A Development of Earthing-Resistance-Estimation Instrument

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Abstract: - Whenever earth construction work is done, the implanted number and depth of electrodes have to be estimated in order to obtain the required resistance value. We call this earth resistance estimation. Under conventional method of earth resistance estimation, special knowledge and manpower are needed. And also, measurement error of values of apparent resistivity cannot be checked. Furthermore, vertical and horizontal resistivity sounding cannot be done simultaneously. To overcome these problems, we have developed a new instrument. This instrument does not need an operation with any special knowledge, because the entire procedure is automatic. That is, it can automatically measure the values of apparent resistivity at the ground surface, analyze the resistivity and thickness of each layer of soil, and estimate earth resistance. The instrument effectively reduces the time and manpower needed for this type of estimation.

Keywords: - earthing-resistance, estimation instrument, soil layer, resistivity sounding

1 Introduction

The earthing-resistance estimation is proceeded as follows. First, the values of apparent resistivity on the surface of the ground are measured [1]. Secondly, the resistivity of each soil layer under the ground is analyzed. Finally, the earthing resistance is estimated using the results of soil layer analysis [2]~[4]. Under the conventional method of the earthing-resistance estimation, experts have to proceed these three jobs separately by manual. And the error of measured values of apparent resistivity is not able to be checked. Also both the vertical and the horizontal resistivity sounding are not able to be proceeded simultaneously. In this way, the conventional earthing resistance estimation method needs the time and manpower. To avoid these problems, we have been developing a new instrument. This instrument does not need an operation with any special knowledge, because the entire procedure is automatic. That is, it can automatically measure the values of apparent resistivity at the ground surface, analyze the resistivity and thickness of each layer of soil, and estimate earthing resistance only by touching the start button of the instrument. In this way, the instrument effectively reduces the time and manpower needed for this type of estimation. Results from several field tests with this instrument showed good agreement between the estimated values before the earth construction and the measured results after the earth construction, which demonstrated the efficiency and importance of this instrument

2 Problem Formulations

Problems with conventional method of estimating earth resistance are as follows.

(1) Although the apparent earth resistivity is measured in the field, the ρ_a -a curve must be made later by the huge amount of data that must be processed.

(2) Vertical and horizontal resistivity sounding must be done separately, which involves changing the electrode locations.

(3) The measurement error cannot be estimated.

(4) It is very difficult to analyze multi-layered soil.

3 Problem Solution by developing Earth-Resistance-Estimation Instrument

To overcome these problems mentioned above, we have developed a new instrument. This instrument can automatically and accurately measure apparent resistivity at the ground surface, analyze the resistivity and thickness of each layer of soil, and estimate earth resistance in the field.

3. 1 Outline of Earth Resistance Estimation Instrument

The outlook of the instrument is shown in Fig.1, and Fig.2 shows a setup example. The configuration of the instrument is shown in Fig.3. The body has three sections for apparent-earth-resistivity measurement, earth-resistivity analysis, and earth-resistance estimation. A special cable and electrodes are attached to the instrument body. The entire procedure is automatic**.**

Fig.1 Outlook of the Instrument

Fig.2 The Setup at the Operating Site

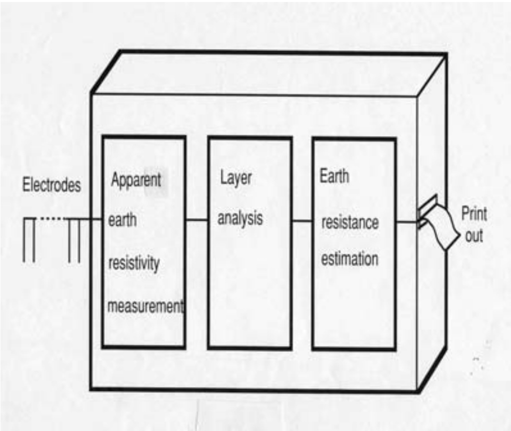

Fig.3 Configuration of the Instrument

3.2 Cable and Electrode

The instrument uses a special cable designed so that vertical and horizontal resistivity sounding can be done simultaneously. Terminals are attached to the cable at the electrode connections (Fig.4).

