Application of geophysical method for determination of sink hole in limestone formation

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Abstract

Kinta Valley is underlain by a limestone bedrock made up of voids and pinnacles. Sink holes are a common phenomenon in limestone formations which could affect the serviceability of buildings or infrastructures. PWD Malaysia conducted a forensic investigation on a reported case of sink hole that had occurred at one of a school block located in Ipoh where a hole of approximately 15 meters in diameter and 2 meters in depth had appeared on the ground surface. A microgravity survey was adopted to ascertain the existence of a cavity underneath the structure and its extent.

For data acquisition of the microgravity survey, a CG-5 Autograv gravity meter was used. The Autograv is a microprocessor-based automated gravity meter that has a measurement range of over 8000 mGals without resetting and a reading resolution of 0.001 mGal. Readings were taken at 36 points located in a 6-point-by-6-point grid with 5 meters spacing. 2 lines of resistivity tests were also carried out to estimate the location and depth of the cavity and 2 boreholes were bored to determine the soil profile, with one bored along one of the resistivity lines.

The result of the microgravity survey reveals a distribution of cavities within the project site. The resistivity analysis estimates the depths of these cavities to up to more than 20 meters. This finding was supported by borehole data showing the presence of clay at the locations of the cavities. This suggests that the cavities acted as underground pathways to channel water, depositing clay as the channels dried up.

Keywords: Geophysical survey, Subsurface, Soil investigation

1. Introduction

A geophysical survey was conducted on 14-15 July and 27 September 2021 at Ipoh, Perak with the objective to delineate possible subsurface cavity within the study area at Block D, SMK Dato' Ahmad Said. The scope included an interpretation of microgravity and 2-Dimensional Electrical Resistivity Imaging (2D-ERI) to characterize the subsurface. A cavity would create an anomaly due to the density contrast between the cavity and compacted soil. Microgravity survey was chosen as it is widely used to locate cavities. According to Samsudin (2003) and Ibrahim et al (2004), this method is one of the best ways to detect subsurface cavities. 2D-ERI was used for detailed 2D subsurface profiling of the area.

1.1 Scope of Work

The scope of work of the microgravity survey is to identify subsurface density distribution information; produce microgravity maps with interpretation on impact towards engineering concern; and produce 2D-ERI section for subsurface profiling of the study area.

2. Methodology and Instrumentation

2.1 Microgravity Measurements

Microgravity is a geophysical method that measures minute changes in the force of the earth's gravity. With modern equipment and careful field procedures it is now possible to measure gravity changes as small as 1 part in 1,000,000,000. Changes in gravity measured at the earth's surface reflect the underlying geological structure, hence the accurate determination of gravity leads to an understanding of the ground beneath. Microgravity is an accurate and reliable method for detecting underground cavities, both natural and manmade.

A microgravity survey is based on measuring localized variations in the earth's gravitational field using an extremely sensitive gravity meter. A microgravity survey targets physical contrasts between materials of contrasting density. Typical targets for microgravity surveys include low density targets such as voids, abandoned mine-working basements, while high density targets igneous, shallow rock and buried walls or foundations.

2.2 Instrumentation

For data acquisition of a microgravity survey, a CG-5 Autograv gravity meter was used for this work as shown n Figure 1. The Autograv is a microprocessor-based automated gravity meter that has a measurement range of over 8000 mGals without resetting and a reading resolution of 0.001 mGal. This enables the Autograv to be used for both detailed field investigations and large scale regional or geodetic surveys. Accurate measurements are taken by pressing a key and under most conditions it takes under one minute to complete the reading. A series of readings of gravity measurements can be performed by setting the Autograv in the auto repeat mode.

