ESS 136A, Lab 3
Gravity
Due Tuesday, January 26th 17:00

In this lab you will learn to measure the gravity on each floor of the geology building. You will need to record the measurements, time, and height of the building on each floor. These measurements will be used to determine the mass of the earth. Due to **COVID19**, the video instruction (Lab3Video.mp4) and measurements (gravity_data_2021_Tuesday.csv) are directly provided to you. Follow the guidelines outlined on the last page to write-up and turn in your lab report. UCLA reading: approximately 3188 (Geology building first floor)

Introduction

We are going to use a Lacoste Romberg Gravimeter. The gravimeter is a relatively simple machine. Contained inside is a mass attached to a beam hinged to the side of the container. The height of this mass is dependent upon a spring attached to an adjusting screw. This spring has a known spring constant that is dependent upon temperature. Because of this, the gravimeter must be kept at **52 degrees Celsius**. Over the course of the experiment, the spring will droop causing error in the readings. This error is known as **drift** and can **be corrected** for by having a base station which is returned to throughout the experiment.

To use a gravimeter, one must first make sure it has been on for at least a day, then use the three screws to level it out on whatever surface it is placed upon. After leveling, unlock the spring, turn on the light and look into the eyepiece. Turn the numbered dial until the needle inside **just touches the left of the 2.5 mark** in the eyepiece. It is important that you always come from the left when you do this to have the most accurate reading. Once the needle is in the correct place, read the first 4 numbers from the odometer-like display and get the tenths' and hundredths' place values from the numbered dial. You should now have a value with six significant figures for the gravity in that location.

There is a light switch on the right side of the box that must be flipped on in order to see the readout inside the eyepiece and that must be switched off before the gravimeter is put away. After the reading, the gravimeter must be locked and returned to its box.

Raw readings from the gravimeter in counts of themselves are not useful for determining geologically useful information without some data analysis. Conversion of the raw gravimeter readings into the System International units of milligalileos (hereafter mGal, or 10^{-5} m/s^{2}) makes the results comparable to other surveys, as well as valid over large changes in gravity force. The conversion table is provided in the Appendix.

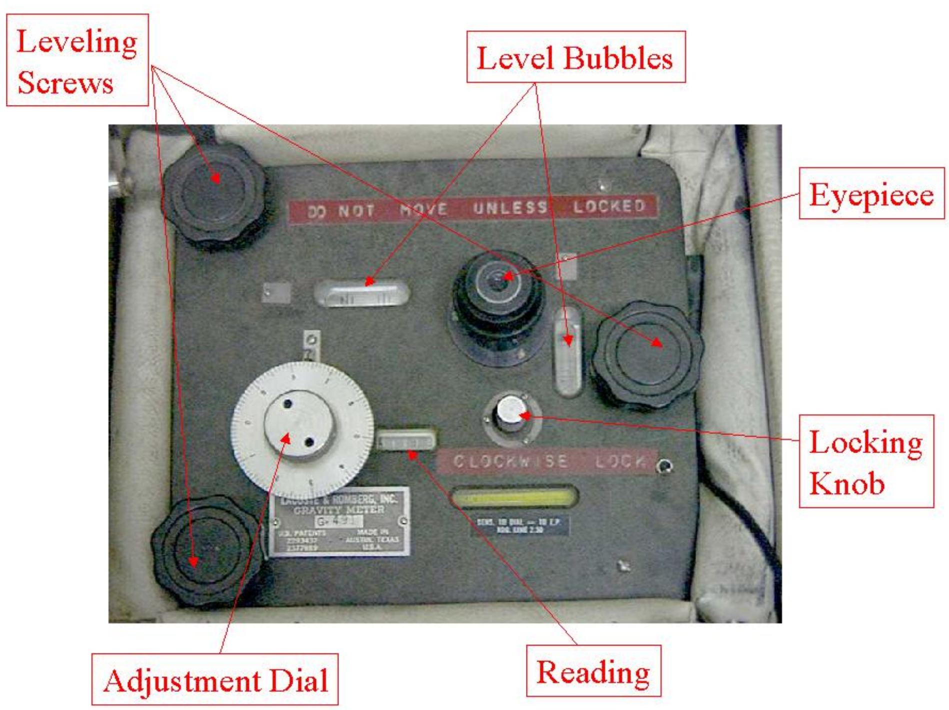
Drift correction is done to correct for changes in the instrument (perhaps due to the spring becoming warmer or colder), and for background changes in the gravity field such as due to the effect of the tides. An interpolation between known base stations is done to approximate for what the expected drift is at the times when the readings were taken.

