Ground Subsidence Hazard at the Main Gate of SUSTech

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1. Setup

The construction office of SUSTech has reported that there is a potential of ground subsidence or even collapse at and near the main gate. Because the Dasha River passes by, the hydrological structure under the gate is subject to active groundwater movement. Strong groundwater flows may carry away sands and soils beneath the pavement, creating large air-filled cavities. As cavities gradually grow, the road surface may eventually collapse. This hazard threatens the safety of students and staff, so the university authority has decided to assess the situation and repair the road before a deadly collapse happens.

Initially the university staff was planning to dig or drill through the pavement to see whether there is any cavity. However, after some calculation, they realized that the cost would be too high to drill the entire area and any invasive operation on the road surface would significantly affect the traffic.

Alternatively, the university seeks help from geophysicists. They would like to obtain an estimate of the size and extent of the cavities uninvasively using geophysical detection methods. Here is a list of their wishes:

1. Determine whether any cavities are developing underground in front of the gate
2. How many cavities are there
3. Determine the horizontal position and depth of the cavities
4. Determine the size of cavities
5. Be quick and cheap but with sufficient information for the follow-up work

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Questions:

Those requirements are from the university administration, who are not expert of geophysics. 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.
5.

---

2. Properties

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

Questions:

Please list at least three physical properties that you think may be used to distinguish a cavity and the surrounding materials.

Your answers:

1.
2.
3.

One of the properties that we may want to use is **density** in the unit of kg/m^3, or more commonly g/cm^3.

Questions:

Please find the densities for the following geologic units with the help of Internet:

Your answers:

1. Air-filled cavity =
2. Water-filled cavity =
3. Soil =
4. Sedimentary rocks =
5. Igneous rocks =

The physics we use here is gravititional force between two objects, which is determined by their mass m_1, m_2 and their mutual distance r

$\mathbf{F} = G\frac{m_1 m_2}{r^2}$.

Suppose m_1 is a test object of unit mass and m_2 is a object with a uniform density ρ and a volume v, then the measurement of $\mathbf{F}$ at m_1 can be used to calculate the density ρ.

Questions:

How do you calculate the earth's average density using the formula above and the Newton's second law $\mathbf{F} = am$? Assume you live in the ancient time and you only know the acceleration of free fall on the earth's surface $g = 9.8m/s^2$ and the earth's radius 6371 km throught experiments. Compare your result with the density values in the previous question, and what is the implication?

Your answers:

-

We can move m_1 around, place it near different m_2 objects, and measure $\mathbf{F}$. Because m_1 has unit mass, the measurement is actually the acceleration g (gravity field), which can be used to infer the density variation among differnet m_2 objects.

Questions:

When the test mass moves from above regular soil to above a cavity, how would the direction and magnitude of $\mathbf{F}$ change?

Your answers:

1. Direction:
2. Magnitude:

---

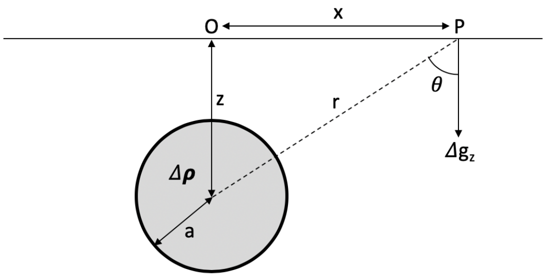
3. Survey

A simplified sphere model helps us understand the physics and desgin a gravity survey. Now, let's consider the cavity as a perfect uniform sphere buried in a uniform underground medium. If there is no sphere, the measured g is a constant. If a sphere exists, g varies. The deviation from the uniform constant is often referred to as "anomaly" (Δg). Most gravitometers can only measure the vertical (z) component of the gravity field, so in practical applications of gravity method, the data are Δg_z.

The interactive app below calculate Δg_z data on the surface along a line across a buried sphere.

