Integration of Magnetic and Geotechnical methods for Shallow Subsurface Soil Characterization at Sungai Batu, Kedah, Malaysia

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Abstract. Magnetic and geotechnical methods were used for shallow subsurface soil characterization at Sungai Batu, Kedah, (Malaysia). Ground magnetic data were collected along a survey line of length 160 m long at 2 m constant station spacing, while soil drilling using hand auger was conducted at 21 m on the survey line using 0.2 m sampling interval drilled to a depth of 5 m. Result from the processed magnetic profile data shows distribution of magnetic residuals in the range of -4.55 to 1.61 nT, with magnetic low (-4.55 nT to -0.058 nT) and were identified at distances 4 m, 10 to 16 m, 20 to 26 m, 58 m, 82 m, 104 to 106 m, 118 m, and 124 to 140 m. The magnetic lows are attributes of sediments. The result from the soil drilling shows sticky samples with variable sizes, greyish to brownish / reddish in colour, and some of the samples show the presence of shiny and black spots. The characteristics of the samples suggest the soil as a by-product of completely weathered rock; weak with high water content and classified as Grade V soil. The study concludes; integration of geophysical and geotechnical methods aided in characterizing the subsurface soil at Sungai Batu. The result was correlated with previous studies and confirms the importance of integrated approach in minimizing ambiguity in interpretation.

1. Introduction
Geophysical application provides non-invasive, non-destructive, fast, cost-effective, and efficient means of probing the earth subsurface. It uses contrast in physical properties of the earth in response to signals, (active or passive) to diagnose the subsurface distribution of earth materials. The choice of geophysical method of investigation is dictated by good response to geophysical signal from some parameters in the subsurface [1].
Magnetic method is a passive geophysical method, and provides faster and cheaper means of investigating subsurface of the earth. It relies on contrast in magnetic susceptibility distribution in the subsurface. Unless where there is magnetite present in soil or rock, magnetic response (susceptibility, k) for most earth materials is low (x 10^-6) [1]. This attribute makes it possible for the method to discriminate between earth materials and any anomalous body, hence a good tool for characterizing the soil for shallow subsurface. In general, geophysical methods have been found to be efficient for site characterization [2]; [3].
Geotechnical method on the other hand, involves site investigation through soil sampling and laboratory tests of the soil samples retrieved. Both methods are complimentary tools in studying subsurface features. This study, integrates two methods (magnetic and hand auger drilling) to characterize Sungai Batu shallow subsurface soil. The principal goal of this work is to provide information on the soil properties using complimentary results from the two methods.
2. Location and geology of the study area
The study area was located at Sungai Batu on latitude 5.6882° and longitude 100.4579°, along the road between Sungai Petani and Merbok in Lembah Bujang, Kedah, north-western Malaysia (Figure 1). It was a famous entrepot and now becoming an archaeological research. It is in Jerai formation with elevation of about 12 m above sea level. It has been documented in the past, between first and second century that mid-southern part of Kedah was known to be a marine area. The sea level receded about 1400 years ago [6] leaving behind some sediments transported by river. The receded area has been transformed to land [7]. The soil types in the area are very poorly sorted sediments, with sandy clay soil covered with fine sand [8]. The geomorphology of the area is flat. There are oil palm and rubber estate dominating the landscape alongside small rivers and swamps to the south and west of the survey line (Figure 2).

![Figure 1. Aerial map of the study site [4]](image1)

![Figure 2. Geology map of the Sungai Batu [9]](image2)

3. Methodology
Magnetic and geotechnical methods were applied in the study. The methods are complimentary tools for subsurface investigation. Magnetic method provides geophysical approach to the study and geotechnical method on the other hand, provides ground truthing. At this study, magnetic method was executed first, followed by geotechnical method.

3.1 Magnetic method
Ground magnetic data was acquired at 2 m station spacing using proton magnetometer (GEM system GSM-19T) trending N-S. The conventional procedures for ground magnetic survey were adapted in this study. A base station was carefully selected at a place devoid of magnetic interference from the survey area where the base magnetometer recorded magnetic readings at a cycle of 60 seconds. Base readings were used to correct diurnal variation. Three sets of readings were taken at each rover station and later averaged. At the end of the survey, the acquired magnetic data was downloaded from the console to a computer. Microsoft Excel application software was used to process the data. The first step in processing the magnetic data was to inspect the raw data for spikes, gaps, and instrument noise or any other irregularities in the data. This is followed by correction for diurnal variation and IGRF correction. Once these corrections were done, the magnetic residual data was plotted against distance. Thereafter, anomaly of interest was isolated for analysis and interpretation [10].
3.2 Geotechnical method
A borehole was drilled using hand auger and soil samples were taken from the surface at 0.2 m depth interval to penetrate a depth of 5 m at station 21 m on magnetic survey line. The samples collected were carefully packed and taken to laboratory for analysis to determine their magnetic susceptibility, soil texture, and colour. The true magnetic susceptibility values were converted from the apparent susceptibility.

4. Results

4.1 Result for magnetic method
The processed magnetic residual intensity data was plotted to produce magnetic residual intensity curve (Figure 3). The Figure shows relatively low magnetic responses at locations 4 m, 10 to 16 m, 20 to 26 m, 58 m, 82 m, 104 to 106 m, 118 m, and 124 to 140 m with corresponding residual magnetic field intensity values at -0.77 nT, -4.54 to -0.16 nT, -1.15 to -0.33 nT, -0.93 nT, -2.88 nT, -1.46 to -1.64 nT, -2.58 nT, and -0.70 to -1.81 nT. The values are typical of response due to sediments and weathered rocks and could be interpreted as materials that are degraded by weathering, such as sandy soil. Physical examination on the samples show some decayed organic materials.

