudo-section
```

In [ ]:

```
# Wenner array
df = pd.read_excel('T190424015.xlsx', sheet_name='DAT', header=0) # specify file na
df.describe() # show contents of data frame

# plot apparent resistivity pseudo-section
```

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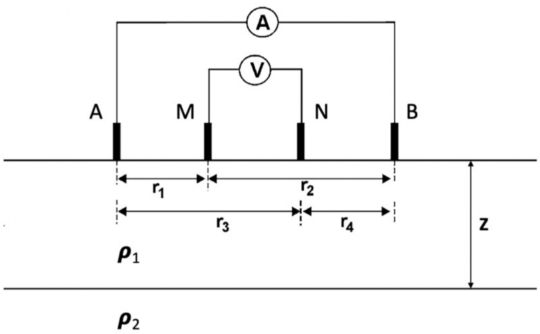
5. Processing

An analytic solution of a layered earth model exists for an arbitrary four-electrode array. In this exercise, we examine a two-layer model characterized by two resistivity values ρ_1 , ρ_2 and a thickness of the first layer z as shown below. The current and potential electrodes ABMN can be at any locations on the surface and their mutual distances are r_1, r_2, r_3 and r_4 respectively. According to Telford et al. (1990), the measured potential difference ΔV between M and N is shown in the figure below, where m is an integer sufficiently large.



$$\Delta V = \frac{I\rho_1}{2\pi}\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)+2\sum_{m=1}^{\infty}k^m\left\{\frac{1}{(r_1^2+4m^2z^2)^{1/2}}-\frac{1}{(r_2^2+4m^2z^2)^{1/2}}-\frac{1}{(r_3^2+4m^2z^2)^{1/2}}+\frac{1}{(r_4^2+4m^2z^2)^{1/2}}\right\}\right]$$

$$k = \frac{\rho_2-\rho_1}{\rho_2+\rho_1}$$

Questions

Make two funnctionss:

1. A function that calculates the potential difference data in a four-electrode electrical survey. The two resistivities, thickness of the top layer and the electrode locations should be adjustable.
2. A function that convert the calculated potential difference data to apparent resistivity values.

Your answers

In [ ]:

```
# function Potential Difference
```

In [ ]:

```
# function Apparent Desistivity
```

Questions

A simple method of validation is to assign the two layers the same resistivity (as a uniform half-space) and verify if the calculated apparent resistivity is the same as the assigned resistivity. Note the solution in the potential difference equation involves an infinite series. In practice, you must choose an m that is sufficiently large to achieve a stable and accurate solution. In the blank below, report the value of your choice and describe how you chose it.

Your answers

- Your m =
- Your reasons:

Questions

Use the program you made to calculate the electrical data from a two-layer earth model, in which the top layer is 1500 Ω·m and 10 m thick and the basement layer is 500 Ω·m. Here we consider four types of arrays: dipole-dipole, pole-dipole, pole-pole and Wenner as shown below. The arrays are specified by a-spacing (in meter) and n-spacing (integer). Calculate the potential difference and apparent resistivity for the four arrays based on the two layer model with a = 1 m and n varying from 1 to 20. Plot curves of **apparent resistivity versus n-spacing** for each type of array. And answer the following questions.

1. Which type of array has better resolution for the near-surface property? And how can you tell?
2. Which type of array has better depth of penetration with the least n-spacing (less expensive field operation)? And how can you tell?
3. Which type of array has the best balance between near-surface resolution and depth of penetration? And why?

Your answers

1.
2.
3.

In [ ]:

```
# Your code plotting curves of apparent resistivity versus n-spacing for each type c
```

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6. Interpretation

Now you have the codes that compute the potential difference of an electrical survey and the corresponding apparent resistivity for a two-layer model. Manually adjust the two-layer model to fit the Lychee Hills field data and make interpretation. Hint: a pseudo-depth versus apparent resistivity plot may be helpful.

Questions

What model (ρ_1 , ρ_2 , z) has the best overall fit to the field data? Support your claims with data and figures.

Your answers

-

In [ ]:

```
# Make plots to find the model that has the best overall fit to the field data
```

Questions

How do the thickness and uniformity of the topsoil vary along the survey profile? Support your claims with data and figures.

Your answers

-

In [ ]:

```
# Make plots to study the thickness and uniformity of the topsoil
```

7. Synthesis

Questions

1. What are the limitations of the two-layer model used in your interpretation?
2. Is the interpretation models you obtained compatible with your general expectation?

3. If a steel pipe is buried under the lawn, how would it impact the data and your interpretation?

Your answers:

1.
2.
3.

End of Worksheet

In [ ]:

```

```