Latitude correction deals with the fact that the Earth is not a perfect sphere, and it is rotating in space. Latitude correction deals with the differences in forces at different latitudes due to the angular momentum of the Earth's spin as well as the slight bulge at the equators relative to the poles. For simplicity sake, we use a Cartesian coordinate system, so we also convert from the latitude/longitude system.

Free air correction deals with the decrease in gravity due to increase or decrease from the center of the Earth. **Bourguer correction** deals with the increased gravity due to the increased (or decreased) mass of material due to elevation changes. Together these two corrections take out the changes in the gravity field due to elevation differences.

By applying all of these corrections the raw gravity can be converted into something that reflects the changes in the rock density at depth.

<u>Free air, Bouguer, Latitude, and Drift corrections are explained in Mussett & Khan (2000)</u>



Part 1

Fill in the following table with data collected during the experiment:

Floor	Gravity Measurement 1 (counter reading)	Gravity Measurement 2 (counter reading)	Time (seconds)	Floor Height (Meters) *
1 (Base Station)				0 m
2				
3				
1** (Base station)				
4				
5				
6				18.5 m
1** (Base Station)				

*Each floor ~3.7 m

**Do not use the last two base station measurements in your calculations for the mass of the Earth. These are only used to correct for drift!

Part 2

Calculate the gravity in mgals using the conversion factor table (provided in the Appendix). And example of how to do the conversion is provided on the back of the page.

Fill in the following table with your conversions:

Floor	Gravity 1	mgals conversion	Gravity 2	mgals conversion
1 (base)				
2				
3				
1 (base)				
4				
5				
6				
1 (base)				

Part 3 Plots

Note: You can either select one column of data, or use the mean values at each floor.
1) Using Python or Excel, plot the gravity (counter reading) vs. the relative elevation. (i.e. you want gravity on the y axis and height on the x axis.)
2) Plot the gravity (mgals) vs. the relative elevation.

Part 4 Drift

In any gravity survey the data needs to be corrected for drift. The drift correction will account for internal changes in the gravimeter, as well as changes in the earth tides. In a day long survey you should take a base station measurement approximately every 2 hours.

Plot the drift of the base stations (gravity converted to mgals) vs. time. Shift all of your time measurements by the same amount such that your first time measurement is zero. Find the slope of the curve (hint: Matlab has a function to do this for you. Type "help polyfit" to see how to do this).

The correction for drift is:

Drift $(\Delta t) = m*t+c$ = (Slope)*(time)
c is set to zero
t is the time of survey measurement [which we have already adjusted so that the 1st base station time is set to zero i.e., t=(survey measurement time)-(1st base station measurement time)}

Correct the data for drift, and fill in the table. (For those of you already familiar with Matlab, note that you could also use interp1.m for this correction).

Floor	1	2	3	4	5	6
Gravity1						
Drift Correction						
Gravity 2						
Drift Correction						
Notes						

Plot the gravity data corrected for drift vs. the relative elevation. Is the drift correction small enough to be ignored?

Part 5: CALCULATION OF THE MASS OF THE EARTH

The objective is to use gravity readings at different heights above the Earth's surface to calculate the mass of the Earth.

From Newton's law of gravity we have

$$g = \frac{GM}{r^2} \qquad (1)$$

where $G = 6.67 \times 10^{-11}$ $\frac{m^3}{s^2 kg}$.

M = the Mass of the earth = 5.9724×10^{24} kg.

r = the distance from the center of the Earth 6371000 m.

<u>DATA</u>

In class we measured *g* at different heights in the geology building to obtain relative *g* with respect to the first floor. Let the relative heights be *dr* and the relative changes in *g* be *dg*.

Equation (1) has to be modified to give relative *g* (i.e. *dg*) and relative heights (*dr*).

