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# *The Comparative Study of Soil Resistivity Based on General Method and Wenner Four-Pole Method*

Liu Fengjiao
Hunan Lightning Protection Center
HNLPC
Changsha, China
870476555@qq.com

Yang Jiayan, Su Kai, Wang Yaoxi,Bing Suzhi
Hunan Lightning Protection Center
HNLPC
Changsha, China
114235260@qq.com

***Abstract*—In this paper, the soil resistivity of two selected Testing Ground with non-uniform soil resistivity distribution is multiply measured by using General method and Wenner four-pole method, respectively, in order to obtain the soil resistivity characteristics under the cases of varying measurement methods, different probe depths and various environmental conditions. Meanwhile, the structure models are built via the CDEGS software (SES Canada) based on the measured data, then a comparing analysis between the models and the real geological exploration data of test sites is conducted. The results indicate that the depths of probe impose few influences on the resistivity measurements in heterogeneous soil; comparing the data measured by General method and by Wenner four-pole method, the data of former can more elaborately characterize the soil structure, and has higher degree of fitting to the geological exploration data. In complex geological environment measurement or analysis of underground pipeline, the concrete structure heterogeneous soil,General method can more accurately characterize the soil resistivity and structure than Wenner four-pole method.**

***Keywords-General method;Wenner four-pole method; soil resistivity; geologic stratification ;CDEGS.***

## I. INTRODUCTION

Earthing is one of the most basic and important safeguard in lightning disaster prevention.Earthing resistance value is an important index for measuring the earthing effect.The main factors controlling the earthing resistance value is the soil resistivity. Therefore the study on the method for accurately measuring soil resistivity is great significant to lightning disaster prevention and mitigation. Recently many scholars are making an effort to the research of the soil resistivity masurement and the factors[7-12] and soil structure reversal[1-6].However, It also found that not enough has been done the contrastive analysis of examining data accuracy from The different soil resistivity measurements，based on the complex soil structure With the development of urbanization and land hardening .So,this paper mainly uses Wenner four-pole method and General method,the first is the most frequently used method,the other is recommended in the technical specification,collects the data in two nonuniform fields, analyses the depth of the poles effect to soil resistivity based on the two methods，and then combines the soil structure reversal from CDEGS with geology and exploration data, carrys on comparative analysis.The results can provide the available information for the soil resistivity accurate masurement.

## II. SETTING TESTING GROUND

To study the accuracy of General method and Wenner four-pole method in measuring soil resistance,we set two different Testing Ground.The one is Computer Factory Testing Ground(ab:#1 Testing Ground) on the small hill in Changsha urban district,the center position at E112.98194° and N28.16333°,the topsoil is yellow soil.The other is Jiuzhoutong Pharmaceutical Logistics Center Testing Ground(ab:#2 Testing Ground),beside the Xiangjiang River,the center position at E112.92442°,N28.33506°,the topsoil is depositing sand soil.

## III. METHODS OF MEASURING

In present,when testing large area of soil,and the soil have horizontal or vertical stratification exists,The main test method using four-pole method.Four-pole method include General method(four-pole non-equidistant method) and Wenner four-pole method(four-pole equidistant method).

### *A. General method*

According to the national standard *Guide for measuring earth resistance,ground impedance and earth surface potemtials of a ground system—Part 1:Normal measurements* ， when measuring soil resistance,take four electrodes arranging in a straight line as FIG1,soil resistance can be calculated by the

distance between the pole and the grounding resistance readings.Wherein C1, C2 are current poles(unit:m),Se1、Si、Se2 are the spacing between different poles(unit:m),Do is the depth of the current poles(unit:m).

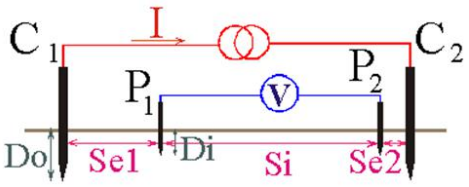


Figure 1. Wenner four-pole method

According to the potential difference between the two current poles,When considering the depth of the electrode,can Infer the soil resistance formula of General method.

$$\rho = 4\pi R /(\frac{1}{\sqrt{h_1^2+S_{e1}^2}}+\frac{1}{\sqrt{h_2^2+S_{e1}^2}}-\frac{1}{\sqrt{h_1^2+(S_{e2}+S_i)^2}}-\frac{1}{\sqrt{h_2^2+(S_{e2}+S_i)^2}}$$

$$+\frac{1}{\sqrt{h_1^2+S_{e2}^2}}+\frac{1}{\sqrt{h_2^2+S_{e2}^2}}--\frac{1}{\sqrt{h_1^2+(S_{e1}+S_i)^2}}-\frac{1}{\sqrt{h_2^2+(S_{e1}+S_i)^2}}) \quad (1)$$

Wherein R is a ground resistor,it's also the ratio of voltage and current.

