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Comparison of Interpretation Between CPT and Res-2d Methods for Geostratigraphic Profiling Determination of Kota Depok

(Perbandingan Interpretasi dengan Menggunakan Metode Cone Penetrometer dan Res-2d untuk Menentukan Profil Geostratigraphi Kota Depok)

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ABSTRACT

In its simplest application, the cone penetrometer offers a quick, expedient, and economical way to profiling a subsurface soil layering at a particular site. No drilling, soil samples, or spoils are generated, therefore, cone penetration test CPT is less disruptive from an environmental standpoint. The continuous nature of CPT reading permits clear delineations of various soil strata, their depths, thicknesses, and extent, perhaps better than conventional rotary drilling operations that use a standard drive sampler at 5-ft vertical intervals. The cone penetrometer is instrumented with load cells to measure point stress and friction during a constant rate of advancement. The results can be interpreted within different theoretical frameworks or by using empirical methods, or both. RES-2D (resistivity – two dimension) completed by Geoscanner devices is applicable to interpret the soil profiling from soil exploration works. Generally, the geoscanner is used to assess the geological subsurface condition for mining works. This paper is addressed to compare the results for soil classification in Kota Depok, West Java using a cone penetration test and RES-2D. From both methods, the result of soil strata shows the soft soil in study area can be classified as clay layers from ground surface to the depth of 15.0 m. However, the CPT is less applicable to measure exactly the elevation of ground water table than RES-2D. In addition, RES-2D is also less applicable to predict the soil properties of the soil type than CPT. In general application, both devices can be applied to soil investigation for geotechnical works.

Keywords: soil profiling, cone penetration test, resistivity, geoscanner

INTRODUCTION

In its simplest application, the CPT offers a quick, expedient, and economical way to profile the subsurface soil layering in real time at a particular site. No drilling, soil samples, or spoils are generated, therefore, cone penetrometer is less disruptive from an environmental standpoint. By recording the cone end resistance *(q_c)* and friction sleeves *(f_s)* measurements vertically with depth (Begemann, 1965).

The cone penetrometer is a tool for profiling strata changes, delineating the interfaces between soil layers, and detecting small lenses, inclusions, and stringers within the ground. The results can be interpreted within different theoretical frameworks or by using empirical methods, or both (e.g., Schmertmann, 1978; Campanella and Robertson, 1988; Briaud and Miran, 1992; Lunne et al, 1997).

Res-2D method is imaging resistivity in 2 (two) dimension meter the data obtained by geoscanner. Geoscanner is a tool for determining type of soil layers; the level of ground water table; resistivity of soil layer in *Ohmmeter* unit (Ωm). In Indonesia, Center for Mineral Resources Technology (Pusat Teknologi Sumberdaya Mineral) at the Center for Research and Application Technology (Badan Pengkajian & Penerapan Teknologi or BPPT) has been developing the Res-2D method for mining exploration works. Res-2D has some advantages, such as in-situ method for chemical analyses of liquid, powder, solid or biogenic matter with a minimum sample preparation, fast non-destructive data acquisition from points 2D-profiles (full spectrum evaluation), high spatial resolution, variable step size and time acquisition. In addition, geoscanner can save exploration cost indirectly by the time shortening and reduction the number of drilling or boring point. This paper will discuss application of Res-2D to predict the geostratigraphic profiling and compare to the soil layers obtained from cone penetrometer test. The study area is focused at around Depok City.

BRIEF REVIEW

This paper refers to several published methods of soil profiling. All but two of these apply cone resistance *(q_c)* were plotted against the friction ratio *(R_f)*.

1. Soil Classification by Cone Penetrometer

Begemann (1965) pioneered soil profiling from the CPT, showing that, while coarse-grained soils generally indicate larger values of cone resistance *(q_c)* and sleeve friction *(f_s)* than do fine-grained soils, the soil type is not a strict function of either cone resistance or sleeve friction, but of a combination of the these values. Figure 1 presents the Begemann soil profiling chart showing q_c as a function of f_s (linear scales). Begemann showed that the soil type is a function of the ratio between the sleeve friction and the cone resistance (the friction ratio, R_f). The slope of the fanned-out lines shows the friction ratio. The friction ratios identify the soil types as shown in Table 1.

TABLE 1. Soil type as a function of friction ratio (Begemann, 1965)

Soil type	Friction ratio (%)
Coarse sand with gravel through fine sand	1.2 -1.6
Silty sand	1.6 - 2.2
Silty sandy, clayey soils	2.2 - 3.2
Clay and loam and loam soils	3.2 - 4.1
Clay	4.1 - 7.0
Peat	> 7

Sanglerat et al (1974) proposed the chart shown in Figure 2, presenting data from an 80 mm diameter research penetrometer. The chart plots the cone resistance (logarithmic scale) versus the friction ratio (linear scale). This manner of plotting has the apparent advantage of showing cone resistance as a direct function of the friction ratio and therefore, of the soil type. Plotting a value against itself makes it a reduced amount of resolution and limits the area of the data to a family of more or less narrow hyperbolic zones near the axes. In reality, the friction ratio is the inverse of the ordinate and the values are patently not independent. That is, the cone resistance is plotted against its own inverse, multiplied by a variable that ranges normally from a low of about 0.01 to a high of about 0.07. The plotting of data against their own inverse values will predispose the plot to a hyperbolically shaped zone ranging from large ordinate values at small abscissa values through small ordinate values at large abscissa values. The resolution of data representing fine-grained soils is very much exaggerated as opposed to the resolution of the data representing coarse-grained soils. Simply put, while both cone resistance and sleeve friction are important soil profiling parameters, plotting one as a function of the other may distort the information. Notice that Figure 2 also defines the soil type by its upper and lower limits of cone resistance and not just by the friction ratio.

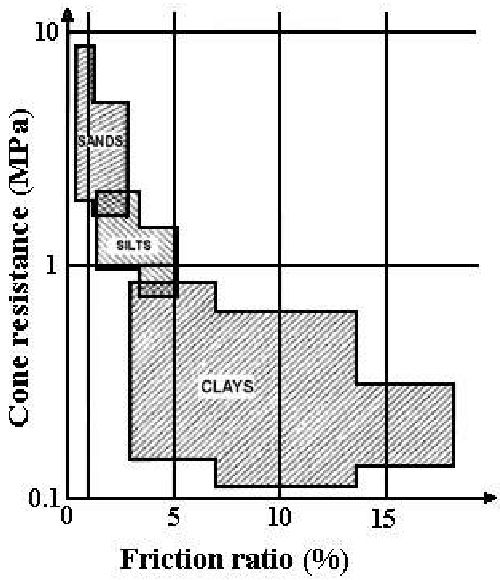


FIGURE 1. The Begemann original profiling chart (Begemann, 1965)

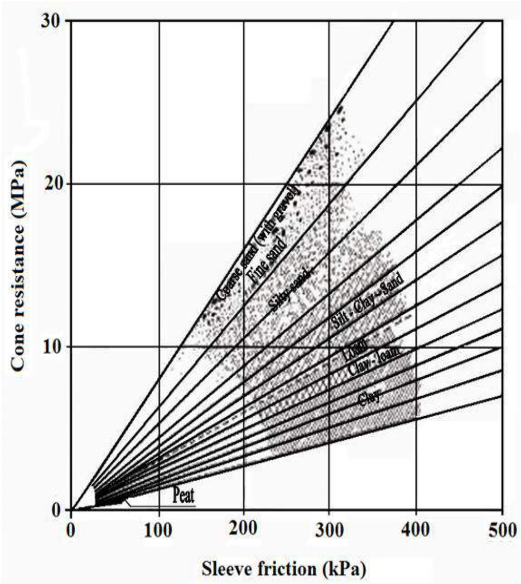


FIGURE 2. Plot of data from research penetrometer (Sanglerat, 1974)

Schmertmann (1978) proposed the soil profiling chart shown in Figure 3. It presents boundaries for loose and dense sand and consistency (undrained shear strength or C_u) of clays and silts, which are imposed by definition and not related to the soil profile interpreted from the CPT results. The Schmertmann (1978) chart also presents the cone resistance as a plot against the friction ratio, that is the data are plotted against their respective inverse. Figure 4 shows the Schmertmann chart converted to a Begemann type graph (logarithmic scales), re-plotting the Figure 3 envelopes and boundaries as well as text information. Schmertmann also mentions that soil sensitivity, friction sleeve surface roughness, soil ductility and pore pressure effects can influence the chart correlation. Above all, the Schmertmann chart is still commonly applied "as is" in North American practice.

Searle (1979) presented a CPT profiling chart shown in Figure 5. This chart is based on mechanical cone penetrometer data. In addition to separation on soil types, the chart details areas for relative density *(R_D)*, undrained shear strength *(C_u)* and friction angle *(ϕ')*, suggesting that these values are functions of both cone resistance and friction ratio. It is questionable if the ability of the cone, indeed the mechanical cone, can provide all these engineering parameters for design works.

Douglas and Olsen (1981) were the first to propose a soil profiling chart based on tests with the electrical cone penetrometer.

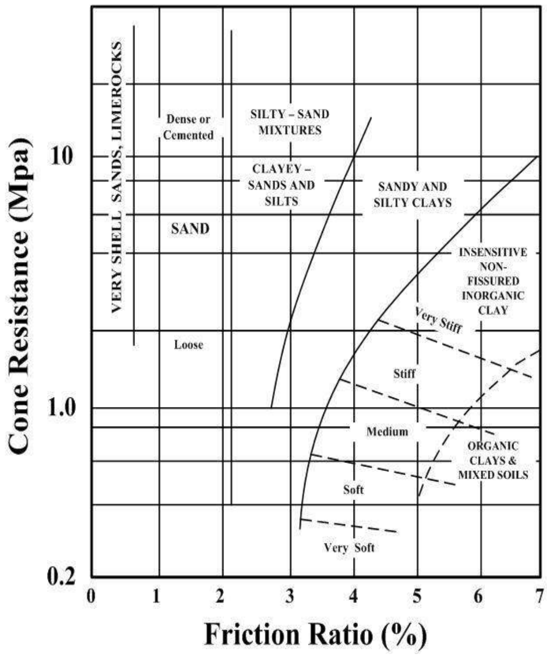


FIGURE 3. The Schmertmann profiling chart (1978)

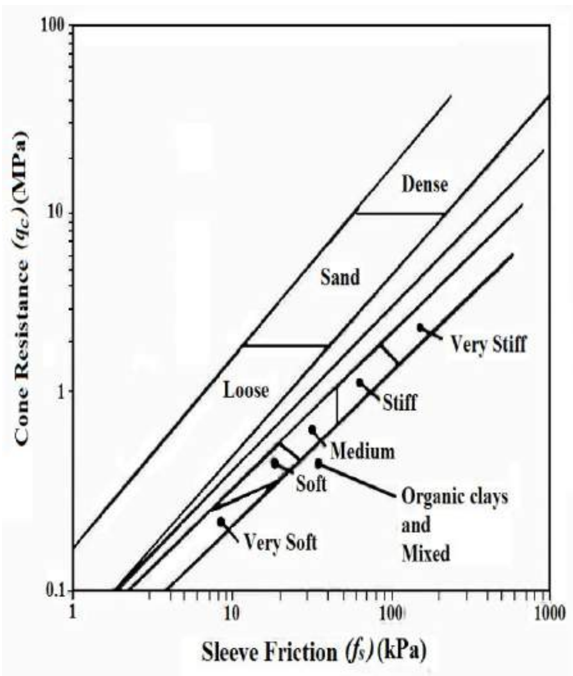


FIGURE 4. The Schmertmann profiling chart converted to a Begemann type profiling chart (Eslami & Fellenius, 2004)

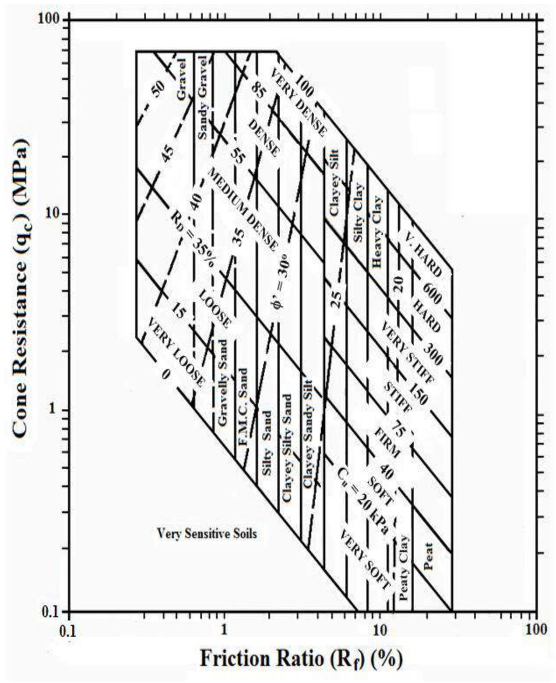


FIGURE 5. Profiling chart by Searle (1979)

They published the chart shown in Figure 6 that appends classification per the unified soil classification system to the soil type zones. The chart also indicates trends for liquidity index and earth pressure coefficient, as well as sensitive soils and "metastable sands". The Douglas and Olsen chart envelops several zones using three upward curving lines representing the increasing content of coarse-grained soil and four lines with equal sleeve friction. In this way, sensitive or "metastable" soils can be distinguished (shown on the lower left corner of the chart). Comparing the Figure 6 with the Figure 3, a difference emerges in implied soil type response**:** while in the Schmertmann chart the soil type envelopes curve downward, in the Douglas and Olsen chart they curve upward. Zones for sand and for clay are approximately the same in the two charts.

Vos (1982) suggested using the electrical cone penetrometer to identify soil types from the friction ratio as shown as Table 2. The percentage are similar, but not identical to those recommended by Begemann (1965). Robertson and Campanella (1983) proposed the profiling chart shown in Figure 7, which is very similar to that shown in Figure 6 of Douglas and Olsen (1981). Most of the CPT methods are locally developed.

TABLE 2. Soil type as a function of friction ratio (Vos, 1982)

Soil type	Friction ratio
Coarse sand and gravel	< 0,5 %
Fine sand	1 % - 5 %
Silt	1,5 % - 3 %
Clay	3 % - 5 %
Clay	4,1 % - 7 %
Peat	> 5 %

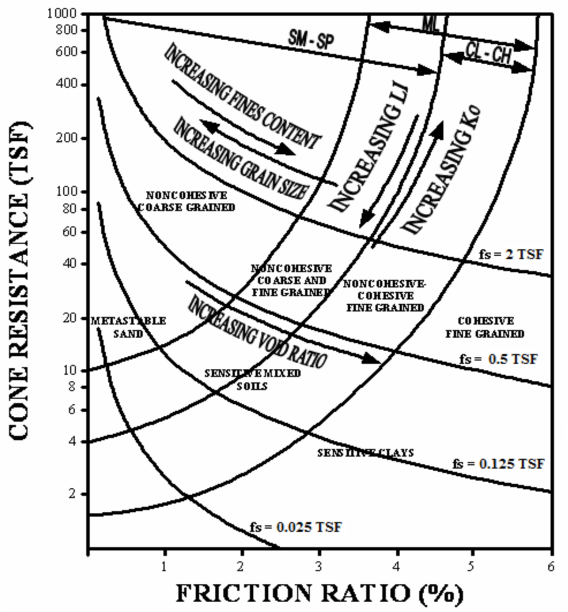


FIGURE 6. Profiling chart by Douglas and Olsen (1981)

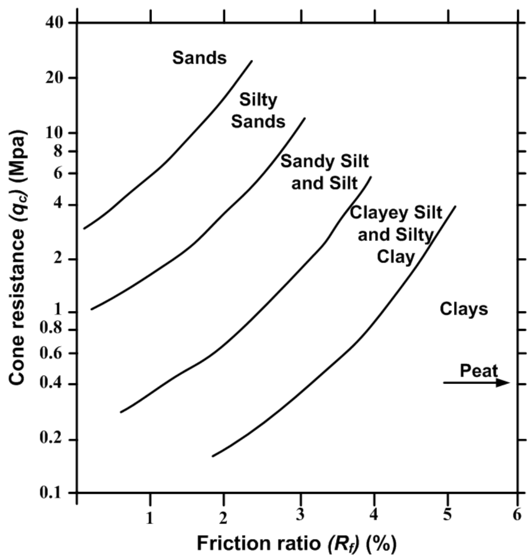


FIGURE 7. Profiling chart per Robertson and Campanella (1983)

When using the referenced CPT methods for soil profiling, the following difficulties arise, such as: (1) most of the CPT methods are locally developed, that is, they are based on limited types of CPT soundings and soils, and therefore may not be relevant outside the local area; (2) The CPT profiling methods based on mechanical and electrical data (Begemann, Schmertmann, Sanglerat, Searle, Douglas and Olsen, Vos, Olsen and Mitchell) was developed before the piezocone came in to general use. Therefore, they do not benefit from the pore pressure measurements achievable with the piezocone, that is, they are not correct for the pore pressure on the cone shoulder and the developed soil profiling can not be correlated to excess pore pressure as an indication of dilation (negative excess pressure) or liquefaction (very large positive excess pressure). The error due to omitting the pore water pressure correction is large in fine-grained soils and smaller in coarse-grained soils; (3) Many of the profiling methods require manipulation of the CPT data which is not easy to perform. For example, in a layered soil, should a guesstimated “typical” total density value be used in determining the overburden stress or a value that accurately reflects density? Moreover, whether the soil is layered or not, determining the effective overburden stress (needed for normalization) requires knowledge of the pore pressure distribution. The latter is far from always hydrostatic, but can have an upward or downward gradient; this information is rarely available; (4) Some profiling methods, e. g., Robertson (1990), include normalizations of the CPT data. The normalization by division with the effective overburden stress does not seem relevant. For example, the normalized values of fine-grained soils obtained at shallow depth (where the overburden stress is small) will often plot in zones for coarse-grained soil.

No doubt CPT sounding information from a specific area or site can be used to detail the chart and result in the adding of envelops. However, there is a danger in producing a very detailed chart inasmuch as the resulting site dependency easily gets lost leading an inexperienced user to apply the detailed distinctions beyond their geologic validity. Naturally, it cannot serve as the exclusive site investigation tool and soil sampling is still required. When the CPT is used to govern the depths from which soil samples are recovered for detailed laboratory study, fewer sample levels are needed, thus reducing the costs of a site investigation while simultaneously increasing the quality of the information because important layer information and layer boundaries are not overlooked.

2. Soil profiling by Res – 2 D

Center of Mineral Resources Technology at BPPT office has applied the Resistivity Method (Res – 2D) for ground water; coal mining; and exploration works. Resistivitymeter has been completed by Geoscanner device for data acquisition on Res – 2D automatically; faster; and more accurate. These devices actually are the modification model for supporting tools of geo-electric. According to data interpretation processed by geoscanner device and Res – 2D model, the data results has shown that the geology condition of subsurface closes to the existing condition. The data results can be used to determine the boring location accurately and to predict the volume of material source.

Parameter predicted by geo-electric method is voltage potential and electric current, and the resistivity value can be determined by:

$$U=-\int_{\infty}^{r}E\,dr=\frac{1}{4\pi\varepsilon}\frac{Q}{r} \quad (1)$$

where U is the potential energy; E is field of electrical current; Q is the Coulomb force; π and ε is constant; r is the distance between the electric charged.

Electric current is negative charge motion of material in the process of setting up itself to the balance. This event occurs when a material susceptible to interference due to electric field. When electric field always has one fixed direction, the electric current flowing also will have a fixed direction. The electric current consists of direct current (DC) and alternating current (AC). The correlation between electric current and electric charge can be expressed by:

$$I=\left(\frac{dQ}{dt}\right) \quad (2)$$

According to Ohm Law, the correlation between the magnitude of electric potential (V); electric current (I); and magnitude of resistance wire conductor is:

$$V=R.I \quad (3)$$

In the geo-electric method 1 D, discussion to electric current on the earth is based on assumption that earth as an isotropic homogeny media. Thus, rock layer at the below of surface earth is assumed that the shaped layer. In such condition, electric potential around the electric current at the below and the surface of earth can be shown by Figure 8 and 9.

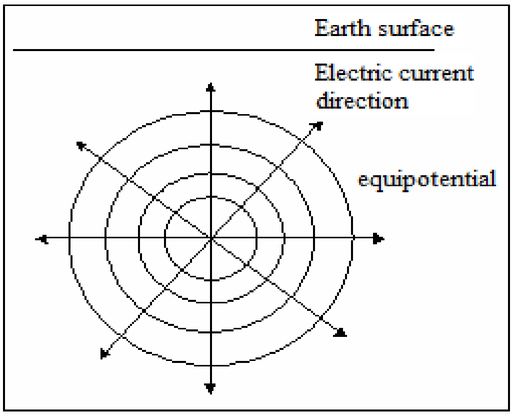


FIGURE 8. The electric current direction and equipotential line from the electric current source at the below of earth (BPPT – 2007)

Figure 8 shows the electric current radially outward from the point source, amount of the electrical current to the outside through the surface of the spherical surface with radius r is:

$$I = JA = J4\pi r^2 = -\sigma\left(\frac{dV}{dr}\right)4\pi r^2 \quad (4)$$

since $\sigma = 1/\rho$; then $I = -\left(\frac{1}{\rho}\frac{V(r)}{r}\right)4\pi r^2$ (5)

Thus, $V(r) = \frac{I\rho}{4\pi r}$ and $\rho = 4\pi r\frac{V}{I}$ (6)

When the point of the electric current on the discussion above is located at the surface of earth, the direction of the electric current and equipotential line can be shown on the Figure 9.

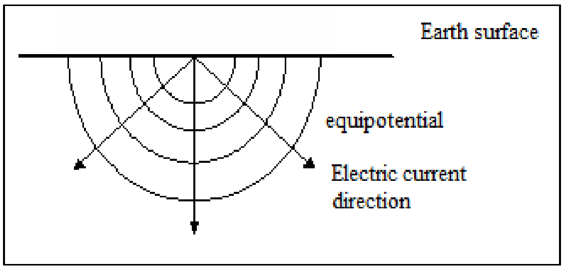


FIGURE 9. The electric current direction and equipotential line from the electric current source at earth surface (BPPT – 2007)

Figure 9 shows distribution area of electric current direction is the half sphere with a surface area equal to 2πr. Thus, the Equation (6) becomes:

$$V(r) = \frac{I\rho}{2\pi r} \text{ and } \rho = 2\pi r\frac{V}{I} \quad (7)$$

Usually, on the geo-electric survey is used 2 (two) electric current sources. Thus, the electric current direction and equipotential line can be shown at Figure 10.

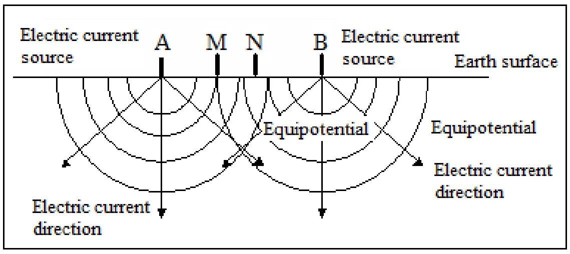


FIGURE 10. The electric current direction and equipotential line from 2 (two) the electric current sources at earth surface (BPPT-2007)

Figure 10 shows 2 (two) sources of the electric current as the point A and B, and measurement of potential difference is conducted at the point M and N. The potential difference between M and N caused by electric current A and B can be determined by:

$$\Delta V = \Delta V_M - \Delta V_N = \frac{I\rho}{2\pi}\left[\left(\frac{1}{AM} - \frac{1}{BM}\right) - \left(\frac{1}{AN} - \frac{1}{BN}\right)\right] \quad (8)$$

$$\rho = 2\pi\frac{\Delta V}{I}\left[\left(\frac{1}{AM} - \frac{1}{BM}\right) - \left(\frac{1}{AN} - \frac{1}{BN}\right)\right]^{-1} \quad (9)$$

The Equation (9) is expressed by AM is the distance between A to M; BM is the distance between B to M; AN is the distance between A to N; BN is the distance between B to N; ΔV is the potential difference measured at the field; I is the the electric current measured at the field; ρ is the resistivity calculated and then used to interpret the soil layer.

Principally, measurement of resistivity method is injection process of electric current (I) (in unit of mA) into the earth through 2 (two) current electrodes, then potential difference (V) occurred (in unit of mV) can be measured from these potential electrodes. Relative resistivity (ρ_a) can be determined by measurement results from electric current and potential difference for each distance of differed electrodes as:

$$\rho_a = k\left(\frac{V}{I}\right) \quad (10)$$

where k is the geometric factor depending on the setting out of electrode (configuration).

Based on configuration of electrodes, Resistivity Method (Res – 2D) (imaging resistivity) is recognized by some measurement configuration, such as dipole – dipole; pole – dipole; Wenner; and Wenner – Schlumberger methods. Difference of type and configuration model has its advantage; shortage; and sensitive values. Some factors influencing type selection of electrodes configuration, such as available space for lay out of electrodes; sensitivity to lateral inhomogeneity; sloping surface; etc. (Reynolds, 1997). As a guideline in the selection of configuration type for measurement resistivity, comparison of measurement resistivity is shown in Table 3.

TABLE 3. Comparison of electrode configuration of Wenner, Shlumberger dan Dipole-dipole (Reynolds, 1997) (BPPT – 2007)

Criteria	**Wenner**	**Schlumberger**	**Dipole-dipole**
Vertical resolution	+++	++	+
Depth penetration	+	++	+++
Suitability to VES	++	+++	+
Suitability to CST	+++	x	+++
Sensitivity to orientation	Yes	Yes	Moderate
Sensitivity to lateral inhomogeneity	High	Moderate	Moderate
Availability of interpretation aids	+++	+++	++

+ = poor; ++ = moderate; +++ = good; x = unsuitable
CST = constant separation traversing
VES = vertical electrical sounding

This research applied the Wenner method. The procedure of Wenner method is shown in Figure 11. The Wenner method is the modification from Schlumberger method, where $a = MN = 1/3\ AB$

The resistivity value for Wenner configuration is:

$$\rho_a = k\left(\frac{V}{I}\right) = 2\pi a\left(\frac{V}{I}\right) \quad (11)$$

Where a adalah space between C1 – P1; P1 – P2; and P2 – C2.
Data results obtained from field measurement are position of every electrode (x,y,z); *V* (potential difference); and I (electric current).

With using Geoscanner 1803 AT consisted of 32 electrodes for Wenner configuration with space measurement (a) equal to 5 m, visualization of target and depth of resistivity measurement are shown in Figure 12.

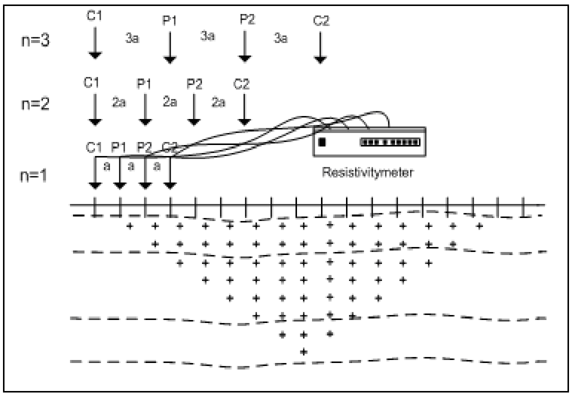


FIGURE 11. Wenner configuration for RES – 2D (BPPT – 2007)

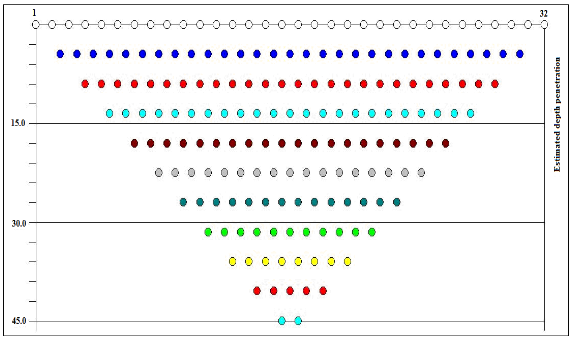


FIGURE 12. Distribution of resistivity point at the sub-surface with Wenner configuration, 32 electrodes, and space of 5 m (BPPT-2007)

Resistivity value calculated is not original resistivity value from subsurface, but relative value where resistivity of homogeneity from soil/rock expressing same resistance value for same electrodes configuration. Relationship between relative and original resistivity is complex correlation. To determine and model the value of resistivity from subsurface can be performed by a computer programing to inverse from relative resistivity values.

Prior to the measurement result data is inserted into the software program, the magnitude of relative resistivity (ρ_a) is calculated accordance with configuration geometric factor. All data is arranged by a format of input file to run the software program. Processing and modeling resistivity data for Res – 2D can be summarized by Figure 13. At present, there is some software for 2D or 3D of resistivity data processing and modeling, such as RES 2D / 3D INV; EARTIMAGER for 2D and 3D.

To obtain the model resistivity close to the actual state of the subsurface, then the required number of reference data as follows:

- Theoretically, assessment for resistivity values of soil and rock.
- Geology data, geology map; and rock data (type; thickness; dispersion; and physically characteristic).
- Boring data for model calibration closing to existing condition.

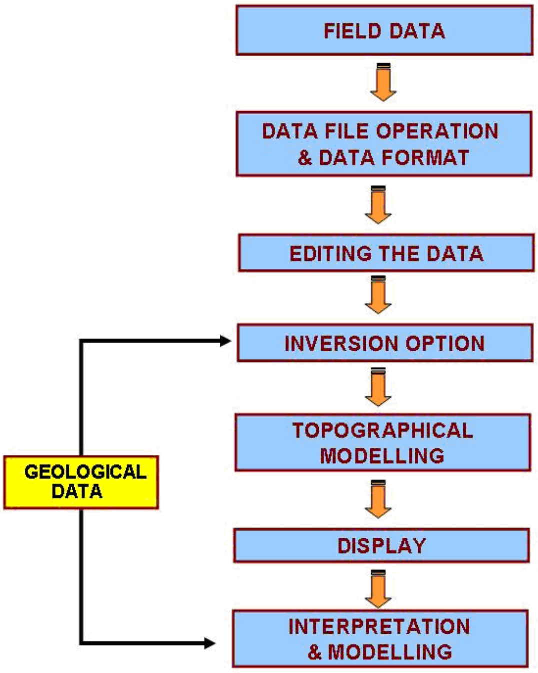


FIGURE 13. Data processing and modeling for *Res - 2D* (BPPT-2007)

INTERPRETATION OF SOIL LAYERS

1. By Cone Penetrometer

Cone penetrometers used for soil exploration is Cone Penetrometer Test (CPT) A CPT system includes the following components: (1) a mechanical of hydraulic penetrometer pushing system with rods (2.5 ton); (2) Manometer with capacity of 60 and 250 kg/cm^2; (3) Biconus. Figure 14 shows the device used for this study. Additional details on these topics may be found in Robertson and Campanella (1984), Briaud and Miran (1992), and Lunne et al. (1997).

The friction ratio (FR) is defined as the ratio of the sleeve friction to cone resistance, designated FR or R_f (%). The friction ratio has been used as a simple index to identify soil type. In clean quartz sands to siliceous sands (comparable parts of quartz and feldspar), it is observed that friction ratios are low: $R_f < 1\%$, whereas in clays and clayey silts of low sensitivity, $R_f > 4\%$. However, in soft sensitive to quick clays, the friction ratio can be quite low, approaching zero in many instances.

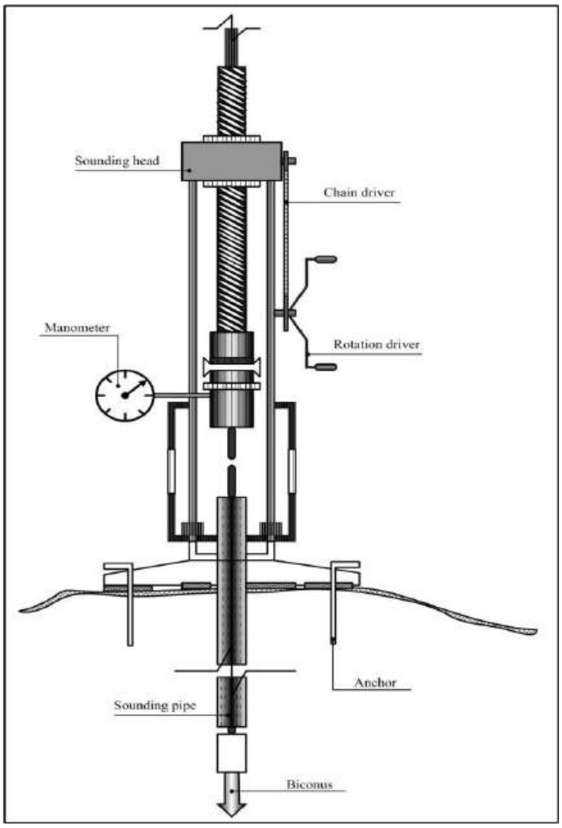


FIGURE 14. Penetrometer devices installation

As noted previously, CPT offers an excellent means for profiling the subsurface geostratigraphy to delineate soil strata and sand stringers. Figure 14 provides an example of a piezocone record located behind of Soil Mechanics of State Polytechnic of Jakarta. This sounding was conducted to final penetration depth of 6.0 m (20 ft) below grade. The exceptional detailing of the clays with interbedded clayey and silty sand layers and small stringers is quite evident.

Two typical sounding results have been selected to investigate the suitable soil classification method. One is at location of borehole No. 1, which represents a relative uniform clay layer about 3.50 m followed by alternative silty clay and sand layers. Another is at borehole No. 2, where deposits a thick clay layer about 2.50 m depth from the ground surface and there are alternative layers of silty clay and sand. Groundwater level is about 10.0 m from the ground surface. Sounding results of the two locations are shown in Figures 15 and 16. Using the existing classification methods, the points will be checked are: (1) which method can be used to classify the soil layer above the groundwater level since the soil strata above the groundwater level; and (2) which method can classify the alternatives clayey and silty sand layers more clearly. Sounding results are compared by borehole records for location No. 1 and No. 2, respectively. Figures 15 and 16 show the comparison of the estimated soil profiles by the methods of Schmertmann profiling chart converted to a Begemann type profiling chart (Eslami & Fellenius, 2004) and Robertson & Campanella (1983).

The other methods have disadvantage at study area when they are used to plot data cone resistance (q_c) and friction ratio (*FR* or R_f). Begemann's chart (1965) is directly applicable only to the specific geologic locality where it was developed. Chart from Sanglerat (1974) shows the resolution of data representing fine-grained soils is very much exaggerated as opposed to the resolution of the data representing coarse-grained soils. Chart from Schmertmann's (1978) is intended for typical reference and includes local correlations are preferred. Chart from Searle (1979) and Douglas & Olsen (1981 proposed a soil profiling chart based on tests with the electrical cone penetrometer, the devised used at study area is the mechanical cone penetrometer. Figures 17 and 18 show the comparison of the estimated soil profiles by the all methods with the borehole records for location No. 1 and No. 2, respectively.

As shown in Figures 17 and 18, the methods from Begemann (1965); Schmertmann (1978); and Robertson & Campanella (1983) can classify the soil strata almost same with the borehole result. But, the methods from Sanglerat (1974); Eslami & Fellenius (2004); Searle (1979); and Douglas & Olsen (1981) can identify the clay layer and obviously it is not correct; and there are discrepancies between borehole records and the classifications by these methods. We judged that these last methods yield poor results on this aspect.

From Figures 17 and 18, it can be seen that Begemann (1965); Schmertmann (1978); and Robertson & Campanella (1983) can classify the alternatives clayey and silty sand layers more clearly and these methods can identify nearly the borehole result. However, the other methods had poor performance on classifying soil strata at the both location of penetrometer tests. These three methods will be used to compare soil strata obtained by *Res – 2 D*.

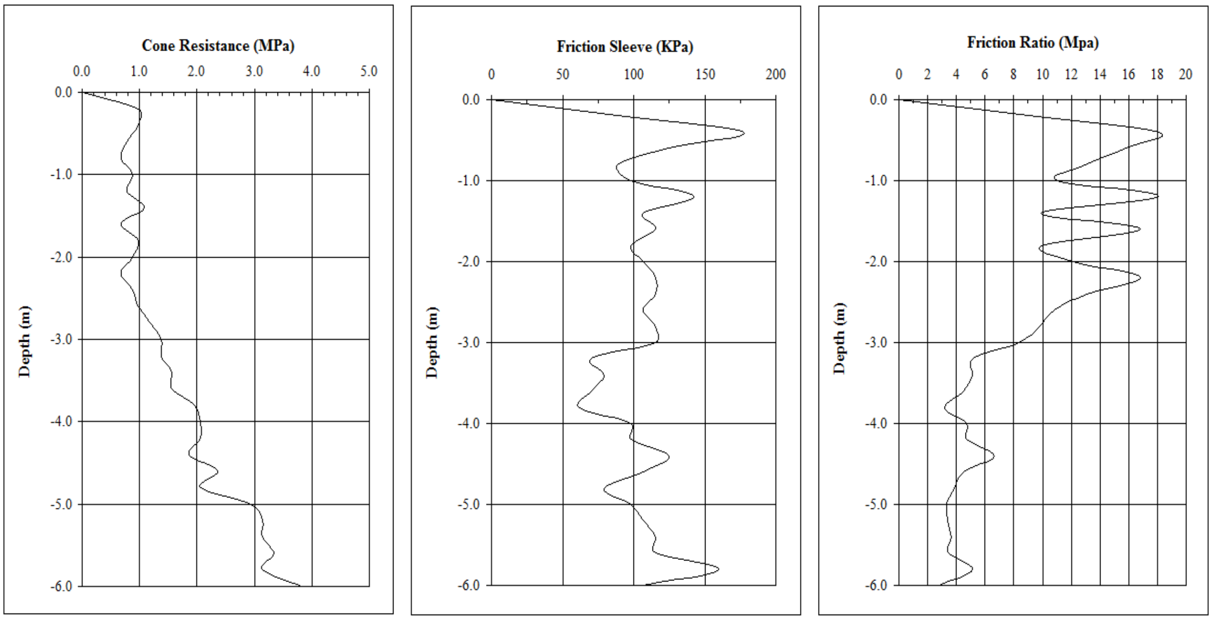


FIGURE 15. Sounding test result at location No. 1

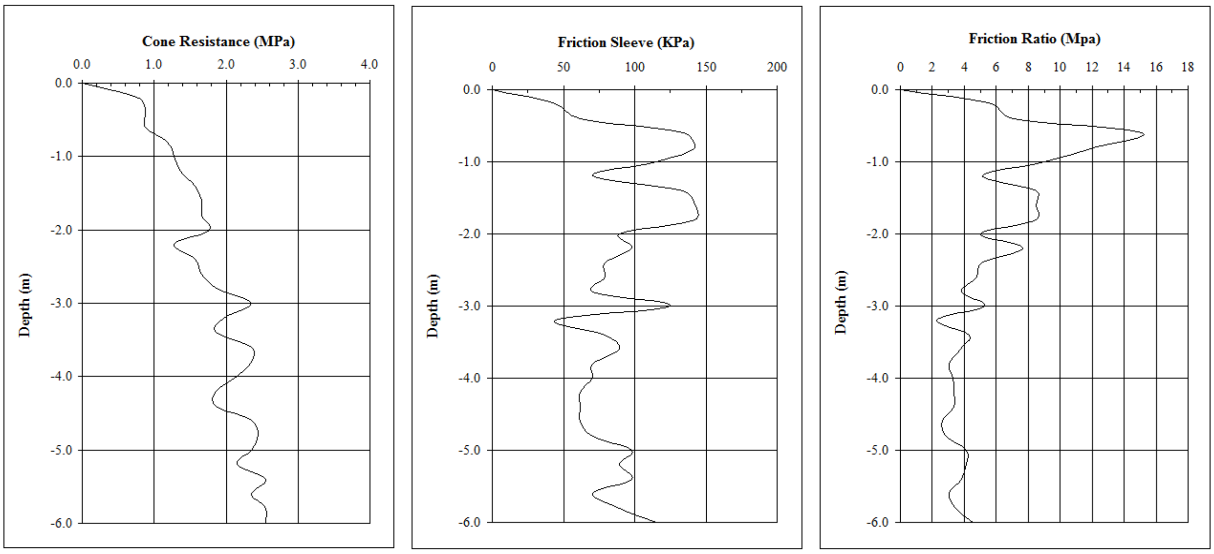
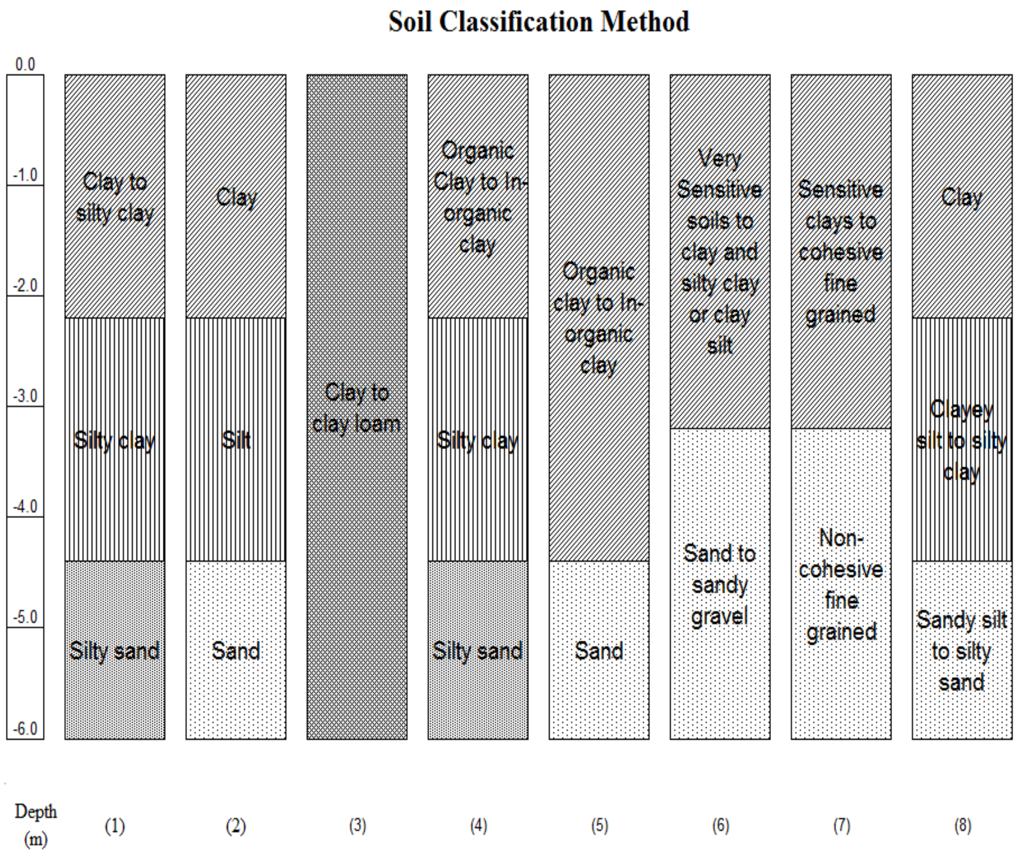


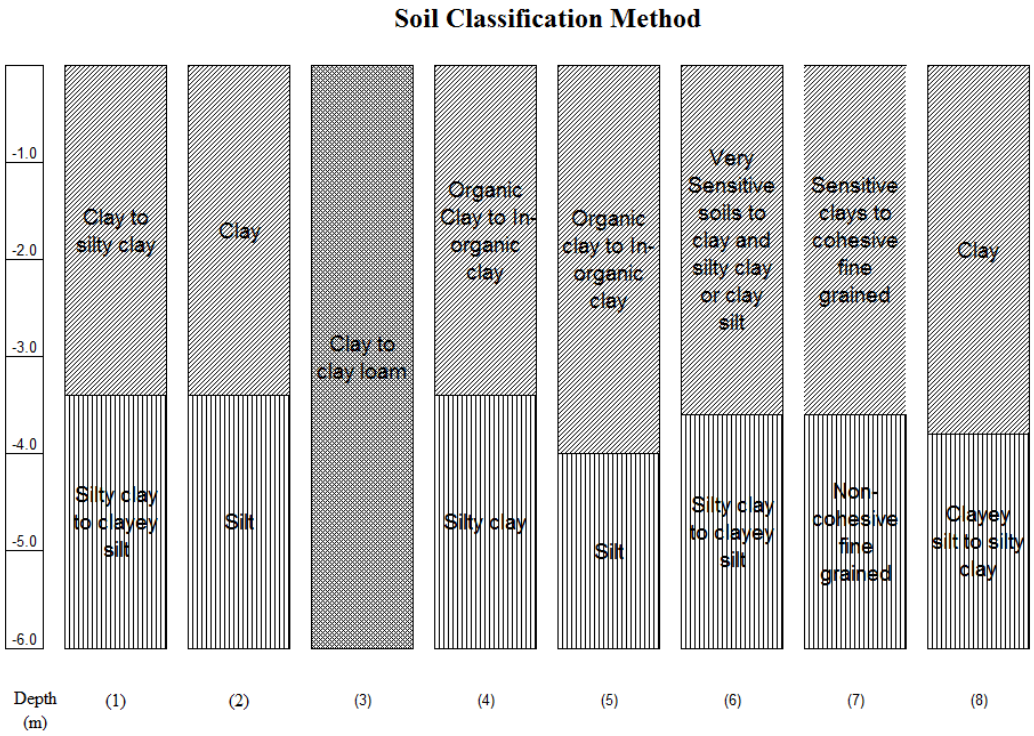
FIGURE 16. Sounding test result at location No. 2



Note:

(1) : Borehole
(2) : Begemann (1965)
(3) : Sanglerat (1974)
(4) : Schmertmann (1978)
(5) : Eslami and Fellenius (2004)
(6) : Searle (1979)
(7) : Douglas & Olsen (1981)
(8) : Robertson & Campanella (1983)

FIGURE 17. Borehole and soil classification method result at location No. 1



Note:
(1) : Borehole
(2) : Begemann (1965)
(3) : Sanglerat (1974)
(4) : Schmertmann (1978)
(5) : Eslami and Fellenius (2004)
(6) : Searle (1979)
(7) : Douglas & Olsen (1981)
(8) : Robertson & Campanella (1983)

FIGURE 18. Borehole and soil classification method result at location No. 2

2. By Res – 2 D

Data result is obtained by geo-electric survey at the study. Then, data results from geo-electric are processed by using a computer programing for Geoscanner 1803 AT consisted of 32 electrodes with geometric factor of Wenner configuration with space measurement (a) equal to 5 m and relative resistivity values are estimated (ρa). Data prepared in accordance with the format of the input file for processing and modeling programs, and incorporated into the program to perform the inversion modeling using some parameters to obtain resistivity 2D or Res-2D at study area.

Results of model measurement decribe a longitudinal section completed with relative resistivity values for existing subsurface condition. The result shows a longitudinal section with 96 m length; 16 m depth; and relative resistvity values between 2.00 to more than 400 Ohmm. Result of longitudinal section of Res-2D at the behind of Soil Mechanics Laboratory PNJ shows in Figures 19 and 20.

From survey result for Res-2D at study area can be identified as follows:

1. Resistivity values for the exixting subsurface at study area has a range between 2.0 to > 400 Ohm.m.
2. Based on geological aspect, range of relative resistivity values in accordance with soil and rock types can be interpreted:
   a. < 150 Ohm.m is a soft clay material to sandy silt to a depth of 3.0 m.
   b. 150 – 250 Ohm.m is a soft – stiff clay material to sandy silt with a depth of 3.0 to 4.0 m.
   c. > 250 Ohm.m is a stiff clay material to sand and gravel from a depth of 5.0 to 6.0 m.

From Figure 20, modeling results illustrate a cross section of soil strata using Res-2D analysis with length of 96 m; depth of 16 m; and resistivity values in a range between 2.0 to 400 ohm.m. Point A (Electrode No. 9) as shown as Figure 20 shows a point to compare soil strata obtained by cone penetrometer.