The easiest way to do this is to differentiate equation (1) with respect to *r*.

$$\frac{dg}{dr} = -2\frac{GM}{r^3} \qquad (2)$$

which can also be written as

$$dg = -2\frac{GM}{r^3}dr \qquad (3)$$

Let us assume that the distance from the center of the Earth to the basement of the geology building is r = 6371000 m. Then *dr* is the height difference between the first floor and all subsequent floors, and *dg* is the relative gravity change at each floor. Note that because *r* is considered constant, equation (3) is the equation of a straight line with slope = $-2\frac{GM}{r^3}$.

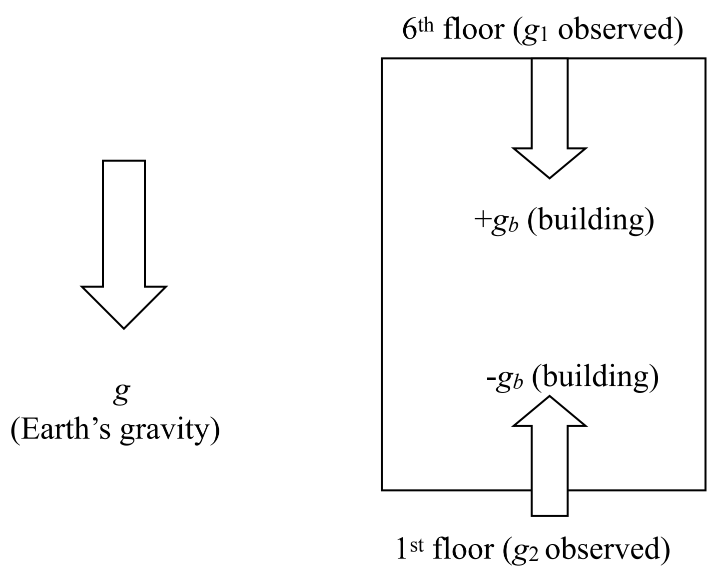
**Note: please be careful not to include the last 2 base station measurements in the *dg* slope. Only include the floor readings in your *dg*.

Plot *dg* versus *dr*.

Question 1. Calculate the mass of the Earth M using equation (2). Note dg/dr is simply the slope of the line from your previous plot.

Note: If you use SI units in equation (2) you get dg in m/s^2, but your data is in mGals. The conversion is: 1 mGal = 10^{-5} m/s^2.

Question 2. Thus far, we have assumed that the concrete of the geology building has had negligible effect on the readings, i.e., the gravity meter was moving vertically in free air. (This is the free air gradient referred to in lecture). However, as we successively move up each floor, the mass of the floors below us lie between the instrument and the datum. Therefore we have not measured a pure free air gradient in gravity as given by equation (2), which means that we need to account for the additional mass of the building. Furthermore, when we are on the 1st floor we have the additional mass of the building above us pulling upward, in the opposite sense of the Earth's force of gravity. Then, as we move up successive floors, more and more mass is being added below us. In order to correct for this, we can treat each floor as a slab of mass and add the slabs together as we move up each floor in the building. Finally, at the top of the building we have the entire weight of the building pulling downward, in the same direction as the force of gravity. The following diagram illustrates this concept:



On the first floor the observed gravity will be decreased by the effect of the mass of the building pulling upward, and on the 6th floor the observed gravity will be increased by the mass of the building pulling downward. This implies that we have two separate equations for the gravity observed on the 6th floor, g_1, and on the 1st floor, g_2:

1st floor: $g_2 = g - g_b$
6th floor: $g_1 = g + g_b$

Therefore the change in gravity is:

$\Delta g_{obs} = g_2 - g_1 = (\text{-H}) * \Delta g(\text{free air gradient}) - 2g_b$

This implies that your free air gradient is:

$\Delta g(\text{free air gradient}) = (\Delta g_{obs} + 2g_b)/(\text{-H})$ (Note here the free air gradient is negative)

To estimate the gravity contribution of the building we will use the Bouger correction. Assume that the effect of each floor is the same as that of a thin infinite horizontal slab 0.3 m thick of density ρ = 2700 kg/m^3. (This is a crude approximation, but will give a reasonable answer.)

$$g_b = 2 \pi G \rho t \qquad (4)$$

$\pi = 3.14159$
ρ = density
t = thickness of slab

Note: When calculating thickness don't forget there are **5 floors** between 1st and 6th floor that we need to consider(i.e. 5 slabs).

Plug this into the previous equation and you will obtain the (corrected) free air gradient.