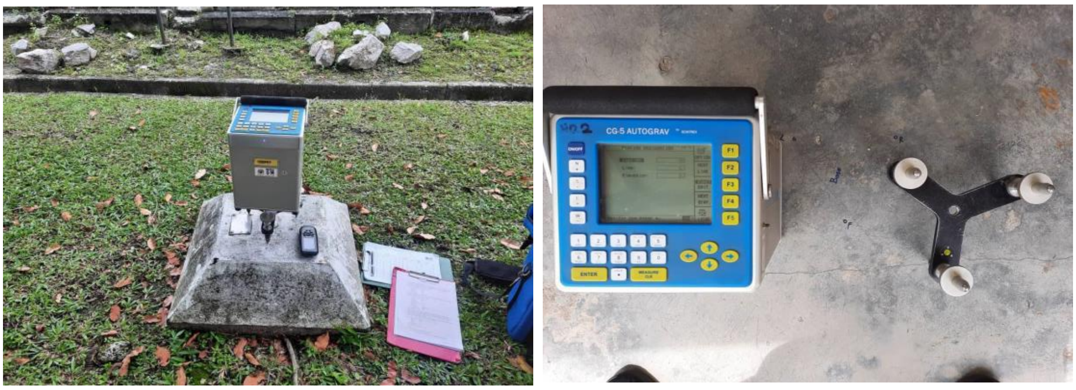

Figure 1: CG-5 Autograv gravitymeter (left) and gravitymeter tripod positioning (right)

The Autograv obtains a reading by continuously averaging a series of 6 Hz samples. The individual readings are displayed directly in mGals. The gravity sensor, control system and battery are integrated into a single instrumentation housing, which doubles as a carrying case. This eliminates the need for packing and unpacking the sensor between readings. Stability is increased and the risk of an accident is reduced by the absence of an external cable between the battery and sensor. The mounting system which indexes the Autograv onto the tripod further increases instrument stability. When setting the Autograv up for a reading, the software-based tilt sensors provide greater accuracy and are easier to operate than conventional bubble levels. The gravity meter displays the outputs from the sensors on high resolution meters on the ¼ VGA display. The gravity base station was tied with the gravity base station located at the state Minerals and Geoscience Department (Jabatan Mineral dan Galian, JMG) Malaysia, Ipoh.

2.3 Data Interpretation Technique

Microgravity is a geophysical potential field method. The gravity method depends mainly on the differences in the density of the earth’s materials. The variations of densities of subsurface rock for example, produce variations in the measured gravity field. Table 1 shows some common materials with their average density values. A GPS measurement should be associated with gravity measurements in order to know the exact coordinates (longitude and latitude or Easting and Northing) of the gravity stations and their altitudes. The microgravity survey method involves making several mathematical corrections to the measured date to correct for: the elevation of the measurement point, the spatial location of the instrument with respect to the earth, the density of the surface material, the tides, and the surrounding topography. The measured gravity data is then processed by removing all the quantifiable disturbing effects and interpreted using computer programs. The most highly processed data is known as Bouguer anomaly and it is measured in units of mGal.

2.4 Application of 2D Electrical Resistivity Tomography (2D-ERI)

The resistivity method basically measures the resistivity distribution of the ground subsurface materials. Table 1 and 2 show the resistivity values of some typical rocks, soils and waters (Keller and Frischknecht, 1996). Igneous and metamorphic rocks typically have high resistivity values. The resistivity of these rocks is mainly dependent on the degree of fracturing. Since the water table in Malaysia is generally shallow, the fractures are commonly filled with groundwater. The greater the fracturing, the lower the resistivity value of the rock. As an example, the resistivity of granite varies from 5000 ohm-m in wet condition to 10,000 ohm-m when dry. When these rocks are saturated with groundwater, the resistivity values are low to moderate, from a few ohm-m to less than a hundred ohm-m.

Soils above the water table are drier and have higher resistivity value of several hundred to several thousand ohm-m, while soils below the water table generally have resistivity values of less than 100 ohm-m. In addition, clay has a significantly lower resistivity than sand.

Material	Resistivity (ohm-m)
Alluvium	10 to 100
Sand	60 to 1000
Clay	1 to 100
Groundwater (fresh)	10 to 100
Sandstone	$8 - 4 \times 10^3$
Shale	$20 – 2 \times 10^3$
Limestone	$50 – 4 \times 10^3$
Granite	5000 to 1000000

Table 1: Resistivity values of rocks and soil (Keller and Frischnecht, 1996)

Type of water	Resistivity (ohm-m)
Precipitation	30 – 1000
Surface water, in areas of igneous rock	30 – 500
Surface water, in areas of sedimentary rock	10 – 100
Groundwater, in areas of igneous rock	30 – 150
Groundwater, in areas of sedimentary rock	> 1
Sea water	≈ 0.2
Drinking water (max. salt content 0.25%)	> 1.8
Water for irrigation and stock watering (max. salt content 0.25%)	> 0.65

Table 2: Resistivity values of waters (Keller and Frischnecht, 1996)

Electrical Imaging System is now mainly carried out with a multi electrode resistivity meter system. Such surveys use a number (usually 25 to 100) of electrodes laid out in a straight line with a constant spacing. A computer controlled system is then used to automatically select the active electrodes for each measurement (Griffith and Barker, 1993). The data collected in the survey can be interpreted using an inexpensive microcomputer.