DITANCE (m)	384	192	96	48	24	21	18	15	12	9	6	3	1.5	0.75	0	0.75	1.5	3	6	9	12	15	18	21	24	48	96	192	384
ELECTRODE	L														/	R													
NOMBER	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SPACING 1													O	O	O	O	O												
2												O	O		O		O	O											
3											O	O			O			O	O										
4									O		O				O				O		O								
5					O				O						O						O				O				
6				O	O										O										O	O			
7			O	O											O											O	O		
8		O	O												O												O	O	
9	O	O													O													O	O

Fig.4 Terminals attached to the Special Cable

For vertical resistivity sounding, we used the offset Wenner electrode arrangement shown in Fig.5 [5]. Measurements are made in five modes with different combinations of current electrodes C_1 and C_2 and voltage electrodes P_1 and P_2. The electrode spans are 0.75, 1.5,3,6,12,24,48,96,192 and 384 meters. The electrode span for horizontal resistivity sounding is 3 meters. Some of the electrodes are used for both vertical and horizontal resistivity sounding, and others are attached at 9, 15, 18, and 21 meters from the edge of the cable. The electrodes are made of highly rust-proof-stainless-steel rods.

MODE						R
A	C_1	P_1		P_2	C_2	R_a
B	C_1	C_2		P_2	P_1	R_b
C	C_1	P_1		C_2	P_2	R_c
D_1	C_1	P_1	P_2	C_2		R_{d1}
D_2		C_1	P_1	P_2	C_2	R_{d2}

Fig.5 Offset Wenner Electrode Arrangement

3.3 Apparent-earth-resistivity Measurement Section

The heart of the apparent-earth-resistivity measurement section is a scanner. It can measure ρ_a by automatically choosing electrodes at various locations. With the offset Wenner electrode arrangement shown in Fig.5, the resistivity's ρ_{d1} and ρ_{d2} measured in modes D_1 and D_2, respectively. These values are obtained by moving the electrodes one span. By taking the average of these two values, we can reduce errors. Also, the resistivity's ρ_a, ρ_b and ρ_c, which are measured in the positions of mode A, mode B and mode C, are related by

$$\rho_a = \rho_b + \rho_c \qquad (1)$$

Because of this, the measurement error δ is defined as

$$\delta = \{\rho_a - (\rho_b + \rho_c)\} / \rho_a \qquad (2)$$

Through monitoring measurement error δ, injection current level is automatically increased in the range of 5 to 200 mA, and number of averaging time is increased up to 16 times in order to improve signal-noise ratio until δ becomes less than 5 %.

3.4 Earth-resistivity Analysis

If the resistivity ρ_i and thickness h_i of each layer shown in Fig. 6 are known, a theoretical apparent resistivity ρ is calculated by means of an inversion technique that uses a linear filter method. Once the filter coefficient is calculated considering a finite number of soil layers, the theoretical value for the surface can simply be determined from ρ_i and h_i [6], [7].

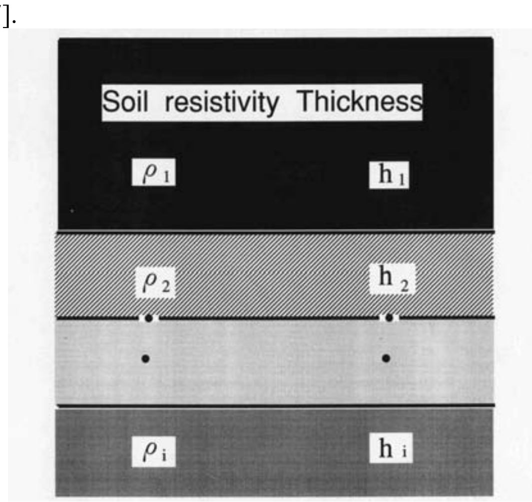

Fig.6 Resistivity and Thickness of each Layer

To apply this method, we determine the ρ_i and h_i of each soil layer by using the algorithm shown in Fig.7. First, the data of the measured apparent resistivity are taken as the initial values ρ_i and h_i. Because true values of ρ_i and h_i are assumed to be close to measured values obtained from the same electrode span.

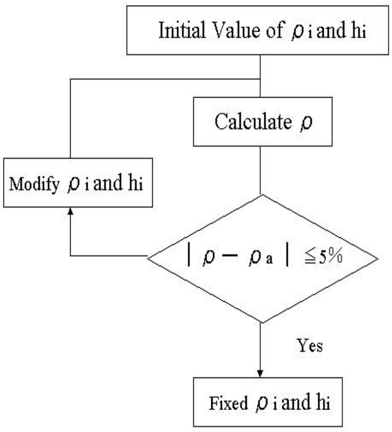

Fig.7 Flowchart for Earth Resistivity Analysis

The theoretical values of ρ are calculated from these initial values using the linear-filter method. We used the filter coefficient of 4 points/decade by Koefoed [7], and a maximum of five soil layers. Then, the theoretically calculated value ρ is compared with the measured value ρ_a by means of the least square method. If the difference between them is more than 5%, ρ_i and h_i are made either larger or smaller to minimize the difference. This process is repeated until the difference is 5% or less. The final values of ρ_i and h_i represent the soil resistivity and thickness of each layer, and the analysis is finished.