Question 3. Use the free air gradient to solve for the mass of the Earth. Use equation (2) with your Δg to approximate the free air gradient , dg, and the height of the building as dr. How does your mass calculation compare with the value you obtained in Question 1 and values listed in text books?

Lab Report

You are expected to hand in a lab write up that consists of the following sections. This will be a **short** write-up but be clear and concise in each of the following sections:

Cover Page (5%)

Choose an appropriate name for your study. An example of a seismic survey on Mars might be the 'Mars Global Seismic Survey'. Include your name, department, school and department address at the bottom of the page.

Abstract (10%)

This is a brief summary of the report. It should include a short statement of the objective of the experiment, the findings, and conclusions. It should be centered and single spaced.

Introduction (10%)

This section should explain where you are doing the study, what you hope to find, and what techniques are you using .

Equipment and setup (15%)

Describe the equipment used (schematic diagrams are useful), and how the experiment is set up. Do this in such a way that someone (who has never used a gravimeter) could duplicate your experiment using your description. You can find a Gravimeter manual over here for more technical details: gravG530_manual.pdf on CCLE website week 3.

Theoretical Analysis (35%)

Describe the tables and graphs used to draw your conclusions. List and explain any formulas used. In this section you should make clear that you understood the theoretical concepts in the book. You need to follow the instructions given in Part 1 through Part 5.

Conclusions (20%)

Discuss the results you obtained. Discuss the plots and the mass calculations obtained. What were the mass calculations obtained? How did the Bouger correction change the mass calculations? How accurate do you think these results are (i.e. discuss Question 3 in the mass calculation section)? What suggestions do you have for future scientists working in that area? Or what would be the next step if you were to go back?

Include your plots and data with the report. You should reference your plots as figures in the report.

Bibliography (5%) Text reference, etc.

Appendix

Table 1 - Milligal Values for Lacoste & Romberg, Inc. Model G Gravity Meter #G-530

Counter Reading	Value in Milligals	Factor for Interval
000	0.00	1.02702
100	102.70	1.02693
200	205.40	1.02689
300	308.08	1.02689
400	410.77	1.02691
500	513.46	1.02695
600	616.16	1.02702
700	718.86	1.02707
800	821.57	1.02708
900	924.28	1.02706
1000	1026.98	1.02704
1100	1129.69	1.02703
1200	1232.39	1.02706
1300	1335.10	1.02708
1400	1437.80	1.02715
1500	1540.52	1.02721
1600	1643.24	1.02727
1700	1745.97	1.02733
1800	1848.70	1.02738
1900	1951.44	1.02743
2000	2054.18	1.02747
2100	2156.93	1.02751
2200	2259.68	1.02755
2300	2362.43	1.02759

2400	2465.19	1.02763
2500	2567.96	1.02767
2600	2670.72	1.02770
2700	2773.49	1.02774
2800	2876.27	1.02776
2900	2979.04	1.02778
3000	**3081.82**	**1.02780**
3100	**3184.60**	**1.02782**
3200	**3287.38**	**1.02783**
3300	**3390.17**	**1.02783**
3400	3492.95	1.02784
3500	3595.73	1.02785
3600	3698.52	1.02785
3700	3801.30	1.02783
3800	3904.09	1.02780
3900	4006.87	1.02776
4000	4109.64	1.02772
4100	4212.41	1.02767
4200	4315.18	1.02760
4300	4417.94	1.02754
4400	4520.69	1.02747
4500	4623.44	1.02740
4600	4726.18	1.02733
4700	4828.91	1.02722
4800	4931.64	1.02702
4900	5034.34	1.02694
5000	5137.03	1.02678
5100	5239.71	1.02661

5200	5342.37	1.02642
5300	5445.01	1.02623
5400	5547.64	1.02603
5500	5650.24	1.02582
5600	5752.82	1.02560
5700	5855.38	1.02537
5800	5957.92	1.02510
5900	6060.43	1.02482
6000	6162.91	1.02452
6100	6265.36	1.02420
6200	6367.78	1.02387
6300	6470.17	1.02349
6400	6572.52	1.02312
6500	6674.83	1.02270
6600	6777.10	1.02229
6700	6879.33	1.02183
6800	6981.51	1.02140
6900	7083.65	1.02093
7000	7185.75	(value not provided on sheet)

**Note: Right- hand wheel on counter indicates approximately 0.1 milligal. 4/9/1979