- $\Delta\rho$: Density contrast defined as the density of the dike minus the density of the host rock (in g/cm^3)
- a: Radius of the sphere (in m)
- z: Depth to the center of the sphere (in m)
- $Step$: Spacing between measurements on the surface (in m)
- $G = 6.674 \times 10^{-8} cm^3 \cdot g^{-1} \cdot s^{-2}$ is the gravititional constant
- $r = \sqrt{x^2 + z^2}$ is the distance between the sphere's center and the observation point on the surface

$\Delta g_z = \frac{4Ga^3 z\Delta\rho}{3r^3}$ in mGal.



Questions:

- Understand the formula above and make a **forward modeling** code that calculates Δg_z anywhere on the surface from a sphere specified by the density contrast $\Delta\rho$, radius a and central depth z.
- Organize the code as a Python function, which takes the observation location, the sphere location, $\Delta\rho$, a and z as the input, and returns Δg_z as the output. Your function will be used later in this worksheet.

Your answers:

In [10]:

```
# Your code goes here
```

Questions:

Now you have the capability of calculating the gravity anomaly at a single station. It is time to do a **survey design** before heading to the field site. Suppose you carry out a survey along a line above the center of the sphere. Find the density properties from the previous questions. Use the function above to simulate Δg_z data for an air-filled cavity (radius 2 m, central depth 2 m) and make some plots. What is the peak value of the gravity anomalous field? What station spacing is needed to capture the peak of anomaly? Can this anomaly be reliably measured by gravitometers?

Your answers:

- Peak value:
- Optimal spacing:
- Gravitometer:

In [11]:

```
# Your code goes here
```

4. Data

A team of gravity survey was sent to the site. They collected Δg_z data over a 21 × 21 grid at a uniform spacing of 2 m. The data are provided below in plain text.

- Columns from left to right: X = 0 to 40 m, 2 m spacing
- Rows from top to bottom: Y = 0 to 40 m, 2 m spacing
- Data unit: mGal

In [12]:

```
# -0.156 -0.169 -0.173 -0.193 -0.199 -0.176 -0.198 -0.198 -0.179 -0.164 -0.137 -0.1
# -0.182 -0.188 -0.221 -0.208 -0.218 -0.229 -0.221 -0.202 -0.194 -0.194 -0.176 -0.1
# -0.198 -0.215 -0.237 -0.235 -0.264 -0.262 -0.253 -0.242 -0.226 -0.225 -0.206 -0.1
# -0.229 -0.220 -0.256 -0.282 -0.272 -0.276 -0.269 -0.262 -0.247 -0.235 -0.223 -0.2
# -0.227 -0.245 -0.280 -0.297 -0.313 -0.293 -0.316 -0.312 -0.282 -0.264 -0.240 -0.2
# -0.259 -0.277 -0.296 -0.309 -0.324 -0.333 -0.326 -0.314 -0.286 -0.264 -0.254 -0.2
# -0.244 -0.273 -0.318 -0.331 -0.342 -0.350 -0.356 -0.322 -0.326 -0.290 -0.254 -0.2
# -0.260 -0.285 -0.335 -0.348 -0.353 -0.356 -0.367 -0.353 -0.326 -0.298 -0.273 -0.2
# -0.284 -0.304 -0.307 -0.356 -0.370 -0.358 -0.350 -0.362 -0.301 -0.306 -0.261 -0.2
# -0.266 -0.291 -0.314 -0.330 -0.342 -0.369 -0.364 -0.356 -0.337 -0.280 -0.286 -0.2
# -0.246 -0.272 -0.295 -0.309 -0.345 -0.353 -0.337 -0.333 -0.296 -0.280 -0.261 -0.2
# -0.230 -0.256 -0.270 -0.300 -0.307 -0.326 -0.327 -0.294 -0.299 -0.260 -0.251 -0.2
# -0.215 -0.252 -0.244 -0.268 -0.283 -0.292 -0.273 -0.271 -0.264 -0.258 -0.243 -0.2
# -0.202 -0.210 -0.220 -0.256 -0.241 -0.248 -0.252 -0.255 -0.250 -0.228 -0.218 -0.2
# -0.184 -0.206 -0.203 -0.220 -0.214 -0.224 -0.220 -0.220 -0.220 -0.218 -0.205 -0.2
# -0.156 -0.184 -0.202 -0.195 -0.200 -0.198 -0.208 -0.192 -0.198 -0.185 -0.201 -0.2
# -0.137 -0.145 -0.153 -0.160 -0.178 -0.171 -0.167 -0.171 -0.182 -0.155 -0.179 -0.1
# -0.105 -0.122 -0.138 -0.146 -0.148 -0.136 -0.187 -0.173 -0.150 -0.157 -0.155 -0.1
# -0.104 -0.124 -0.108 -0.127 -0.132 -0.136 -0.133 -0.117 -0.131 -0.149 -0.130 -0.1
# -0.099 -0.096 -0.113 -0.104 -0.100 -0.117 -0.117 -0.113 -0.103 -0.105 -0.107 -0.0
# -0.091 -0.080 -0.092 -0.093 -0.111 -0.094 -0.102 -0.111 -0.095 -0.096 -0.095 -0.0
```