2.5 Electrical Resistivity Tomography Equipment

The Schlumberger-Wenner Array is an array where four electrodes are placed along a line around a common midpoint. In Figure 2 the two outer electrodes, A and B, are current electrodes, and the two inner electrodes, M and N, are potential electrodes placed together. With the Schlumberger array, for each measurement the current electrodes A and B are moved outward to a greater separation throughout the survey, while the potential electrodes M and N stay in the same position until the observed voltage becomes too small to measure. At this point, the potential electrodes M and N are moved outward to a new spacing. As a rule of thumb, the reasonable distance between M and N should be equal or less than one-fifth of the distance between A and B at the beginning. This ratio goes about up to one-tenth or one-fifteenth depending on the signal strength. Compared to other conventional arrays, Schlumberger array is known to have comparatively better vertical resolution and great vertical electrical sounding (VES) as well as sensitive to lateral resistivity changes.

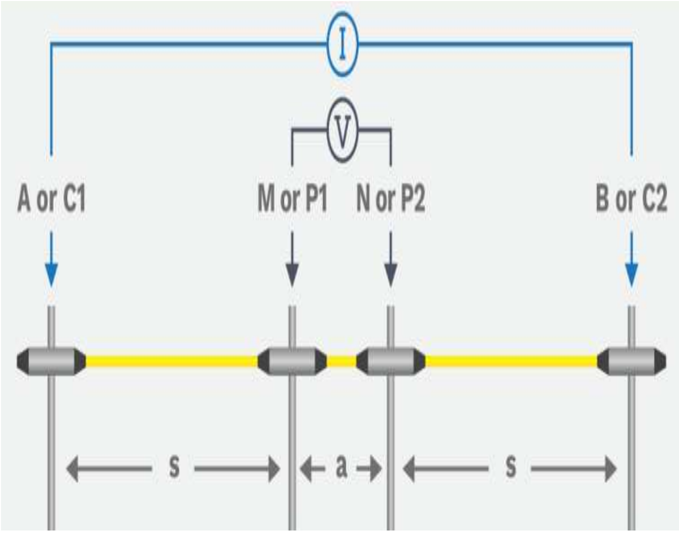

Figure 2: Schlumberger array method

3. Field Survey

Microgravity survey is a geophysical method used to identify subsurface density distribution. In this study it was supposed that considerable density distribution contrasts between compacted subsurface (good strength), and the uncompacted/loose subsurface can be detected. Figure 3 shows the survey location which is on a considerable flat compound of SMK Dato' Ahmad Said, Ipoh.

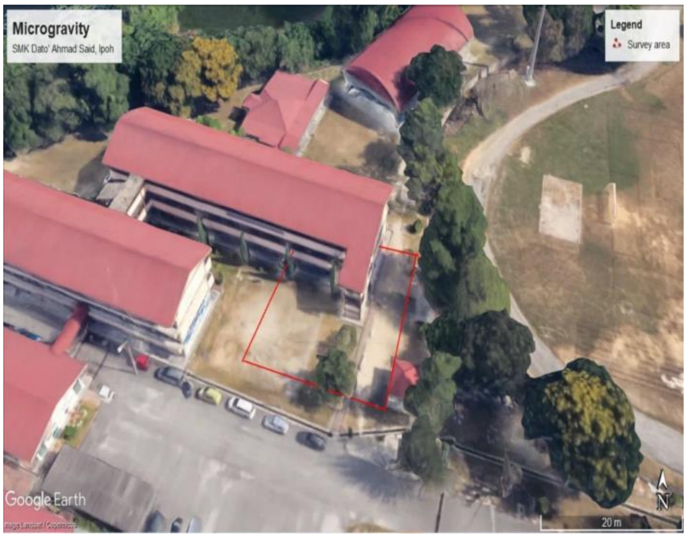

Figure 3: Overview of microgravity survey site at SMK Dato' Ahmad Said, Ipoh

For this work, a total of 36 microgravity points were set with 5 meter intervals of each point. The total area covered was 25 m^2. The study area is located in Kinta Valley which has an underlying limestone as illustrated in Figure 4. According to Meng et al (2016), Kinta Valley is characterized as Paleozoic limestone which formed a narrow-deformed strip between the late Triassic-early Jurassic batholiths of northern Peninsular Malaysia.