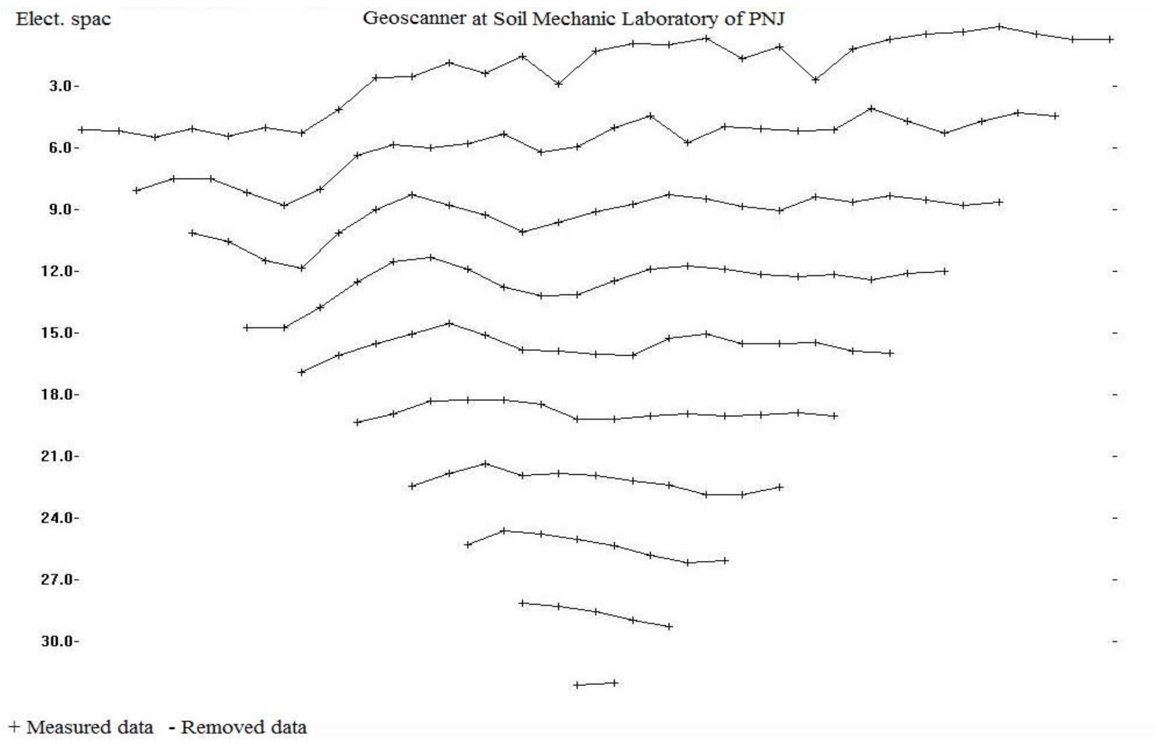


FIGURE 19. Data measurement results of Geoscanner

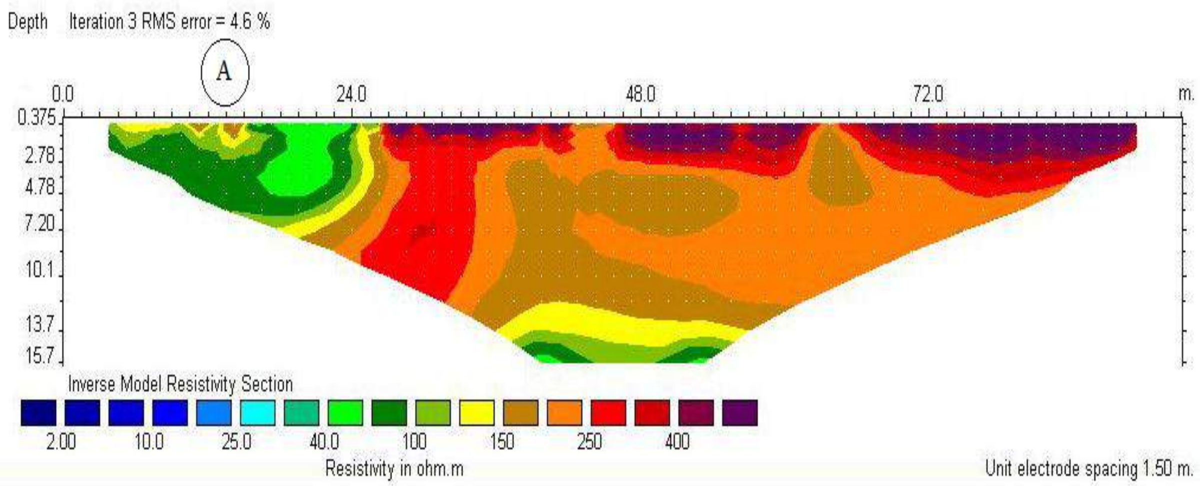


FIGURE 20. Vertical cross-section results from *Res-2D* program

COMPARISON BETWEEN CONE PENETROMETER AND RES – 2D RESULTS

From Begemann (1965); Schmertmann (1978); and Robertson & Campanella (1983) methods at locations 1 and 2, soil strata can be identified as follows:

a. For a depth of < 3.4 m is a clay layer.
b. Between a depth of 3.4 m to 4.8 m is clayey silt and silty clay.
c. Depth of 4.8 m to 6.0 m is sandy silt and silt.

From *Res-2D* at Electrode No. 9, soil strata at behind of Soil Mechanics Laboratory of PNJ based on the range of soil resistivity values can be interpreted as follows:

a. For a depth of < 3.4 m has resistivity values of 0.0 to 100 Ohm.m and it can be identified as a clay layer.
b. From a depth of 3.4 m to 4.8 m has resistivity values of 100 to 150 Ohm.m and it can be classified as a clayey silt or silty clay layer.
c. From a depth of 4.8 m to 6.0 m has resistivity value > 150 Ohm.m and it can be identified as a silty sand or sandy silt.

CONCLUSION

Seven existing methods for classifying in the soil strata from cone penetrometer records have been applied to classify the soil layer at Soil Mechanics Laboratory of PNJ. For two locations investigated, the "true" soil strata have been established from borehole records, the continuous core retrieved from the borehole.

By comparing the classifications from cone penetrometer results and the "true" soil strata, it is suggested that Begemann (1965); Schmertmann (1978); and Robertson & Campanella (1983) methods can be used to classify the soil strata at study area.

From geoscanner test and *Res-2D* analysis results produces soil strata close to borehole and cone penetrometer using 3 (three) methods above. Configuration used geo-electric is Wenner configuration because it is only for shallow depths (less than 10 m). For both should be performed at the same time to minimize the differences in soil conditions.

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REFERENCES

Begemann, H.K. (1965). The Friction Jacket Cone as an Aide in Determining the Soil Profile," *Proceedings, 6th International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, Montreal, QC, Canada, pp. 17–20.

BPPT (2007). *Metoda Tahanan Jenis 2D, Prinsip Dasar, Pengambilan Data, Pengolahan Data dan Pemodelan*. Pusat Teknologi Sumber Daya Mineral, Deputi Bidang Teknologi Mineral, Badan Pengkajian dan Penerapan Teknologi.

Briaud, J. L. and J. Miran (1992). *The Cone Penetrometer Test*, Report FHWA-SA-91-043, Fed. Highway Administration, Washington, D.C., Feb., 161 pp.

Campanella, R.G. and P.K. Robertson (1988). Current Status of the Piezocone Test. *Proceedings of the First International Symposium on Penetration Testing*, Vol. 1, Orlando, Fla. (Penetration Testing 1988), Balkema, Rotterdam, The Netherlands, Mar. 20–24, pp. 93–116.

EARTIMAGER 2D & 3D, *Resistivity and IP Inversion Software*, Advanced Geosciences, Inc., 12700 Volente Rd., FM 2769, Bldg A, Austin, Texas 78726.

Eslami, A. and Felenius, B. H. (2004). CPT and CPTu Data for Soil Profile Interpretation: Review of Methods and a Proposed New Approach, Iranian *Journal of Science & Technology, Transaction B, Vol. 28, No. B1*, Printed in Islamic Republic of Iran, Shiraz University.

Lunne, T., Robertson, P.K. and Powell, J.J.M. (1997). *Cone Penetration Testing in Geotechnical Practice*, Blackie Academic, EF Spon / Routledge Publishers, New York, N.Y., 312 pp.

Robertson, P.K. and R.G. Campanella (1984). *Guidelines for Use and Interpretation of the Electronic Cone Penetration Test*, Hogentogler & Company, Inc., Gaithersburg, Md., 154 pp.

RES2DINV & RES3DINV, Goetomo Software, 5 Cangkat Minden Lorong 6, Minden Heights 11700 Gelugor, Penang, Malaysia.

Schmertmann, J.H. (1978). *Guidelines for Cone Penetration Test: Performance and Design*, Report FHWA-TS-78-209, Federal Highway Administration, Washington, D.C, 146 pp.

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