3.5 Earth-resistance Estimation

If ρ_i and h_i of each soil layer are known, the earth resistance of a multi-layered structure can be found by using the calculation as dealt with in reference [8]. There are two types of earthing method. One is single long earthing electrode buried in the depth direction so that called “boring method”. The other is so that called “parallel method” consisting of several short electrodes connected in parallel. The earth-resistance-estimation section uses the ρ_i and h_i of each layer to calculate the earth resistance of either the boring method or the parallel method.

4. Field Test Results

4.1 Improvements made in the Field

When developing the instrument, we made various improvements based on our results from field trials. In the Fig. 8(a), mark ○ shows measured data, and solid line shows estimated calculation result. When electrode span is increased, the differences of measured data and calculation result become obvious. Here, we will discuss the elimination of the residual charge. When changing the electrodes, especially when the electrode span is large, the effects of the residual charge become significant and distort the data. Therefore, if the electrode span is over 24 meters, we start injecting the current a few times to disperse any residual charge. As shown in Fig.8(b), this removes almost all the distortion, even for large electrode spans.

4.2 Response to Estimated and Actual Values of Earth Resistance

After making these improvements, an experiment was carried out at Tsukuba R&D Center in Japan to check the accuracy of this instrument. First, the earth resistance was estimated using this instrument. Next, we bored electrodes into the earth to depths of up to 100 meters, and measured the earth resistance at each depth. We then compared all the measurement results.

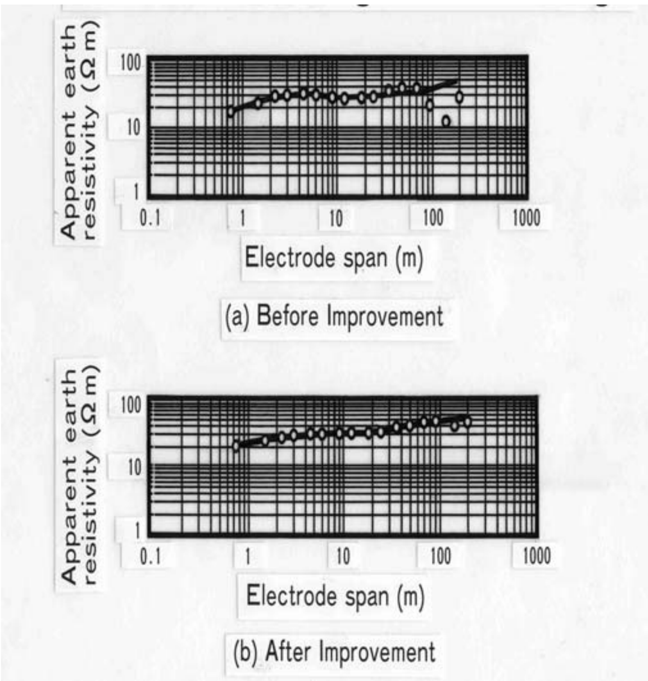

Fig.8 Results of Removing Residual Charge

4.2.1 Estimation of Earth Resistance

The measurement values of the apparent earth resistivity are shown in Fig.9.

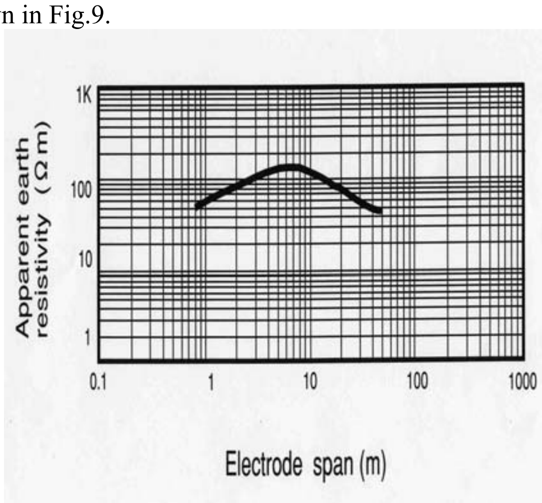

Fig.9 Measurement values of Apparent Earth Resistivity

The results of the earth-resistivity analysis, using the measured apparent resistivity, clearly show that earth consisted of four layers of soil (Fig.10).