A total of 300m resistivity survey line was proposed and carried out. The 300m proposed line is further subdivided into two separate survey lines of 200 m and 100m namely Line 1 for the latter and Line 2 for the former. The 100m length line is surveyed using a 41 electrode system with 2.5m electrode spacing while the 200m length line is surveyed using a 41 electrode system with 5m spacing. The 100m survey line will have greater resolution due to smaller spacing and also an only maximum 25m average depth of investigation. The 200m survey line will have deeper depth of investigation of 35m.

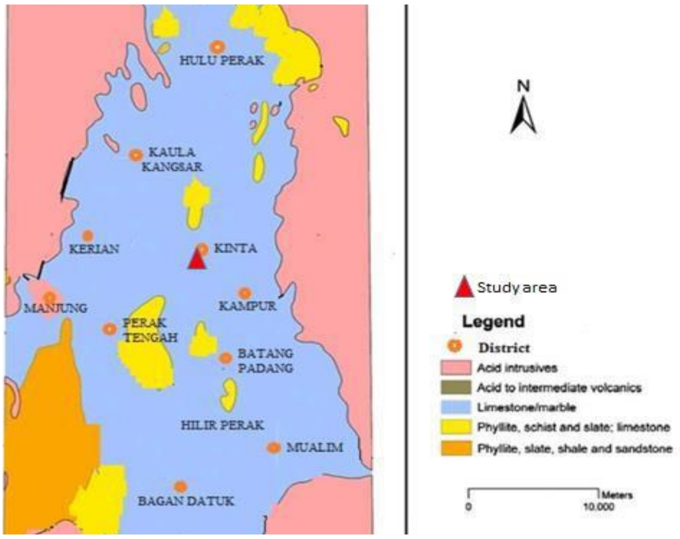

Figure 4: Geological map of study area (Yassin et al., 2013)

Figure 5: Overview of 2D-ERI survey at SMK Dato'Ahmad Said

4. Results and Discussion

4.1 Microgravity

In this section, all the microgravity data points were interpreted in terms of 2D mapping to meet the scope of work. The results of the 2D residual anomaly map shows that the subsurface condition of the study area can be classified into two main regions, namely low gravity anomaly and high gravity anomaly. Figure 6 shows the residual anomaly map corresponding to shallow sources at the study area. The relative difference in residual anomaly is found between +0.11 to 0.08 mGal. The region indicated by values of 0-0.08 mGal shows that the subsurface is interpreted as high density. BH1 and BH2 suggest that there is limestone bedrock with significant varying depths. However, the area is a reclaimed abandoned tin mine, suggesting that substantial man-made cuts, tunnels and shafts might be present underground. Possible method of extracting tin back then include open cast mining, mining tunnels and shafts. The high value of 'peak' of mGal may suggest it was a typical mining tunnel or mining room owing to its almost man-made feature. This interpretation however is limited to the location of the gravity points proposed. Figure 7 shows regional anomaly map at the study area. The relative difference in regional anomaly is found in the range of -24.12 to -23.78 mGal. The region indicated by values in the range of -23.94-23.78 mGal shows that the subsurface is interpreted as high density, thus indicating that the subsurface bedrock may be shallower. Meanwhile, the region indicated by values within the range -24.12-23.94 shows that the subsurface is interpreted as low density, thus may indicate that the bedrock is deeper there. The regional anomaly map (corresponding to deep sources) shows good transition of density distribution from low to high in northeastern direction. Overall, the residual and regional anomaly maps of this study area show that there is variation in density distribution, highlighting predicted bedrock level.

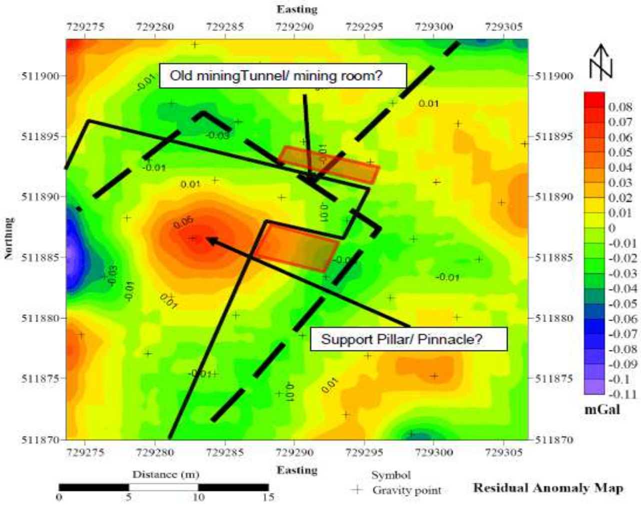

Figure 6: Residual anomaly map of the study area (corresponding to shallow sources)

