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Comparison of Two Geophysical Methods to Investigate Sand and Gravel Deposits, a Case Study in Chumphuang District, Nakhornratchasima, Thailand

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Abstract: Sand and gravel are the most important raw materials in construction processes. Conventionally, sand and gravel explorations are done by surface geological mapping and drilling. However, those techniques usually provide inadequate subsurface information and sometimes are insufficient for pit design and development. Geophysical methods are considered to be cost effective tools to provide continuous subsurface information, but there are many geophysics methods that are available for sand and gravel exploration and it is not clear which are optimal under different circumstances or financial- or time-constraints. In this study, two widely used geophysical methods, two-dimensional (2D)-resistivity imaging and multichannel analysis of surface seismic waves (MASW) were evaluated in direct comparison to each other to determine the effectiveness of each method in providing geological subsurface information for sand and gravel exploration. These methods were compared in terms of their efficiency and field functionality. The results revealed that the 2D-resistivity method was the most cost- and time-effective tool for providing accurate and reliable subsurface information. This method also helped in reducing the number of required boreholes and improving the sand pit design and development.

Key words: Sand exploration; 2D Resistivity imaging; MASW.

INTRODUCTION

Sand and gravel are generally used in the construction industry to build and maintain urban, suburban, and rural infrastructures, including highways, roads, and bridges; commercial and residential buildings; factories and power generating facilities; and water supply and waste-treatment facilities. To supply these resources, traditional sand and gravel exploration usually involves point bar observing in aerial photographs, and borehole drilling for locating the optimal location of the sand pit. However, this method cannot provide information on the subsurface geology in sufficient detail, but rather only provides incomplete data from which it is difficult to calculate the sand reserve. Geophysical methods are considered to provide the aerial extent and thickness of the deposit, thickness of overburden, and critical geologic contacts. Moreover, geophysical measurements can be taken where closely spaced geological changes may be undetected by drilling, such as areas of suspected buried channels. When combined with borehole information, geophysical data can be extremely useful for optimal sand pit location, design and development. However, there are many geophysical techniques that are currently used in sand and gravel exploration, such as electrical, electromagnetic, ground penetrating radar, and seismic methods (Ellefsen and others, 1998; Ellefsen *et. al.*, 2005; Langer, 2006). Selecting the appropriate method may help improve subsurface geological data and also reduce the cost and time involved.

In this study, the two geophysical methods of two dimensional (2D)-resistivity imaging and 2D multi-channel analysis of surface seismic waves (MASW) were comparatively evaluated for their potential suitability in sand and gravel deposit exploration. The 2D-resistivity method is the most widely used method in geological exploration, and can detect the contact between aggregate and bedrock, the presence of clay layers, and the water table. The 2D-MASW method, developed by Kansas Geological survey in 1990, is also now widely used in engineering and environmental applications because it is very easy to acquire and process the data.

2. Study Area:

Chumphuang is a district in Nakhornratchasima province with an area of 546.57 km^2 and is located about 98 km northeast (NE) from Nakhornratchasima and about 250 km NE from Bangkok. Chumphuang district consists of 60% and 30% mountain and floodplain by area. The highest elevation is about 230 m above mean sea level (amsl) and the lowest elevation is about 139 m amsl. The Mun River is the major river in the area and is located in the northern part of the city and flows in a broadly West-East direction to later join the Mekong River.

Chumpuang area is covered by a fluvial plain and is the source of sand for the area. The sand deposits in this area mostly come from the erosion of rocks of the Khorat Group to the southwest and are transported by the

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Mun River. The study area (red square in Figure 1) is situated on the flood plain of the Mun River. The area is relatively flat and is mostly covered by plantation fields. Several boreholes have been drilled in the past to preliminary evaluate the reserve and quality of the sand and gravel in this area, and two of these are used in this study.

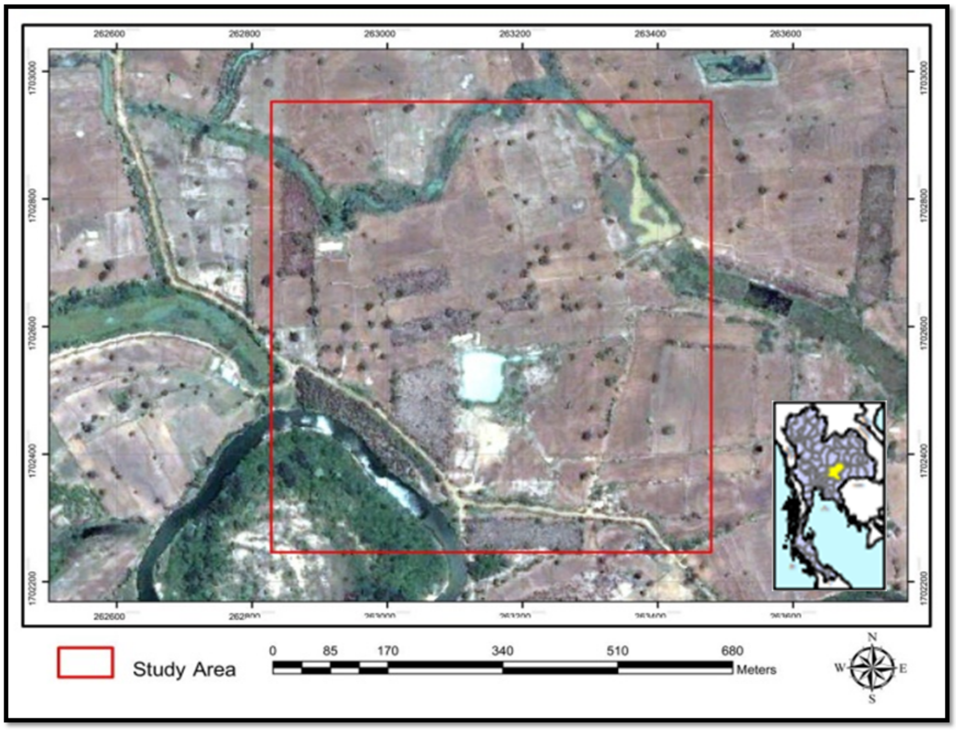

Fig. 1: Location map of study area in Chumpuang District, Nakhonratchasima Province, Thailand.

3. Methodology:

In this study the two geophysical methods of 2D-resisitivity imaging and 2D-MASW were evaluated for their efficiency in providing accurate subsurface information in a reasonable cost and time. All geophysical data were acquired along the same 200 m SSW – NNE lying survey line, except that for the 2D-resistivity imaging extended slightly in both directions by a total of a further 35 m (Figure 2), since the 2D-resistivity data were acquired over a 235 m length transect compared to 200 m for the 2D-MASW transect.

The data were also correlated with that from the two available local boreholes (CPS-27 and CPS47) that lie on the transect, about 70 m apart from each other and drilled to a depth of 20 m. From the borehole data (Figure 3), the geologic layers of the study area can be divided into three major units. The first unit is the topsoil that contains a high clay content and is about 2 - 4 m thick. The second unit is the yellow to grey sand of about 5 - 7 m depth and forms the major unit of sand production due to the clean quality of the sand within it. The third unit is that of the clayey sand, which forms the secondary sand production layer (6 – 13 m thick) due to the higher clay content that has to be cleaned out. In addition, two other localized layers (units 4 and 5) can be found in the CPS-27 borehole, comprised of a sandy clay layer (fourth unit) of less than 1 m thick and a clayey sand layer (fifth unit), but these are not found in the CPS-47 bore hole so do not exit though out the area.

3.1 2D-MASW Method:

There are many types of seismic methods commonly used in geological exploration, such as seismic refraction and reflection methods. The 2D-MASW technique is a relatively new seismic technique that utilizes the surface wave or ground roll to indirectly determine the shear wave velocity (Vs) of the shallow subsurface (Park *et al*, 1999). The surface wave is typically of a low velocity, low frequency and high amplitude. In this study 24 of 4.5-Hz geophones placed 2 m apart were used to record the seismic waves. Figure 4 shows the seismic equipment and data acquisition in the field. A 12-lb sledgehammer was used as the source and the minimum offset was 5 m from the first geophone. This field setup was then moved 2 m along the transect and the process repeated in order to create a 200 m Vs profile from a total of 200 seismic data files. The MASW data were processed using the SurfSeis software package, in order to create a 2D-Vs section.

Fig. 2: Location of the geophysical survey line. The 2D-resistivity transect (235 m, shown in red) and 2D-MASW transect (200 m, shown in blue) are actually on the same location (bar the 35 m extra for the 2D-resistivity transect), that shown in red, but the 2D-MASW transect is drawn slightly displaced for clarity of presentation only.

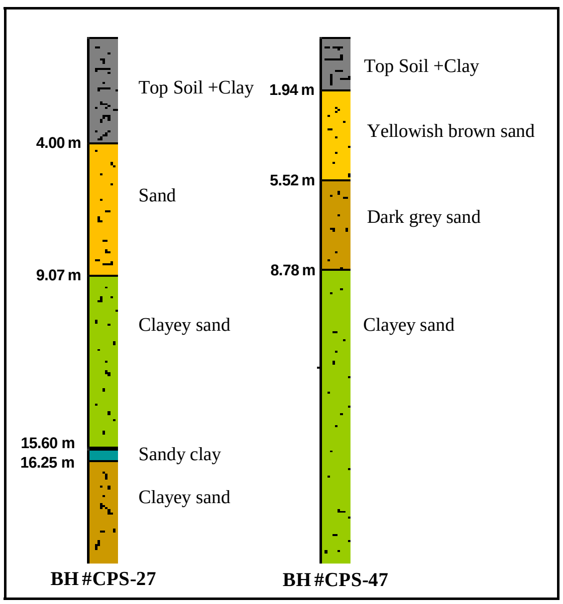

Fig. 3: Borehole data used in correlation with geophysical data.

The basic steps in the MASW data processing are summarized in Figure 5. Generally, each seismic data, which contains the surface wave, was transformed into a phase velocity and frequency domain and then the fundamental mode of the surface wave (dispersion curve) was identified. This fundamental mode of surface was then inverted to derive the 1D-Vs profile. The individual 1D-Vs profiles were then placed side-by-side at 2 m intervals to construct the 2D-Vs section.

Fig. 4: Seismic data acquisitions in the field.

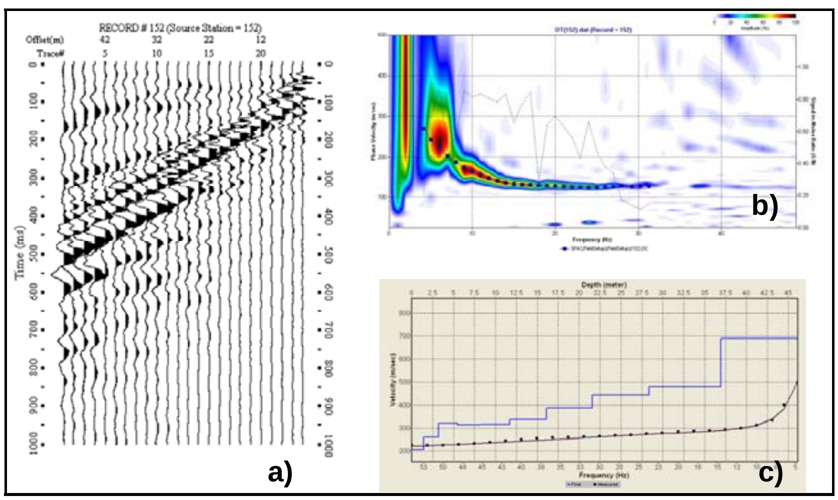

Fig. 5: The three basic steps of the MASW data processing. (a) Raw seismic data, (b) the corresponding dispersion curve, and (c) the inverted shear-wave velocity (Vs) profile.

3.2 2D-Resistivity Imaging Method:

The 2D-resistivity method works by generating a direct electrical current into the earth subsurface. The differences in the electrical properties of the different earth materials cause different potential differences that can be measured at the surface (Kearey *et al*, 2002). These differences in the earth resistivity can then be used to interpret the subsurface geological features. The electrical resistivity geophysical method was used to explore for sand and gravel prior to the late 1930s (Patterson, 1937), and has become the standard method in sand and gravel exploration.

In this study, a 48-electrode resistivity imaging system was used. The electrode spacing was at 5 m apart making the total line length 235 m. Figure 6 shows the equipment and field operation of the 2D-resistivity technique. The acquired resistivity data was processed and interpreted using the RES2D software package.

Fig. 6: 2D-resistivity data acquisition.

4. Results:

The correlation between the 2D-MASW data and the borehole information is shown in Figure 7. From the image the soil can be separated into three layers based on their Vs value. The topsoil and clay layers have Vs values of less than 150 m/s. The sand layer has Vs values in the range of 150 - 250 m/s, whilst the clayey sand layer has Vs values higher than 250 m/s. However, the high velocity layer at the deeper part of the image cannot be identified because of the limited depth of the two available boreholes.

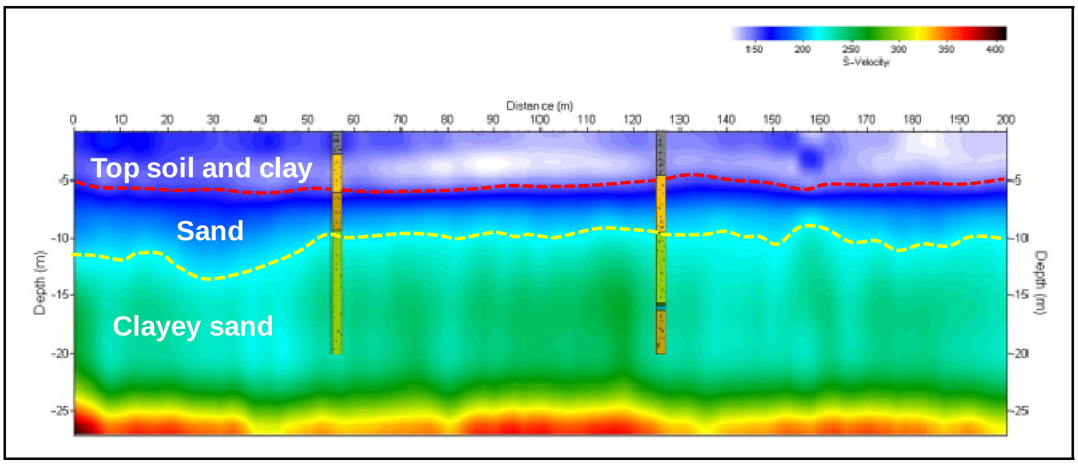

Fig. 7: 2D-MASW sections along the 200 m transect and two available boreholes (see Fig. 3).

The seismic Vs profiles gave the best image of the geologic layers. All contacts between each soil layer were well correlated with the data from the two boreholes. This method also gave a reasonable depth of investigation (25 m) for the sand layer exploration, but it is the most expensive and time consuming method compared with the other methods.

Figure 8 shows the comparison of the 2D-resistivity data with the two boreholes. The 2D-resistivity data correlated very well with the borehole information and shows the detail of the shallow part of the survey line. The top soil layer has average resistivity of 5 - 6 ohm.m and appears in the early and in the middle part of the profile. The contact between the sand and clayey sand layer is very clear at a depth of 10 m as the sand layer has a resistivity value of more than 10 ohm.m. However, it is clear that the thickness of the major sand layer varies along the line, information that could not be determined from the two boreholes alone. The clayey sand layer has a very low resistivity value (lower than 2 ohm.m), which is probably due to the high percentage of clay content and high saline ground water level in the area. The clayey sand layer is thinner towards the right side of the profile (NNE direction) and there is another sand layer that appears below clayey sand layer at a distance of 160 m along the transect that is not observed in the borehole data. The depth of resistivity section is about 35 m. The 2D-resistivity data provides a very high detail of the lateral variation of the surface of the survey line.

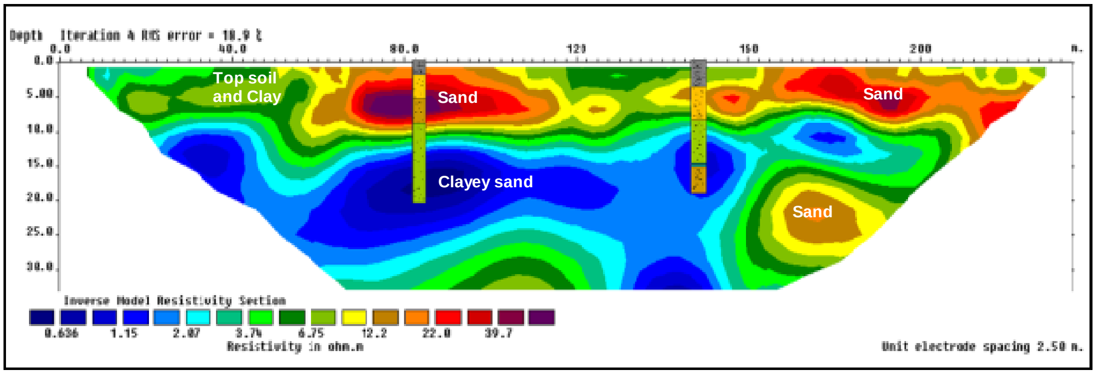

Fig. 8: 2D-resistivity imaging correlating with the data from the two boreholes.

5. Conclusion and Discussion:

Geophysical methods provide valuable subsurface information for the exploration of sand deposits and for sand pit design and development. In this study, the two geophysical methods of 2D-resistivity and 2D-MASW were compared for their effectiveness in providing subsurface information for sand and gravel deposit exploration. The 2D-resistivity method was the most cost-and time-effective tool for providing accurate and reliable subsurface information. This method would also help reduce the number of required boreholes and improve the sand pit design and development.

Table 1 summarizes the comparison of the two methods used in this study, based only on data from field observations and the comparisons were evaluated only for the purpose of determining sand and gravel deposits.

Data Acquisition:

Data acquisition functionality for each method was based on providing the subsurface information to a depth of over 25 m. The 2D-resistivity method was the best (fastest) in terms of the field data acquisition. A set of 48 electrodes can be deployed in less than 1 h and the data automatically collected immediately afterwards. The total time for the fieldwork was less than 2 h using a 48-multielectrode resistivity unit with a 5 m electrode spacing. The 2D-MASW technique took much longer because all 24 geophones had to placed on the ground and connected before the seismic source was generated and then the same source-geophone configuration was moved to the next station (2 m along the transect) and repeated. This data acquisition procedure is similar to that of the conventional seismic exploration used in petroleum exploration. A total time of at least 5 – 6 h was spent to acquire the MASW data over a 200 m transect.

Data Processing:

Data processing functionality was based on the necessity for qualitative input and the potential for resultant human error. The 2D-resistivity tool was deemed to be the best for data processing. The field data can be edited and processed with fewer steps and the edited data was inverted to get the resistivity pseudo-section without difficulty, and so is fast with a low error probability. In contrast the 2D-MASW approach required all of the field seismic data to be transformed into a phase velocity-frequency domain and the dispersion curve had to be picked by the processer. The picked dispersion curve was then inverted to get the 1D-Vs profile. However, the quality of the dispersion curve was very important influence on obtaining a reliable Vs profile but different data processors may select different dispersion curve from the same MASW data, potentially leading to unreliable Vs data.

Provided Information:

Both methods provided clear and sharp boundary images of the soil units but the 2D-resistivity tool gave a better lateral variation in the subsurface image. The 2D-resistivity, acquired with 48 electrodes and a 5 mm electrode spacing, gave a better depth of penetration to about 35 m. In contrast, the 2D-MASW data gave a slightly lower depth of penetration (25 m). Although this could be increased by using a heavier seismic source or by increasing the geophone spacing, this would be at a higher cost and reduced portability.

Cost:

The 2D-resistivity tool had the lowest time and financial cost per survey. The data can be acquired from a 235 m line with only three people in less than 2 h. The equipment is portable and the data can be processed and displayed in the field. The 2D-MASW method has a high equipment cost and operational time, with a 200 m long transect requiring 4 - 5 people for at least 5 to 6 h.

Table 1: Comparison of Geophysical Methods for Sand Deposit Exploration.

Items	Geophysical Methods	
	2D-MASW	2D-Resistivity Imaging
Data acquisition	Slow	Fast
Data processing	Slow, high error risk	Fast, low error risk
Provided information - Layer Boundaries - Depth of Penetration	 Very good Good	 Very good Very good
Cost	High	Moderate

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