At the same time, when the depth of the pole is not considered,can Infer the soil resistance formula as equation 2.

$$\rho = \frac{2\pi R}{\frac{1}{S_{e1}}+\frac{1}{S_{e2}}-\frac{1}{S_{e1}+S_i}-\frac{1}{S_{e2}+S_i}} \quad (2)$$

The Distance between the poles is indefinite,so it will be unlimited by the measurement conditions.When $S_{e1}=S_{e2}\neq S_i$, it called Bamo method, is one of the methods of measurement of soil resistance.When $S_{e1}=S_i=S_{e2}$, it called Wenner four-pole method, is also more commonly used method for measuring soil resistance recently.

### B. *Wenner four-pole method*

Figure 2 shows Wenner four-pole method,In order to facilitate the calculation,the distance between the pole a should much larger than the depth of the pole, general shall satisfy a> 20h.

According to formula (1),deduced when considering the depth of the poles,the Soil resistance formula by Wenner four-pole method as formula (3).

$$\rho = \frac{2\pi R}{\frac{1}{\sqrt{h_1^2+a^2}}+\frac{1}{\sqrt{h_2^2+a^2}}-\frac{1}{\sqrt{h_1^2+4a^2}}-\frac{1}{\sqrt{h_2^2+4a^2}}} \quad (3)$$

Wherein a is the distance between poles, the unit is meter, $a=S_{e1}=S_i=S_{e2}$.

When not considering the depth of the poles, into the formula (3),deduced the Soil resistance formula by Wenner four-pole method as formula (4).it's consistent with Other standards,can be proved the derivation correct.

$$\rho = 2\pi aR \quad (4)$$

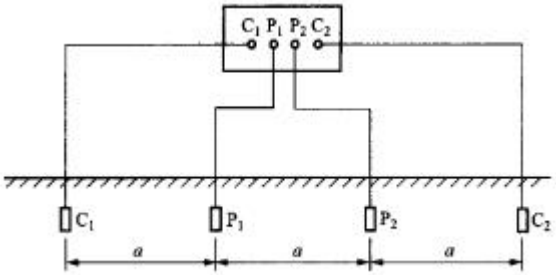


Figure 2. Wenner four-pole method

### C. *Data Collection*

Using General method and Wenner four-pole method,measuring data multiple times in #1 Testing Ground and #2 Testing Ground.The instrument is KD2571BV grounding resistance tester.Using different electrodes spacing and depth to measure the soil resistance ,we got 60 and 161 groups data from the two groups respectively,Detailed data are shown in Table 1.

From the soil resistance results,the soil resistance data by General method vary with the pole distance changed,Inferred different soil hierarchy,as shown in Table 2 Group 4 data are close with the exploration report.the soil resistance data by Wenner four-pole method don't vary with the pole distance changed,the data are more concentrated,as shown in Table 2 Group 5/6 and Group 7/8 data,but big gap with the exploration report.

## IV. DATA ANALYSIS

### A. *Analysis the influence of poles depth*

The depth of the poles influence the electrical discharges distribution and will have a impact on measurement data in the soil resistivity measurement. So， this paper collects several rows of data with the same pole distance but different depth of the poles. Use formula （5）to calculate the difference of soil resistivity when considering or not considering the depth of the poles.

$$d = \frac{\rho_1-\rho_2}{\rho_1}\times 100\% \quad (5)$$

Based on soil resistivity measurements, we plot the effect of the depth of the poles to the soil resistivity in two testing grounds. Formula (6) and (7) are given the value of d varying for different pole distance based on General method and Wenner four-pole method. Fig 3 indicates that the two curves are successfully simulated. The correlation coefficients are 0.7336 and 0.9244, respectively. In light of these, the differences of soil resistivity when considering or not considering the depth of the poles are minor(they all are less than 14%).In the same field，that difference based on General method is bigger than the difference based on Wenner four-pole method. But they all increase as pole distance increases.

