GEOPHYSICS

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CHAPTER 1: GRAVITY METHOD

Gravitation:

Due to the Earth's lack of perfect homogeneity, the value of gravity (g) varies across its surface. This non-constant magnitude of gravity is influenced by five factors: latitude, elevation, topography of the terrain, Earth's tides, and density variations in the subsurface

Principles:

Newton's law of gravity: If there are two objects with masses M and m separated by a distance of R, then the force F between them is given by:

$F = GMm/R^2$

Where G = gravitational constant = 6.67 * 10^-11 $N.m^2 / kg^2$

Acceleration due to gravity g is defined as

$g = GM/R^2$

$g_1 = g_0 (1 – 2h/R)$

g_1 = gravity at height h above the surface

$g_2 = g_0 (1-h/R)$

g_2 = gravity at depth h to the Earth surface

Units of Gravity:

The CGS unit of gravity at the Earth's surface is milligal. Gravity unit(gu) is defined by µm/s2.

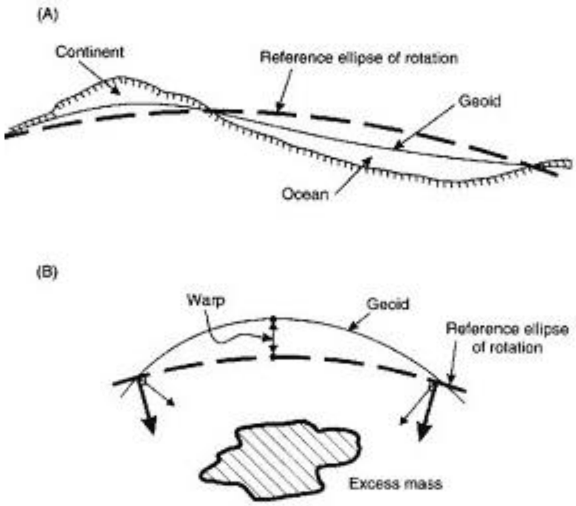
1mgal= 10gu

Shape of the earth:

By studying the gravitational field of the Earth, a gravity survey can be used to determine the Earth's shape. The shape of the Earth is approximately spheroidal, with a bulge at the equator and flattening at the poles. To approximate the mean sea level, a reference spheroid is used, which takes the form of an oblate ellipsoid.

Geoid:

The geoid is a surface that approximates mean sea level and is defined by an equipotential surface where gravity is constant. Unlike the reference spheroid, the geoid is influenced by local variations in mass. This means that over continents, the geoid may show an upward warp due to attracting masses, while over oceans, it may show a downward warp due to a lack of mass. Therefore, the geoid and the reference spheroid do not coincide.

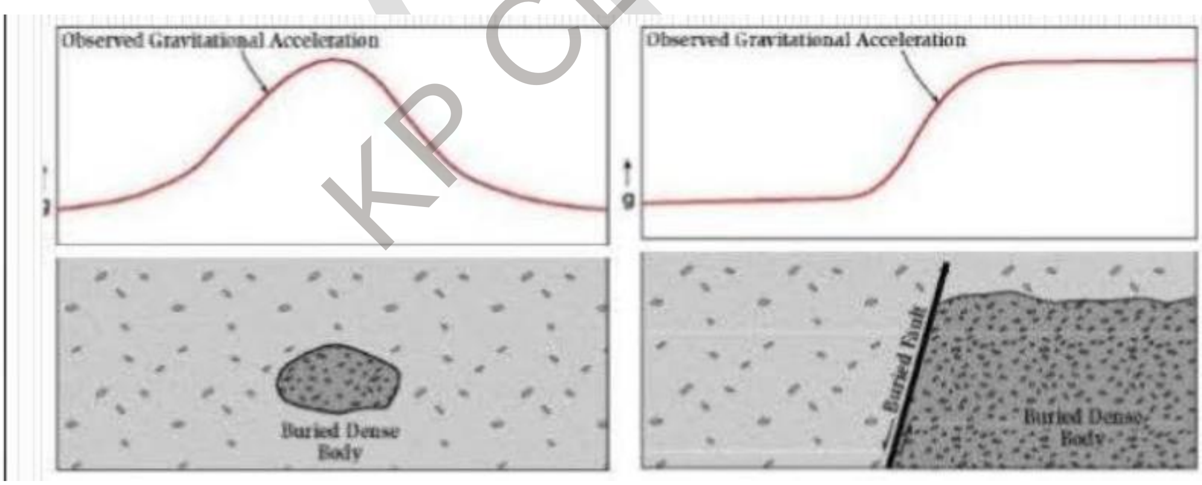


Relationship between Gravity & Density of rock:

Gravity methods detect only lateral contrast in density of rocks. Gravity anomalies are computed by a subtracting a regional field from the measured field. This results in gravitational anomalies which correlate with the source body density variation.

Shallow high density bodies give positive gravity anomalies whereas negative gravity anomalies are associated with shallow low density bodies.

High density minerals include Chromite, Barite, Hematite etc & low density minerals are Halite, Salt dome and weathered kimberlite body.



Methods and Corrections:

Drift correction:

Drift correction or instrument drift is associated with gravity variation which are only due to gravimeter readings. This changes caused by mechanical, thermal and electrical changes in the instrument.

During surveys, it is difficult to monitor drift with the same gravimeter. Therefore, repeated measurements are taken by returning to a base station and the change in gravity due to drift is recorded.

Latitude correction:

Gravity value varies with geodetic latitude from equator to polar region is given by

$g = g_0 (1+ \alpha \sin^2\lambda + \beta \sin^2 2\lambda)$

Gravity at Pole = 983218.6 mGal

Gravity at Equator = 978032.7 mGal

Difference between pole and equator is 5186 mGal.

The reason behind gravity is more at Pole , not at equator are

The distance to Centre of mass of the Earth is shorter at the poles than at equator giving rise to an excess gravity of 6600 mGal at Pole.

Effect of the centrifugal force diminishes gravity at the equator giving rise to an excess of gravity of 3375 mGal at Poles.

A latitude correction is required to apply where there is any appreciable North- South difference of gravity stations.

It is obtained by differentiating the international gravity formula

$g_L = 0.811 \sin 2\lambda$ mGal/Km

At 45^0 latitude the correction is maximum.

Free air correction:

Gravity varies inversely with the square of the distance. Free air correction does not take into account the material between the station and the datum plane.

Free air correction added when the station is above the datum plane and it is subtracted when the station is below the datum plane.

Free air correction (F.A.C) is given by the formula:

F.A.C = 0.3086 h mGal/ m

F.A.C at0^0latitude = 0.3067 mGal/m

F.A.C at 45^0latitude = 0.3086 mGal/m

F.A.C at 90^0 latitude = 0.3093 mGal/m

Bouguer correction:

In this correction the material between the station and the datum plane takes into account.

This is a first order correction to account the excess mass lying in between the station and the datum plane.

The correction is added when the observation point is below the datum plane and it is subtracted when the station is above the datum plane.

Bouguer correction is given by the formula :

g_b= 0.04193 ρh mGal
ρ= average density of the material
h= elevation

Elevation correction:

Elevation correction is the combination of free air and Bouguer correction.
This correction is applied as the same way as the free air correction.

Terrain correction:

Terrain correction is accounts for the variation in topography at each observation point.
Terrain correction is added to the measured gravity in both mountain and valley case. Therefore it is always positive.

Tidal correction:

To record the changes in gravity due to tides instruments are used.
Tidal correction is necessary when the effect of sun and moon is not detected in drift correction.

Etovos correction:

When gravity is measured in moving vehicles this correction is necessary.
Etovos correction is mathematically expressed by
$EC = 75.03 \sin \alpha \cos\phi + 0.0415 V^2$
Where EC = Etovos correction in gravity unit (gu)
α= vehicle heading
Φ= latitude
V = speed in knots

Gravity anomalies:

Introduction:

Difference between corrected, measured and theoretical gravity values is called anomaly.
Anomalies are computed by a subtracting a regional field from the measured field which results in gravitational anomalies that correlate with the source body density variation.
Positive gravity anomalies are associated with shallow high density bodies whereas negative anomalies are associated with shallow low density bodies.

