2-D Electrical Resistivity Tomography (ERT) Assessment of Ground Failure in Urban Area

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Abstract. This study was carried out to assess the foundation defects affects around an urban area in Selangor, Malaysia using 2-D electrical resistivity tomography (ERT). The affected structure is a three storey houses and having severe foundation-based cracks. Six 2-D ERT survey lines with 5 m minimum electrode spacing using Pole-dipole array were executed parallel to building’s wall. Four boreholes were conducted to identify the depth to competent layer to verify the 2-D ERT results. Inversion model of 2-D resistivity show that the study area consists of two main zones. The first zone is a low resistivity value (<100 Ωm), which appears to be a zone that is fully saturated with sandy silt and this could be an influence factor the increasing water level because sandy silt is highly permeable in nature and alluvium (silt, sand and clay), boulder (1200-3500 Ωm) or highly weathered with the resistivity values of 100-1000 Ωm at 20-70 m depth. The second zone is the granite bedrock of more than 3500 Ωm with depth greater than 70 m. These results were complimented and confirmed by borehole records. The ERT and borehole record suggest that the clay, sand, saturated zone, highly weathered zone and boulders at foundation depths may lead to ground movements which affected the stability of the building.

1. Introduction
Foundation cracks on buildings occur as a result of differential movement on the building. The size, shape, pattern and location of foundation cracks on a building, when correlated with other site and construction conditions, help to distinguish among probable causes of foundation based failures [1]. Construction activities in modern cities change soil, geological, and hydrological conditions and often caused dramatic changes in groundwater level [2][3]. In building construction, poor soil stability is one of the factors that cause havoc. This is because some soils are very sensitive to moisture gain or loss. Certain clay soils for instance, can expand multiple times in volume if they get saturated and when there is loss of water in them, they shrink in volume. This expansion and shrinkages of clayey soils cause foundation cracks on buildings shortly after they are built in the process of their settlement [4]. Moreover, the previous of reclaim work at the river area actually exacerbated the problem rather than helping it. These zones of underground water flow in the slope created permeable pockets that readily filled with subsurface water, added to the weight and allowed the infiltration to penetrate deeper into the subsurface soils. A tension crack is observed on the road near the retaining wall. Figure 1 shows the problems faced by the resident at Selangor. Obtaining the subsurface information with rapid and non-destructive methods for soil investigation and subsurface conditions are highly desirable in modern cities [5][6].
Figure 1. Sample of affected building structure and road from the area during landslides.

2. 2-D Electrical resistivity tomography (ERT)
The purpose of resistivity surveys is to determine the subsurface resistivity distribution by taking measurements on the ground surface. The true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as mineral and fluid content, porosity and degree of water saturation in rock. Variations in electrical resistivity may indicate changes in composition, layer or contaminant levels [7].

3. Methodology
The surveyed area was investigated by six 2-D ERT profiles parallel to building’s wall, each consisting of a 5 m spaced with 41 electrodes in order to delineate the resistivity of the subsurface materials. 2-D ERT was used to delineate the overburden, weathered zones, fractures, saturated zone and bedrock at the study area. For the measurements, Pole-dipole array was performed and four channel selector ES10-64C was employed. Processing was performed using Res2DinV and surfer10 software. In addition, borehole information from the standard penetration test (SPT) N-values was used to constrain the interpretation of resistivity data.

4. Study area
The study area was situated at Selangor, Malaysia. Selangor was located at N 3°11’08.61” E 101°46’02.34”. This area was underlain with fine grey and coarse grain leucocratic granite. Vary size of boulders has found distributive at landslide scar. Basically the remains include sandy clay with the thickness about 15-30 m and became thinner directly towards the middle of slope, followed by granite barely at foot slope. Medium and highly weathered granite produced clayey sand to sandy clay [8]. This area has highly saturated shale or schist which is easily weathered to form oxide clay or ferralicl during the absorption of water. Six 2-D ERT survey lines were conducted at BR1 to BR6 with the borehole location as shown in Figure 2. Selecting the best array is important in working with 2-D ERT
in urban area to get the best results based on site characteristics such as site accessibility. Pole dipole may penetrate deeper and good resolution even though there was a short survey line as compare with other arrays.