$$d = 4.2774e^{-0.086x} \quad (6)$$

$$d = 14.771e^{-0.147x} \qquad (7)$$

TABLE I. THE SUMMARY TABLE OF THE SOIL RESISTIVITY MEASUREMENT DATA(SET)

| field | | the data set of General method | the data set of Wenner four-pole method | Remark |
|---|---|---|---|---|
| #1 Testing Ground | | 45 | 15 | poles distances: 2m-10 m, poles depth: 0.2m-0.4m |
| #1 Testing Ground | No.1 | 46 | 33 | poles distances: 1m-20 m, poles depth: 0.2m-0.4m |
| | No.2 | 24 | 5 | poles distances: 1m-20 m, poles depth: 0.4m |
| | No.3 | 44① | 8 | poles distances: 1m-20 m, poles depth: 0.4m |
| | Totle | 115 | 46 | / |

Remark：①use Bamo method to collect soil resistivity measurement data.

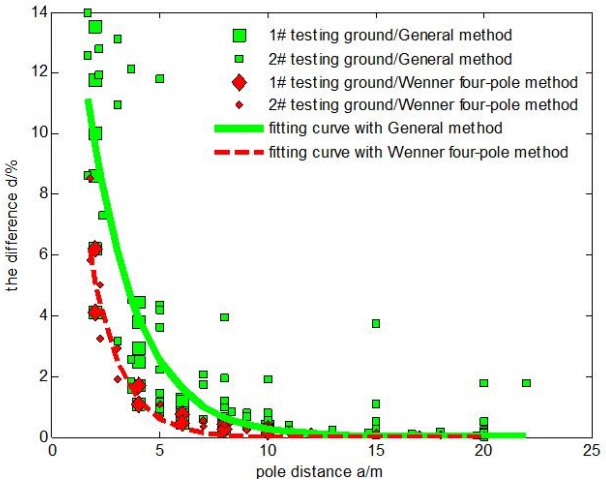


Figure 3. The effect of the depth of the poles to the soil resistivity in two testing Grounds based on two methods

### *B. CDEGS software calculation result contrast*

Because of soil layer, the measured apparent resistivities are not a real resistance, These data are counted inversion using CDEGS grounding RESAP calculation module,One of the results is figure 4.

TABLE II. SOME SOIL RESISTIVITY MEASUREMENT DATA AND THEIR CALCULATIONS

| No. | Field | Method | $S_{e1}$（m） | $D_o$（m） | $D_i$（m） | $S_i$（m） | $S_{e2}$（m） | Earth resistance R（Ω） | Soil resistivity（Ω.m）① | Soil resistivity（Ω.m）②( |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1# | General | 6 | 0.2 | 0.4 | 8 | 10 | 2.4 | 108.3 | 107.96 |
| 2 | 1# | General | 8 | 0.4 | 0.2 | 10 | 6 | 2.6 | 94.4 | 94.1 |
| 3 | 2# | General | 9 | 0.4 | 0.2 | 15 | 21 | 4.5 | 317.2 | 316.67 |
| 4 | 2# | General | 28 | 0.2 | 0.4 | 11 | 21 | 11.2 | 2662.4 | 2661.33 |
| 5 | 1# | Wenner | 6 | 0.4 | 0.4 | 6 | 6 | 1.2 | 45.59 | 45.24 |
| 6 | 1# | Wenner | 6 | 0.4 | 0.2 | 6 | 6 | 0.9 | 34.09 | 33.93 |
| 7 | 2# | Wenner | 3 | 0.4 | 0.2 | 3 | 3 | 7.6 | 146.2 | 143.45 |
| 8 | 2# | Wenner | 3 | 0.2 | 0.4 | 3 | 3 | 7.5 | 143.32 | 140.62 |
| 9 | 2# | Bamo | 12 | 0.4 | 0.4 | 21 | 12 | 4.56 | 270.59 | 270.14 |
| 10 | 2# | Bamo | 10 | 0.4 | 0.4 | 25 | 10 | 5.8 | 255.65 | 255.1 |

Note：①the soil resistivity calculations considering the depth of the poles with formula (1) or (3).

②the soil resistivity calculations not considering the depth of the poles with formula (2)or(4).