Free air anomaly& Bouguer anomaly:

The free air anomaly is computed by

F.A.A = $g_{obs} - g_t + (g_L + g_{FA} + g_T)$

The Bouguer anomaly is given by

B. A = $g_{obs} - g_t + (g_L + g_{FA} - g_B + g_T)$

Gravity anomaly across mountain chain, ocean ridge and at subduction zones:

Across mountain chain gravity anomaly is negative due to large low-density root zone and Bouguer anomaly is strongly positive over an ocean ridge.

At subduction zone, beneath Andes mountain large negative Bouguer anomaly and positive Free-air anomaly is observed. Besides, a strong positive free-air anomaly is observed between Andes and the shore line of Pacific Ocean due to subduction of Nazca plate beneath South America.

Trench shows negative free-air anomaly due to mass deficiency of the water and sediments.

Instruments:

Stable type:

In stable type gravimeter mass is supported by a spring. The mass is moved with small changes in gravity against the restoring force of the spring. The change in gravity is measured.

The sensitivity of the instrument is defined by

$g = 4\pi^2 s / T^2$

T= time period

If the time period is large, variation of gravity takes considerable time. The factors that effect the sensitivity of instrument are temperature, pressure, magnetic and seismic variations.

Gulf gravimeter is a example of stable gravimeter.

Unstable type:

Advantage of using this type of gravimeter is the additional negative restoring force that is opposite to the restoring force of spring .

The sensitivity is larger than the stable gravimeter and they are in unstable equilibrium so they are called as unstable type.

These are null instruments as their linear range is smaller than the table type. The followings are the examples of unstable types.

Lacoste & Romberg gravimeter:

This is a zero-length spring indicating the tension is proportional to the actual length of the spring.

This instrument is used in a constant temperature condition.

The sensitivity is 0.01 mGal.

Worden gravimeter:

The sensitivity of Worden gravimeter is 0.01 mGal.

It is a small and light weight instrument which is less sensitive during changes in temperature and pressure.

Applications:

1. Mostly used for locating subsurface hydrocarbon reservoirs, lithology, geological structures, mineralized deposits and groundwater.
2. To determine shape and size of the earth.
3. Used to understand the interaction of hydrosphere and atmosphere.

Some important formulas:

Gravity anomalies over uniform sphere

$g_{max} = 4/3\ \pi\ G\ (\Delta\rho R^3/Z^2)$

Where g_{max} = gravity anomaly

G = gravitational constant

Δρ = density contrast

R = radius of the sphere

Z= depth to the center of the sphere

Z = 1.3 * half -widths

Gravity anomaly for horizontal cylinder

$g_{max} = 2G\ (\ \Delta\rho\ R^2\ /\ Z\ )$

Where g_{max} = gravity anomaly

G= gravitational constant, R = radius

Z= depth to the center, Δρ = density contrast across the body

Z = half-width

Gravity anomaly for vertical fault

$g_{max} = 2\ G\Delta\rho h\ (\pi/2 + \tan^{-1}(x/Z))$

Δρ = density contrast across the body

Multiple choice questions

Previous year easy questions

1.Which one of the following is only a correction and not a reduction in the computation of gravity anomalies with respect to a datum? (GATE 2019)

a)Free air b) Bouguer

c)Terrain d) Isostatic

2. The geoid can be best defined as (GATE 2018)

a)an oblate spheroid that best approximates the shape of the earth.

b)a surface over which the value of gravity is constant.

c)the physical surface of the earth.

d)an equipotential surface of gravity of the earth.

3. Which one of the following corrections is always added during reduction of the observed gravity data? (GATE 2018)

a)Latitude b) Free-air

c) Bouguer d) Terrain

4. normal gravity formula is a function of (GATE 2017)

a)Geocentric latitude b)Geodetic latitude c)Longitude d)Altitude

5.According to Airy's model, gravity anomalies for fully isostatically compensated topography are characterized by (GATE 2016)

a)negative Bouguer anomaly and positive free-air anomaly.

b)positive Bouguer anomaly and negative free-air anomaly.

c)zero Bouguer anomaly and negative free-air anomaly.

d)positive Bouguer anomaly and zero free-air anomaly.