![Figure 2](image_url)

**Figure 2.** Study area with 2-D electrical resistivity tomography (2-D ERT) profile lines (BR1 to BR6) and borehole location.

**5. Results and Discussions**

The results of 2-D ERT and borehole can be used to develop useful correlation that can predict soil parameters from the soil resistivity data. All the inversion model of 2-D resistivity (Figure 3 to 6) was display in distance (m) for x-axis and depth (m) for y-axis. From the inversion model of resistivity of BR1 (Figure 3) there are alluvium/highly weathered (100-3500 Ωm) with depth >30 meter. These zone consists of saturated zone (1-100 Ωm) and boulders (1200-3500 Ωm) [6][7][9]. This layer is unfavourable for foundation of engineering structure along this traverse.

![Figure 3](image_url)

**Figure 3.** Inversion model resistivity for BR1.
Figure 4 shows three main zones at BR2. First zone is alluvium/highly weathered (100-3500 Ωm) with depth <20 m. These zone consists of saturated zone (1-100 Ωm) and boulders (1200-3500 Ωm) [6][7][9]. The low resistivity values from 150-240 m at the surface caused crack along the road. This is also confirm by the borehole record that area has < 10 SPT N-values which indicate as very soft and loose soil at depth of <9 m. The second zone with resistivity value of 3500-5000 Ωm is a weathered zone. The area with >5000 Ωm is the granite bedrock at depth of 20 m from the surface with SPT N-values of 50. The is also fractured found on the study area due to highly contrast between low and high resistivity values [9].

![Figure 4. Inversion model resistivity for BR2.](image)

Figure 5 shows low resistivity values (1-100 Ωm) at BR3 which was interpreted as saturation zone. This saturation of the subsurface was due to water seepages from Seriang River into the foundation depths at the drainage paths section near the building. Besides, the low resistivity could be mainly due to sandy silt and this could be an influence factor the increasing water level because sandy silt is highly permeable in nature. The borehole record also show that soil is loose and medium stiff with SPT N-value <10 up to 17 m from the surface.
Figure 5. Inversion model resistivity for BR3.

Figure 6 shows BR4-BR6 which has three main zones. First zone is alluvium/highly weathered (100-3500 Ωm) with depth >30 m. These zone consists of saturated zone (1-100 Ωm) and boulders (1200-3500 Ωm). The aluvium might be consist of clay, silt and sand. Surface layer consists of clayey sand which able to keep water for long term may effect low resistivity values. The second zone with resistivity value of 3500-5000 Ωm is a weathered zone. The third zone with >5000 Ωm is the granite bedrock [6][7][9] and SPT N-value of 50 at depth >15 m from the surface.

Table 1 shows the summary of representative SPT N-values for subsurface materials. Figure 7 shows the inversion model resistivity of all survey lines at selected area in Selangor.

Table 1. Description of soil strength based on SPT N-values.

| N-value | Description            |
|---------|------------------------|
| 0-5     | Very soft and very loose soil |
| 5-10    | Medium stiff and loose  |
| 10-15   | Stiff and medium dense  |
| 15-20   | Very stiff and dense   |
| 20-50   | Hard and very dense    |
Figure 6. Inversion model resistivity for BR4 to BR6.
6. Conclusion
The 2-D ERT of all profiles characterized by relatively low resistivity values of the range of 1-1000 \( \Omega \)m. This suggests that the subsurface can be affected by water and clay content. The inversion model resistivity reveals other features such as fractures and boulders that can lead to structural failure. A saturated zone has also been identified by the survey which could be a concern in relation to the possible cause of landslides, fractured wall and collapse of the retaining wall. The results of 2-D ERT method could be used to detect subsurface problem in landslides area supported by borehole records.

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