Questions:

Write a few lines of code to import the data above and visualize the gravity data:

1. A plan view (colored maps or contours)
2. Profile along survey lines

Your answers:

In [13]:

```
# Your code goes here

# Plan view

# Profile
```

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5. Processing

In order to better use the field data for interpretation, some data processing are required. In the following, we explore three processing methods that may be useful for gravity data.

1. Low-pass filtering
2. Regional removal
3. Inversion

Questions: Low-pass filtering

A low-pass filter removes the short-wavelength components from the data, so the data look smoother. It is often used to suppress strong data oscillation caused by noise. There are many different way of doing it. In the following, make a code of moving window averaging to smooth the noisy field data. Provide plots before and after the processing.

Your answers:

In [14]:

```
# Your code goes here

# figures before and after the low-pass filtering
```

Questions: Regional removal

Multiple objects in different sizes and at different depths can simultaneously contribute to the measured data on surface. Small and shallow objects have narrow and spiky data anomaly, whereas large and deep objects have wide and smooth data anomaly. For some applications that only concern near-surface problems, it is desired to remove the long-wavelength components from the data (aka "regional"). Make a code of regional removal to reveal the data variation that is more related to the shallow structure. Provide plots before and after the processing.

Your answers:

In [15]:

```
# Your code goes here

# figures before and after the regional removal
```

Questions: Inversion

Quantitative interpretations require the data to be converted to models specified by some model parameters. In this exercise, we paramerize the cavities as some air-filled spheres of different sizes and depth buried in a uniform earth. Your task is to find the sphere models that can reproduce the field data. In the following:

1. Superposition holds for gravity, so Δg_z from multiple spheres can be obtained by summing up individual responses.
2. Manipulate the sphere parameters so the predicted Δg_z response can best match the field data.

Your answers:

In [16]:

```
# Your code goes here

# Specify sphere parameters

# Do the calculation

# Plot the predicted data and field data
```

---

6. Interpretation

With the results from **Processing**, you can now carry out **Interpretation** that links plots, numbers and models to geology.

Questions:

How do smoothing, regional removal and inversion help you answer the questions in **Setup**?

Your answers:

- Smoothing:
- Regional removal:
- Inversion:

---

7. Synthesis

We have just finished one iteration of the 7-step procedure and some preliminary results have been obtained for the ground subsidence problem at SUSTech. Do you think the problems on the wishlist in **Setup** have been solved? It is time to go back to **Setup** and revise your answers.

Questions:

At this step, we may consider the following questions:

1. Are your data processing and interpretation stable and reliable? Alternative processing or interpretation results?
2. Are data acquisition good enough to support the final results? (coverage, noise, spacing, etc.)
3. Can your results be confirmed by other methods?
4. Provide one location for the first drill.

Your answers:

1.
2.
3.
4.

End of Worksheet

In [ ]: