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Determination of Subsurface Bulk Density Distribution for Geotechnical Investigation using Gravity Technique

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Abstract

Gravity survey was carried out to determine the sub-surface spatial bulk density distribution for geotechnical investigation. The survey involves the determination of station coordinate (Lat, Long and height) and observed gravity. Gravity measurements were made in survey loops using LaCoste & Romberg gravity meter, starting off at known base station and ending at the same base station. Seven station locations were spread out across the survey area in order to get good range of vertically (rather than horizontally) spaced stations. Corrections were carried out to obtained bulk density that truly represents the subsurface geology across the area, such corrections are terrain, drift and tidal corrections. Two methods were investigated to determine the bulk density. The Nettleton's and Parasnis' methods, the bulk density values obtained from the methods were (2.6g/cc±0.2329) using the Nettleton's method and (2.5919g/cc±0.9612) using Parasnis' method respectively. The bulk density values obtained were inferred to be crystalline/consolidated sedimentary rocks which would be suitable for geotechnical construction purposes.

Keywords: Bulk Density, Tidal correction, Sedimentary, Gravity survey and Geotechnical.

1 Introduction

Geophysical exploration methods exploit the fact that as lithology varies, so do the physical properties of the rock concerned. One of the physical properties

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exploited in this work; is the rock density, using gravity exploration method. Here the object is to determine the spatial variation in the acceleration due to gravity (small g) which depends on the mass (density and volume) of the rocks underlying the survey area. Density is a scalar quantity (has only magnitude, not direction). This makes the shape of gravity anomalies simpler and generally easier to interpret than magnetic anomalies (Fairhead, 2009). Density boundaries tend to be associated with: porosity changes, faults, unconformities, basin edges or basin floor, limestones, dolomite or evaporite occurrences, salt occurrences and major lithologic boundaries (Fairhead, 2009). Therefore gravity survey method determines the sub-surface spatial distribution of rock density which causes small changes in the earth's gravitational field strength. The survey was carried out across the Yorkshire valley with the aim to determine the subsurface spatial bulk density distribution for construction purposes.

2 Data Acquisition

The survey involves the determination of station coordinates (Lat, Long and height) and observed gravity data. Equipments used for the survey are: Lesser leveler system, gravity meter, dish, small tripod, tape and an Abney level. The gravity measurements were made in survey loops using LaCoste & Romberg gravity meter starting off at known base station (98138429mGal) and ending at the same base station (98138429mGal). Seven station locations (Fig.1.0) were spread out across the valley in order to get good range of vertically (rather than horizontally) spaced stations. At each station including the base station the information recorded were: Station name or number, Station location, time of measurement to nearest minute, two measurements of gravity meter reading to repeat to 0.01mgal, Height of ground under gravity meter plus height of meter dish above the ground and measure the variation of the terrain about each station. Figure 2 shows the topography of the surveyed stations across the valley.

3 Data Processing

Inorder to obtained true bulk density that represent the subsurface geology, series of corrections where carried out on the datasets as follows:

- **Terrain correction:** (i.e. topography surrounding the measurement site). Estimate of terrain correction are made partly at each measuring site and in the laboratory with the aid of topographic map. These are done by estimating the mean height difference between the gravity station and the centre of each segment of zones, an Abney level is used to speed the process.

- **Drift correction:** Instrument drift, the 'loop' survey method is able to monitor the time dependent variation due to earth gravitational tides as well as physical changes to the spring system in the gravity meter. Drift can be determined and corrected directly for; if the survey starts and finishes at the base station and the time of each measurement is noted.

- **Tidal correction:** The earth's gravitational (or solid earth) tides are predictable and can be calculated using a computer programme. After taken all corrections into account and well computed the resulting variation in gravity data are: Free air anomaly and Bouguer anomaly. These anomaly types are interrelated.

3.1 Free Air Anomaly (FAA) Determination

The Free Air Anomaly **(FAA)** is given as:

FAA = **gobs - gth** + Free air correction **(FAC).**

Where:

- **gobs** = Vertical component of gravity measured with gravity meter (observed gravity).
- **gth** = Theoretical or normal value of gravity at sea level at measuring site (sometimes called latitude correction). This correction removes the major component of gravity leaving only local effects (**gth** = $978031.8(1+0.0053024\sin 2\theta - 0.0000058\sin 22\theta)$ mgal).
- **FAC** is the correction for height above sea level (**FAC** = $0.3086h$); where h is the height of the station above sea level in meters.

3.2 Bouguer Anomaly (BA) Determinations

The Bouguer Anomaly (BA) is given as: **BA = Free air anomaly - Bouguer correction + Terrain correction.** Where; (Bouguer correction = $2\pi G\rho h$ = $0.04191\rho h$) in mgal and $\boldsymbol{\rho}$ is density in g/cc. Two methods were investigated to determine the bulk density across the survey area. These methods are the Nettleton's and Parasnis's methods.

4 Nettleton's Method

The calculate Bouguer anomaly values at each station along the gravity profile for an assumed density (Fig.3). If the density is less than the bulk density of the rocks making up the topography then the Bouguer anomaly profile will have a positive correlation with the topography (if density = 0 the maximum positive correlation since now BA = Free air anomaly). The converse is true; if density is higher than bulk density then there will be a negative correlation. Thus a zero correlation occurs when density = bulk density. Thus just by plotting the same profile with range of different densities you can 'eyeball ' the approximate density (Fig.3). A more precise estimate of density can be determined by calculating the Correlation Coefficient (Fig. 4).

5 Parasnis's Method

Rearranging the Bouguer Anomaly (BA) equation we get:

(gobs - gth + 0.3086h) = ρ (0.04191h - T) + BA.

This equation is in the form of a straight line **(y = mx +C),** where the slope is density **ρ**. This assumes that the **BA** is a constant subject to random error. This will be the case if the assumption on the regional gradient is correct. Figure 5 shows the result of the Parasnis's method.

6 Labels of Figures

Figure 1: Stations location and Coordinates across the survey valley

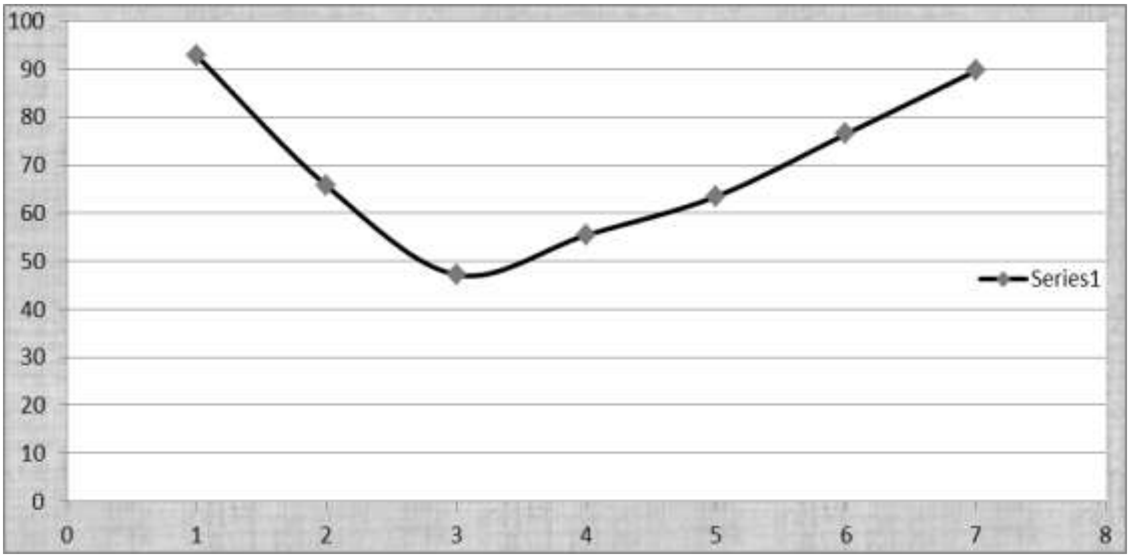

Figure 2: Topography across the survey area (Height (m) Vs Stations location.

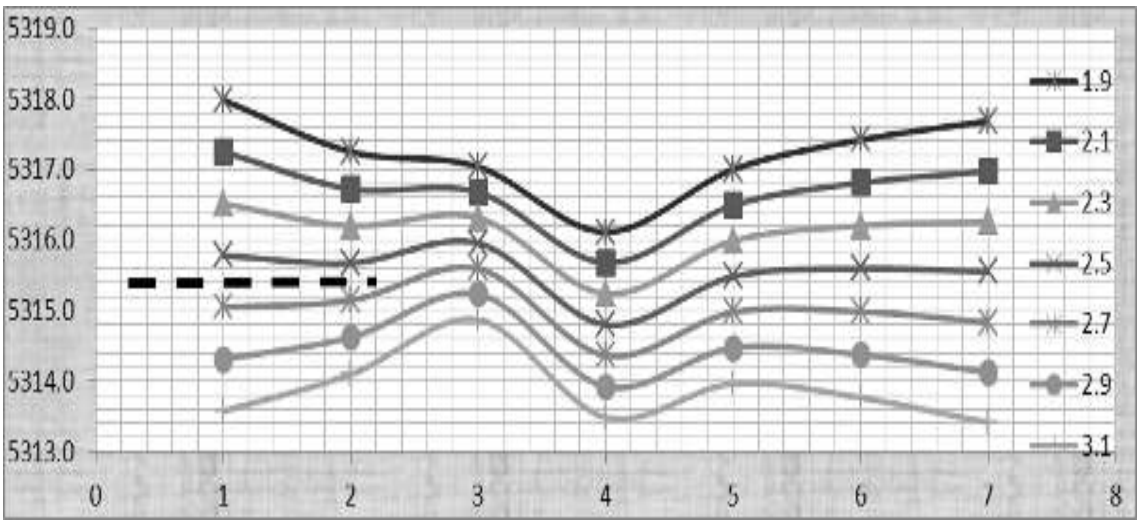

Figure 3: Nettleton's profiles (Bouguer anomaly of different densities).

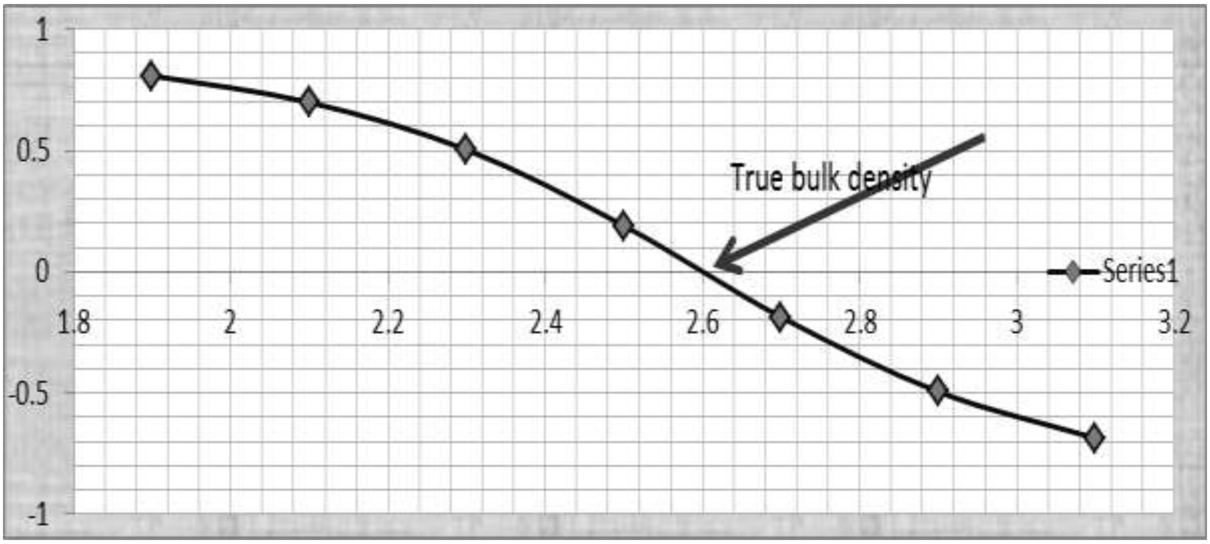

Figure 4: Correlation Coefficient against ranges of densities.

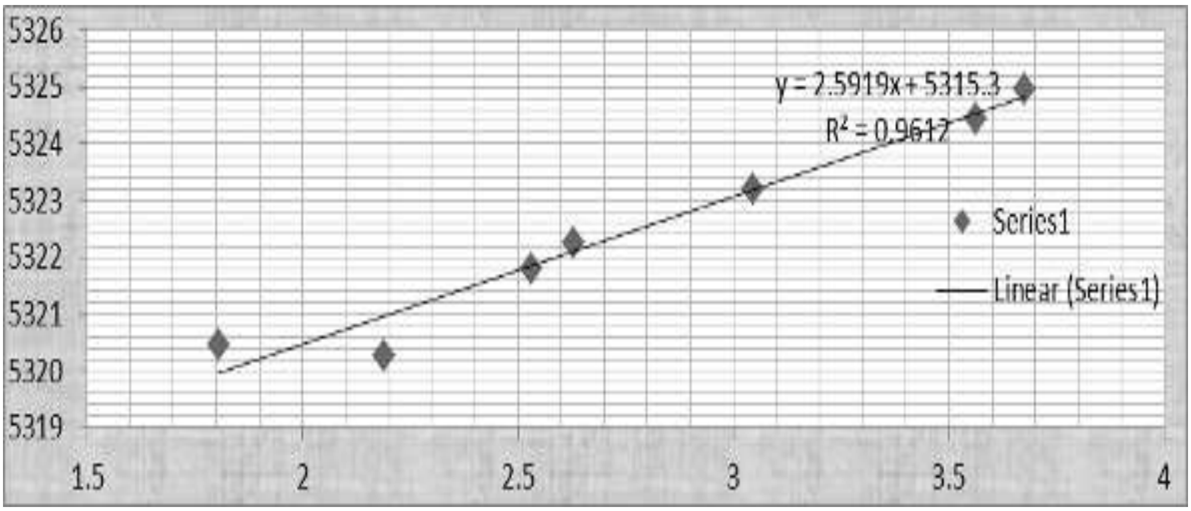

Figure 5: Regression analysis: (gobs - gth + 0.3086h) against (0.04191h - T).

7 Summary and Conclusion

The bulk density results obtained from the Nettleton's method (26g/cc±1.2329) and Parasnis's method (2.5919g/cc±0.9612) agree with each other. The slightly difference in the density values obtained, are due to human error and instrumental error couple with environmental factors such as tides. The Parasnis's method is more preferable because the bulk density value was computed through regression analysis of the observed gravity data. In conclusions based on the bulk density values obtained we suggest that the sub-surface spatial distribution of rocks density across the area are crystalline/consolidated sedimentary rocks which would be suitable for geotechnical engneering purposes. This paper demonstrated a procedure for determining subsurface bulk density distribution for a any gravity survey method.

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