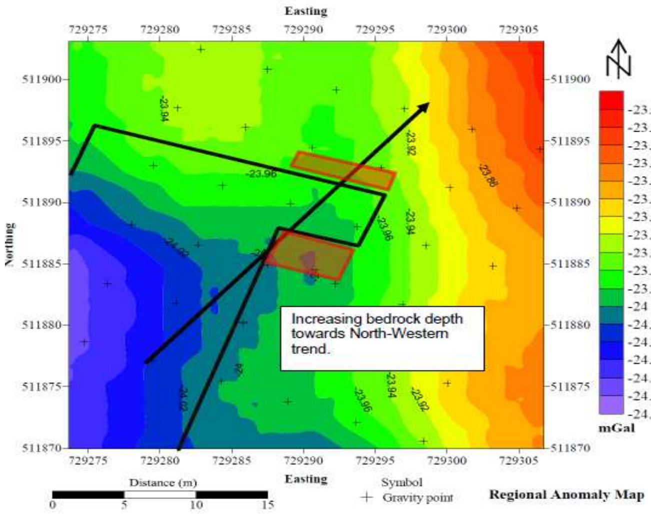

Figure 7: 2D regional anomaly map of the study area (corresponding to deep sources)

4.2 Electrical Resistivity Survey

The 2D-ERI survey lines that had been carried out yielded interesting results. The study area is largely considered as reclaimed abandoned tin mining area that may have employed various types of mining methods such as open casts, tunnel and open shaft mining. It is possible that the reclaimed soil is sourced from a nearby area or within the site itself that may derived from limestone origin. These reclaimed soils are high in carbonate and clay minerals that are easily weathered and may overtime reduce their effective strength due to prolonged exposure to high ground water level. BH1 that was bored until 42.50 m below ground level encountered limestone formation a depth of 36.50m with a 1.5m deep groundwater level (GWL) as well as cover soil having mainly sandy and gravel material and traces of wood, perfect for channelling water. BH2, carried out approximately 60m from BH1, yields a limestone bedrock depth of 21.50m and terminated at 27.50m below ground level with an average water level of 1.50m below ground level. This may indicate that this bedrock of the reclaimed mining area varies significantly in depth. The finding of the boreholes suggests there were significant level of ground water presence. Resistivity Line 1 and 2 detected several possible isolated low regions of resistivity value that may have behaved as underground channels. These channels may function as funnels for the weak clay layer, constantly channelling water to the area, weakening the strata around it as well as transporting the clay away from the area. Clay layers may retain a large sum water creating excess pore water pressure. Under the building load, the water will diffuse and the clay will take the load and shrinks in volume. Under extreme circumstances, the clay will start to shrink and fill the voids between reclaimed sand and gravel layer. An induced polarity (IP) survey was done to map the chargeability of the study area. High value of chargeability of 8.0-20.0 msec was possible with high clay content, with regions of 0.05-8.0 msec may represent the reclaimed soil of sand, gravel and clayey silt.

5. Conclusion

The microgravity survey method is a non-destructive geophysical method that measures differences in the earth's gravitational field between specific locations. In this study, microgravity method was used with intervals of 5 meters to map the bedrock distribution of the study area. The results showed that the subsurface of the study area can be classified into two regions, namely low density and high density respectively for both residual and regional anomaly maps. The residual anomaly map represents the gravity corresponding to shallow sources. Meanwhile, the regional anomaly map represents gravity corresponding to deep sources. Pinnacles or support pillar, old mining tunnels, mining shafts and mining rooms were initially suspected based on the trends of the gravity readings. However, upon checking with JMG the team was informed that there is no historical record of mining shafts in the study area.

2D-ERI of 300 m in total, subdivided into 200 m and 100 m lines were carried out and better ground characterization and possible subsidence were identified for both of the lines. Generally, low ohm regions were identified as underground channels that may affect the soil subsidence and migration of soil from the failure area.

It is recommended that additional boreholes to be done at the potential old mining tunnels to further investigate ground subsidence, and to confirm the possibility of collapsed old mining tunnels and mining rooms.

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