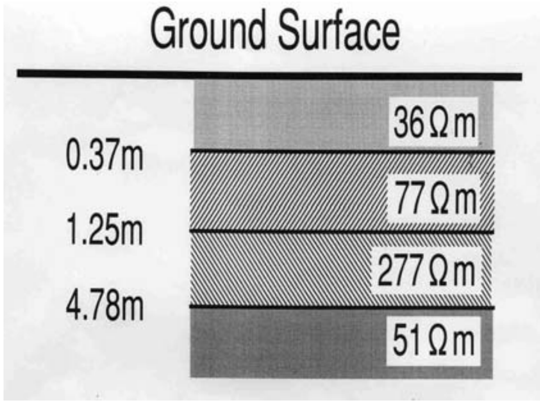

Fig.10 Results of the Analysis

The results of estimating the earth resistance are shown in Fig.11. The solid line shows the earth resistance as a function of the depth of a single earthed electrode implanted vertically in the earth (the boring method), while the dotted line shows the earth resistance as a function of the number of electrodes when short earth-rod electrodes (2.4 m long, 14 mm diameter) were connected in parallel.

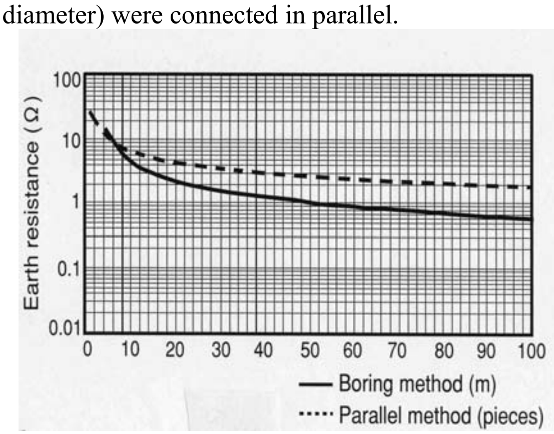

Fig.11 Results of Earth-resistance Estimation

4.2.2 Actual Measurements by Earth Boring

The diameter of the boring hole used for the actual measurement was 66 mm and it was bored to a depth of 100 meters. The earth resistance values were measured using YEW 3244. The earth resistance values were estimated using the instrument. The earth resistance values estimated using the instrument and that of measured from the earthed electrodes using YEW 3244 agreed closely as shown in Fig 12. We have done many other field tests at different locations, and have also had good agreement between the estimated and measured resistances in those cases. The average time needed to perform the entire procedure with this instrument is about 30 minutes.

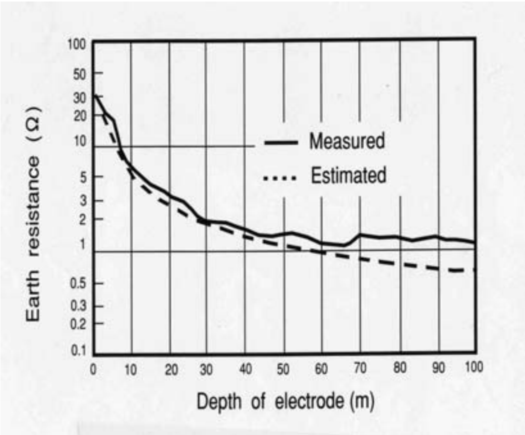

Fig.12 Comparison of the Estimated and Measured Earth Resistances

5 Conclusion

We have developed an earth-resistance estimation instrument. This instrument does not need an operation with any special knowledge, because the entire procedure is automatic. That is, it can automatically measure the values of apparent resistivity at the ground surface, analyze the resistivity and thickness of each layer of soil, and estimate earth resistance only by touching the start button of the instrument within 30 minutes in the field.

Our field tests showed good agreement between the estimated and measured resistances. Because accurate earth resistance estimation can be quickly obtained, we are sure this instrument will be very useful for estimating earth resistance.

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Prof. Dr. Hitoshi KIJIMA. He obtained the best paper award for the 9th WSEAS International Conference (EHAC '10) University of Cambridge, UK, February 20-22, **2010,** Electromagnetic Force Analyzed Results on Switchgear of Disconnector for Overevoltage Protector, pp.135-140 Hitoshi Kijima, Tomooki Hasegawa.

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