Lab 1: Introduction to Gravity

Purpose

The purpose of this lab is to introduce you to the use of a gravimeter and to familiarize you with a simple gravity survey and the collection of data. A survey will be done in MSEC to determine the free-air correction by measuring the gravitational acceleration at different elevations.

Introduction to gravity

The acceleration of gravity is not constant across the surface of the Earth. The differences are causes by the varying densities of sub-surface rocks, location on the surface (such as your latitude) and the elevation (which is the distance from the center of the Earth). The acceleration due to gravity can be expressed by combining Newton's Law of Gravitation with Newton's second law of motion.

Newton's law of gravitation

$$\mathrm{F} = \frac{\mathrm{GMm}}{\mathrm{R}^2}$$

where G is the gravitational constant ($\mathrm{G} = 6.67 \times 10^{-11}\ \mathrm{Nm^2kg^{-2}}$), M is the mass of the Earth, m is the mass of the object and R is the distance between the masses.

Newton's second law of motion

$$\mathrm{F} = \mathrm{mg}$$

where m is the mass and g is the acceleration. Solving for the acceleration due to the Earth gives

$$\mathrm{g} = \frac{\mathrm{Gm}}{\mathrm{R}^2}$$

Gravity is usually measured in units of *Gal* ($1\ \mathrm{cm/s^2}$) (named after Galileo). The variations measured in gravity are usually quite small so measurements are made in mGal (10^{-3} Gal) and μGal (10^{-6} Gal).

As mentioned above, the value of grvity is affected by both the shape of the Earth and its rotation. The rotating Earth is not a perfect sphere, but rather a flattened ellipse, bulging at the equator. The centrifugal acceleration due to the rotation also causes the gravitational acceleration to be less at the equator where this force is greatest. A formulation was developed to calculate the theoretical acceleration at a given geographic latitude relative to that at sea level. This formula is known as the Geodetic Reference System 1967 (GRS67) and is given by:

$$g_\phi = 9.78031846(1 + 0.005278895 \sin^2 \phi + 0.000023462 \sin^4 \phi)$$

where ϕ is the latitude. The constants in front of the $sin\ \phi$ terms depend of the degree of flattening of the Earth and the speed of rotation.

Gravimeters

There are a few different types of gravimeters used, but most are based on the principle of measuring the amount some type of spring has stretched due to an increase in gravitational acceleration. Gravimeters fall into two main catergories: stable (static) and unstable (astatic). Stable gravimeters were developed in the 1930's and are based on the simple design of measuring the movement of a mass supported by a spring. The more sophisticated unstable gravimeters have been used much more extensively than the stable type. These gravimeters do not measure a movement in mass but rather restore the position of the mass using a micrometer. In general, measurements with these types of gravimeters have accuracies of 0.01 mGal.

Gravity measurements and corrections

Gravimeters do not measure the absolute value of gravity, but rather relative changes in gravity. The dial reading for each measurement needs to be multiplied by the instrumental dial constant to provide the relative gravity in mGals. In order to interprete the gravity measurements in terms of the geology of the survey area, various corrections need to be applied to the data. These include correcting for instrumental drift, tides and elevation (which includes the free-air correction and Bouguer correction). The gravity anomaly is determined by taking the difference between the observed measurements and the theoretically calculated value (GRS67) for that location. Once the corrections have been applied and the gravity anomaly determined, the data can now be interpreted in terms of subsurface properties.

Experiment

In order to determine the free-air correction, you will use a gravimeter to make measurements on different floors (elevations) in MSEC. A Worden gravimeter will be used for this survey.

Worden Gravimeter

This type of gravimeter uses a quartz glass spring insulated in an evacuated flask rather than a metal spring making it easier to reduce thermal effects. This type of gravimeter is very sensitive to vibrations and thus must be handled and transported carefully. The gravimeter is read by aligning a light beam with cross-hairs on the eyepiece. The beam is moved by tensioning a zero-length spring to compensate for the changes in gravitational acceleration.

Procedure

- Plan out your survey: which floors you will measure and where, how many measurements per location, location of the base station, etc.
- Do the survey - record the data, making sure you include: time of each measurement, station location, elevation, dial reading and anything else you feel is relevant
- Measure the distances between floors (you can do this either before or after making the measurements)
- Use your data to determine with instrumental drift and the free-air correction

Instrumental drift

The base station readings will be plotted as a function of time. The correction to be applied to the readings is determined by fitting a line to the data and determining the slope.

$$\mathrm{g_{corrected}} = \mathrm{g_{measured}} - \mathrm{t}(\frac{\mathrm{g}}{\Delta \mathrm{t}})$$

where $\frac{g}{\Delta t}$ is the slope of the line and t is the time (in seconds). The time of the first reading at the base station should be set equal to zero.

Free-air correction

After you have corrected the measurements for drift, plot the gravity measurements as a function of elevation (height). Fit a line to this data and determine the slope, which is the experimentally determined free-air correction or gradient. The theoretical value is 0.3086 mGal/m. What are some of the reasons why your experimental value is different from the theoretical value?

Lab report

A written report will be required for this lab. Include a brief description of the purpose of the survey, the experimental procedurem, the data and results and any relevant conclusions. You writing will as be graded. As this is the first lab, grading will be very reasonable.