TABLE III. MEASURING DATA INVERSION STATISTICAL TABLE USING WENNER METHOD

| Field | The number of measurement data (group) | Probe depth (m) | Layers | Thickness of layers (m) |
|---|---|---|---|---|
| #1 | 15 | 7.5 | 2 | 0.23 |
| #2 | 33 | 15 | 2 | 2.55 |
| #2 | 5 | 15 | 2 | 0.33 |
| #2 | 8 | 15 | 2 | 0.71 |
| Other area | 9 | 225 | 3 | 20.07 |

TABLE IV. TESTING GROUND OF WENNER FOUR-POLE METHOD OF INVERSION OF SOIL STRUCTURE

| Considering depth of the probe | | | Regardless of the probe depth | | |
|---|---|---|---|---|---|
| *Stratification* | *Layer height (m)* | *Soil resistivity (Ω·m)* | *Stratification* | *Layer height (m)* | *Soil resistivity (Ω·m)* |
| Top | 0.228 | 59.44128 | Top | 0.207 | 52.80252 |
| Bottom | ∞ | 41.60616 | Bottom | ∞ | 41.47434 |
| Mean square error | 14.01% | | Mean square error | 13.90% | |

Note: measuring pole spacing of 2 m, 4 m, 6 m, 8 m, 10 m, measured depth of 7.5 m.

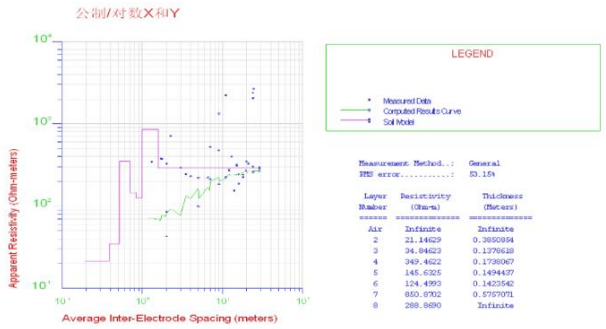


Figure 4. One of calculation results in the 2 # test area using General method

The two methods of measuring soil layered structure are given in the tables III and IV, respectively, at two sites using CDEGS software calculation.The table shows General method and Wenner four-pole method measuring results showed that 1 # Testing Ground soil structure can be regarded as a simple horizontal layered structure.

TABLE V. 1 # TESTING GROUND GENERAL METHOD OF INVERSION OF SOIL STRUCTURE

| Considering depth of the probe | | | Regardless of the probe depth | | |
|---|---|---|---|---|---|
| *Stratification* | *Layer height (m)* | *Soil resistivity (Ω·m)* | *Stratification* | *Layer height (m)* | *Soil resistivity (Ω·m)* |
| Top | 0.761361 | 80.54811 | Top | 0.6261093 | 103.6541 |
| Middle | 0.7574377 | 12.11929 | Middle | 0.7429308 | 11.13688 |
| Bottom | ∞ | 345.5737 | Bottom | ∞ | 362.0526 |
| Mean square error | 14.01% | | Mean square error | 13.90% | |

Note: measuring pole spacing of 2 m, 4 m, 6 m, 8 m, 10 m, measured depth of 7.5 m.

Wenner four-pole method of measurement data (table IV) shows that 1 # Testing Ground soil is divided into the lower level.The horizontal layered soil resistivity mean square error is about 14%.But General method of data (table V) showed that in the middle tier of the 1 # Testing Ground soil resistivity is much smaller than the top and bottom soil resistivity .And General method of soil resistance calculated value is greater an order of magnitude ratio than Wenner four-pole method calculated value on the bottom.Wenner four-pole method of measurement data shows 2 # Testing Ground soil relatively uniform.But the actual geological exploration data shows 2 # Testing Ground for the five layer of uneven soil.Obviously, General method of measurement data is more refined to reflect the 2 # Testing Ground soil Real layers， This may be associated with General method of measurement principle.

TABLE VI. MEASURING DATA INVERSION STATISTICAL TABLE USING GENERAL METHOD

| Field | The number of measurement data (group) | Measuring depth (m) | Layers | Thickness of layers (m) |
|---|---|---|---|---|
| #1 | 45 | 7.5 | 3 | 1.76 |
| #2 | 46 | 15 | 7 | 3.17 |
| #2 | 38 | 15 | 4 | 3.14 |
| #2 | 24 | 15 | 2 | 3.89 |
| #2 | 45 | 15 | 9 | 12.4 |

TABLE VII. SOIL LAYERS CALCULATED BY WENNER FOUR-POLE METHOD(A UNIVERSITY EXPERIMENT)

| Stratification | Layer height (m) | Soil resistivity (Ω·m) |
|---|---|---|
| Top | 2.99 | 86.6 |
| Middle | 20.07 | 38.38 |
| Bottom | ∞ | 316.00 |

Note: Total 9 sets data,pole spacing is 1m,5m,10m,25m,50m,80m,120m,200m,300m, the measuring depth is 7.5 m.