4.2 Result for geotechnical method
Figure 4 shows variation in susceptibility with depth. It is shown a generally low susceptibility value, which is typical of sedimentary materials of the order of $10^{-6}$ SI unit [10]. However, there are outliers observed at depth 0.6-0.8 m, 2.4-2.8 m, and 4.6-4.8 m with susceptibility values of $160 \times 10^{-6}$, $16 \times 10^{-6}$ and $1.29 \times 10^{-6}$ SI units respectively. Laboratory observation on the soil samples revealed the samples have been found to be sticky, with varying colours from grey to red/brown at different depths. Shiny and black spots were also observed on some of the samples. This is suggestive of muscovite mica, biotite and indicative of a product of heavily weathered granite. The materials were classified as Grade V weak soil, and the high-water content indicated the study site was waterlogged. The texture is made of grains of different sizes; clay at the top-most and coarse size at depths from 4.2- 5.0 m. Table 2 shows the interpretation of the hand auger borehole.

![Figure 3. Magnetic residual field intensity plot of Sungai Batu, Kedah.](image-url)
Figure 4. Magnetic susceptibility plot of Sungai Batu, Kedah.

Table 1. Sungai Batu soil samples apparent and true susceptibility values.

| x (m) | y (m) | Description                        | Apparent susceptibility value (x10^-6) | Apparent susceptibility value (x10^-6) | True susceptibility (x10^-6) SI unit |
|-------|-------|------------------------------------|----------------------------------------|----------------------------------------|-------------------------------------|
| 21    | 0 - 0.2 | Brownish clay                      | 12                                     | 150.816                                | 96.52224                            |
| 21    | 0.2 - 0.4 | Brownish clay                     | 12                                     | 150.816                                | 96.52224                            |
| 21    | 0.4 - 0.6 | Brownish clay                      | 12                                     | 150.816                                | 96.52224                            |
| 21    | 0.6 - 0.8 | Brownish clay                      | 20                                     | 251.36                                 | 160.8704                            |
| 21    | 0.8 - 1.0 | Mixture of brown and grey clay     | 20                                     | 251.36                                 | 160.8704                            |
| 21    | 1.0 - 1.2 | Mixture of brown and grey clay     | 10                                     | 125.68                                 | 80.4352                             |
| 21    | 1.2 - 1.4 | Mixture of brown and grey clay     | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 1.4 - 1.6 | Mixture of brown and grey clay     | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 1.6 - 1.8 | Mixture of brown and grey clay     | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 1.8 - 2.0 | Mixture of brown and grey clay     | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 2.0 - 2.2 | Mixture of brown and grey clay     | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 2.2 - 2.4 | Mixture of brown and grey clay     | 9                                      | 113.112                                | 72.39168                            |
|       |        | with decayed leaf                  |                                        |                                        |                                     |
| 21    | 2.4 - 2.6 | Grey clay                           | 2                                      | 25.136                                 | 16.08704                            |
| 21    | 2.6 - 2.8 | Grey clay                           | 2                                      | 25.136                                 | 16.08704                            |
| 21    | 2.8 - 3.0 | Grey clay                           | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 3.0 - 3.2 | Grey clay                           | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 3.2 - 3.4 | Grey clay                           | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 3.4 - 3.6 | Grey clay                           | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 3.6 - 3.8 | Grey clay                           | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 3.8 - 4.0 | Grey clay                           | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 4.0 - 4.2 | Grey sand                           | 6                                      | 75.408                                 | 48.26112                            |
| 21    | 4.2 - 4.4 | Grey sand                           | 8                                      | 100.544                                | 64.34816                            |
| 21    | 4.4 - 4.6 | Grey sand with leaf                | 10                                     | 125.68                                 | 80.4352                             |
| 21    | 4.6 - 4.8 | Grey sand                           | 16                                     | 201.088                                | 128.69632                           |
| 21    | 4.8 - 5.0 | Grey sand                           | 10                                     | 125.68                                 | 80.4352                             |

True susceptibility value = Apparent susceptibility * square of the ratio of standard sample diameter to true sample diameter.
Table 2. Sungai Batu soil samples hand auger borehole log.

| Depth (m) | Description of Soil                                                                 | Inference                        |
|----------|-------------------------------------------------------------------------------------|----------------------------------|
| 0-1.6    | Consist of fine grain minerals, sticky and reddish in colour owing to oxidation of iron. | Clay                             |
| 1.6-3.6  | Consist of less reddish and greyer fine grain, with some shiny alongside dark colour particles. These particles are suspected to be mica and biotite. | Clay material from weathered granite |
| 3.6-4.2  | Traces of sand and silt. Increase in particle size and grey in colour. The presence of mica, biotite and quartz becomes visibly clear. | Sandy clay                       |
| 4.2-5.0  | Highly weathered granite with coarser grain size and grey in colour.                 | Sandy clay                       |

The study results agree with previous resistivity and seismic works carried out by [11] and [12] respectively which identified the area as alluvium deposit with resistivity value of >50 Ωm and seismic velocity of < 1400 m / s.

Conclusion
Two methods (magnetic and geotechnical) were integrated for site characterization at Sungai Batu area. Results from the methods identified that sediments characterized the site. Samples obtained at different depths in the drilled hole were found to be sticky soil of different grain sizes, ranging from clay size to coarse grain soil with mixed colours from grey to red / brown. Shiny and black spots were also observed on some of the samples. This is suggestive of muscovite mica, biotite and indicative of a product of heavily weathered granite. The material was classified as Grade V weak soil, and the high-water content indicated the study site was waterlogged. The study showed the importance of geophysical method as a non-invasive method for site characterization. Result from hand auger revealed the real properties of the subsurface soil and agree with result from previous study conducted.

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