6.The shape of the Earth is best described by (GATE 2015)

a)Spheroid b)Prolate ellipsoid

c)Ellipsoid d)Oblate spheroid

7. The International Gravity Formula predicts the theoretical gravity value at a given point assuming a (GATE 2014)

a)non-rotating homogeneous spherical earth model

b)rotating inhomogeneous spherical earth model

c)rotating homogeneous oblate spheroidal earth model

d)rotating inhomogeneous oblate spheroidal earth model

8. The acceleration due to gravity, 'g' is maximum at (GATE 2013)

a)equator b) poles

c) mid-latitudes d) sub-tropical regions

9.Bouguer correction is applied to correct for the gravity anomaly due to mass between station location and (GATE 2012)

a)mean sea level b) local datum plane

c)base of upper crust d) Mohorovicic discontinuity

10. Earth's reference spheroid (NET JUNE 2018)

a)coincides with the geoid in the oceanic region

b)coincides with the geoid in the land region

c)is below the geoid in the oceanic region

d)is above the geoid in the oceanic region

Previous year difficult questions

1.The gravity value measured over a 1.0 km thick elevated land mass is found to be smaller than the normal gravity value by 310 milligals. Which of the following statements is TRUE ? (NET JUNE 2018)

a)The level of isostatic compensation of the land mass cannot be ascertained due to inadequate data

b)The land mass is isostatically undercompensated

c)The land mass is isostatically overcompensated

d)The land mass is isostatically compensated

2.As one travels towards the north, the Earth's normal gravity field on the surface (NET JUNE 2017)

a)decreases everywhere

b)increases everywhere

c)increases in India, but not in Australia

d)decreases in Australia, but not in India

3. Elevated land masses are associated with (NET JUNE 2017)

a)negative Bouguer anomalies always

b)positive Bouguer anomalies always

c)positive Bouguer anomalies for undercompensation and negative for overcompensation
d)negative Bouguer anomalies for over compensation and positive for undercompensation
4. Compared to that on the surface, the Earth's gravity field at the core-mantle boundary is (NET JUNE 2016)
a)the same b)higher
c)about 50% d)about 25%
5. Elevated land masses undergoing subsidence are associated with strong (NET JUNE 2015)?
a)-ve isostatic and +ve Bouguer anomalies
b)-ve isostatic and -ve Bouguer anomalies
c)+ve isostatic and -ve Bouguer anomalies
d)+ve isostatic and +ve Bouguer anomalies
6.Which one of the following statements correctly depicts the variation of the gravity field inside the Earth ? (NET DEC 2018)
a) Increases in the lower mantle, but decreases sharply in the outer core
b) Increases in the lower mantle as well as in the outer core
c) Decreases in the lower mantle as well as in the outer core
d) Decreases in the lower mantle, but increases sharply in the outer core

7. Which one of the following is CORRECT ? (NET DEC 2018)
The plumb line used by a mason gets oriented perpendicular to the
a)spheroidal surface and passes through the Earth's centre
b)spheroidal surface, but does not pass through the Earth's centre
c)geoidal surface and passes through the Earth's centre
d)geoidal surface but does not pass through the Earth's centre
8. A geophysicist travelling from the Bay of Bengal through the Ganga plain to the Himalaya, estimates the depth of Moho discontinuity. Which one of the following is the correct order of the Moho-depth estimates? (NET DEC 2017)
a)Bay of Bengal > Ganga plain > Himalaya
b)Himalaya > Ganga plain > Bay of Bengal
c)Ganga plain > Bay of Bengal > Himalaya
d)Ganga plain = Bay of Bengal = Himalaya
9. On a rotating spheroidal Earth, its gravity field increases from the equator to the poles. On a non-rotating spheroidal Earth, the gravity field (NET DEC 2015)
a)remains constant on the Earth's surface
b)decreases from the equator to the poles
c)increases from the equator to the poles
d)decreases up to a latitude of $45^0$and then increases towards the poles
10.An elevated land mass attaining isostatic (NET DEC 2015)
a)is always uplifted
b)always undergoes subsidence
c)is uplifted in the case of over compensation and undergoes subsidence otherwise
d)undergoes subsidence in the case of over compensation and is uplifted otherwise