Wenner four-pole method is used to obtain the nine groups of soil resistivity measurements of apparent soil resistan in a university，The maximum is 254 Ω·m，Measuring distance is 1 m, span to 50 m, 80 m, 120 m and 200 m and 120 m、

200m and 300m。But levels of soil structure also is only three layer structure using CDEGS inversion in table VII，Soil resistivity is 316 Ω，The top soil thickness and the middle layer the thickness of the soil is 23 meters，It is only one over ten based on maximum measurable 225m，So once again prove that results of real measurements using Wenner method is not accurate.

*C. Comparative analysis with the results of geological exploration*

Considering geological exploration data of 2 # Testing Ground.The geological exploration data is compared with the CDEGS software calculation results in 2 # Testing Ground。Geological exploration results show (see table VIII) .From top to bottom, 2 # Testing Grounds contain artificial filled soil, gravel, silt layer viscous soil, strongly weathered granite layer and weathered granite in five levels such as stratification. General method inversion of layers of soil and five layer geological exploration results are corresponding well in table VI.Clearly in table III Wenner four-pole method inversion of two layers of soil and the actual situation there is a huge difference.

TABLE VIII. 2 # TESTING GROUND GEOLOGICAL EXPLORATION RESULTS COMPARED WITH CDEGS INVERSION OF SOIL STRUCTURE

| No. | Geological Exploration Data | | | | The average of the soil resistivity | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | General method | | Wenner four-pole method | |
| | Soil properties | depth（m） | Average thickness of detection | Estimate of soil resistivity（Ω·m） | Average measurement depth（m） | Count of soil resistivity（Ω·m） | Average measurement depth（m） | Count of soil resistivity（Ω·m） |
| 1 | artificial fill | 1.2-3.8 | 2.52 | 100-300 | 2.5 | 344 | 2.3 | 127.00 |
| 2 | sludge | 2.8-5.9 | 1.85 | <100 | 4.6 | 235 | 6.0 | 211.33 |
| 3 | Gravelly clayey soils | 4.4-17.4 | 5.90 | 300-1000 | 10.00 | 711 (Max:2235) | 10.0 | 270.00 |
| 4 | intensely weathered granite | 5.5-27.7 | 4.37 | 1000-5000 | 14.64 | 271 | 15.0 | 301.25 |
| 5 | The weathered granite | 8-34.7 | >3.00 | 1000-5000 | 19.6 | 1122 (Max:2663) | 19.0 | 316.3 |

Meanwhile, based on geological prospecting layers of soil conditions, combined with *Guide for measuring earth resistance,ground impedance and earth surface potemtials of a ground system—Part 1:Normal measurements GB / T 17949.1-2000*, draw a conclusion that # 2 Testing Ground of each horizontal layered soil resistivity range of estimates; According to the exploration report, setting five corresponding measured depth , according to the general principles of law and Wenner four-pole method, setting the appropriate electrode spacing, using the CDEGS software,draw the calculated values of soil resistivity. It found that the use of layers of soil resistivity Wenner four-pole law in 100-300Ω • m interval, the fourth layer and the fifth layer distortion is large. The layers of soil resistivity according to the results of the general measurement calculated are 1,2,3,5layers and has good data corresponding to the Geological Prospecting.

Relative to Wenner four-pole method, General method can better represent the 2 # Testing Ground of layered soil. The latter period can take multiple measurements from more palces and multipoint,and then clear measuring the range of General method,and clear the correlation coefficient between the two methods.

## V. CONCLUSION

- When using General method and Wenner four-pole method to measure soil resistivity, the difference between the depth of probes of taking consideration or not is much small(the influences less than 14%),and the difference decreases with increasing of polar distance. It is indicates that the depths of probes

impose few influences on the resistivity measurements in heterogeneous soil.

- By building the structure models via the CDEGS software (SES Canada) based on the measured data, Wenner four-pole method for two test sites is always considered simple horizontal layered structure of upper and lower two layers, and General method is more exactly characterize the middle geologic horizon.
- Under the cases of varying weather conditions and multiple measurement for soil resistivity test in the two selected sites, inversion of soil structure by General method is more exactly characterize and higher degree of fitting to the geological exploration data,so it is of higher accuracy.
- Wenner four-pole method is suitable to measure soil resistivity of uniform or shallow soil， whereas to measure heterogeneous soil with increasing under-ground pipelines and concrete structure,it is suggested to adopt the General method which can characterize the soil resistivity more accurately.


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