Development of a Leakage Detection System for Waste Disposal Yards

K. Arai & H. Arai
Maeda Co Ltd., Tokyo, Japan

N. Yamazaki & M. Hatano
Radic Inc., Japan

ABSTRACT: When an alternating current voltage is applied to a disposal yard with leakage in the geomembrane sheet, the current through the leakage can be extracted from the total current by a phase sensitive detector, compared with the phase of the applied alternating voltage. By placing a set of linear electrodes in parallel and at equal intervals above the geomembrane and another set below the membrane but orthogonal to the upper set, leakage position can be determined by the electrical current flowing between selected electrodes above and below the sheet. The observed performance of the system in experiments shows that: (1) except in wet condition, $2\ \mathrm{cm}^2$ leakage can be pinpointed and existence of $1\ \mathrm{cm}^2$ leakage can be determined, (2) smaller interval of electrodes improves the accuracy of the leakage detection and (3) the buried electrical conductors may not hinder detection of the leakage positions.

1. INTRODUCTION

When the geomembrane sheets at waste disposal yards are damaged, hazardous materials in the waste may leak and the ground water may be contaminated. In these cases the leakages in the geomembrane sheets must be located and repaired as soon as possible. For an electrical method of determining the leakage positions in disposal yards the charged potential method can be applied, but there is perturbation of the electrical conductivity with the non- uniformity of the ground and the accuracy of the measurements becomes low, and so this method is unpractical.

Therefore the authors have developed a leakage positioning method for geomembrane sheets based on principles of measurement different from those used in the existing methods.

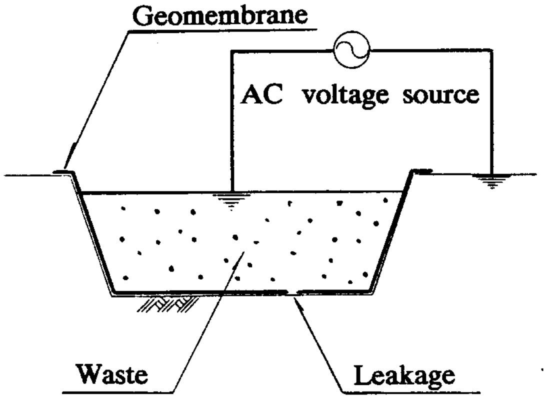


Figure 1. Waste Disposal Yard with Leakage.

2. PRINCIPLES OF MEASUREMENT

2.1 Electrical Characteristics at Waste Disposal Yards and Phase Sensitive Detection

In cases where alternating voltage is applied to disposal yards with leakages in the geomembrane sheets, shown in Figure 1, the equivalent circuit can be formed with the following factors as in Figure 2: the electrical resistance (R_W) of the waste; the electrical resistance (R_G) of the ground; the electrical resistance (R_L) of the leakages; and the capacitance of the geomembrane sheets (C). The alternating voltage (V) is expressed by the angular velocity (ω), time (t), and amplitude (A) as shown in Equation 1, while the charge (q) electrifying the sheets is expressed by Equation 2.

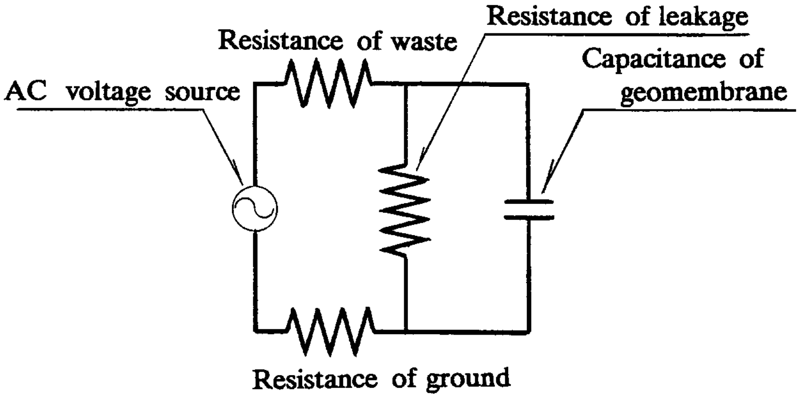


Figure 2. Equivalent Circuit for a Waste Disposal Yard with Leakage.

The current flowing through the sheets (i_C), the current flowing through the leakages (i_R), and the total current flowing in the disposal yard (i) are expressed by Equations 3-5 respectively.With Equations 1 and 4 the current flowing through the leakages and the applied voltage are in-phase, shown in Figure 3 and therefore with phase sensitive detection circuits the in-phase applied voltage and current may be extracted from the total current flowing in the disposal yard, and measurement of the leakages with high accuracy becomes possible.

$$V = A\sin\omega t \qquad (1)$$

$$q = CV = CA\sin\omega t \qquad (2)$$

$$i_C = \frac{dq}{dt} = \omega CA\cos\omega t = \omega CA\sin(\omega t + \pi / 2) \qquad (3)$$

$$i_R = (A / R)\sin\omega t \qquad (4)$$
$$(R = R_W + R_G + R_L)$$

$$i = i_C + i_R = A\{(1/R)\sin\omega t + \omega C\cos\omega t\} = A\{(1/R)^2 + (\omega C)^2\}^{1/2}\sin(\omega t + \theta) \qquad (5)$$
$$(\theta : \text{Phase shift})$$

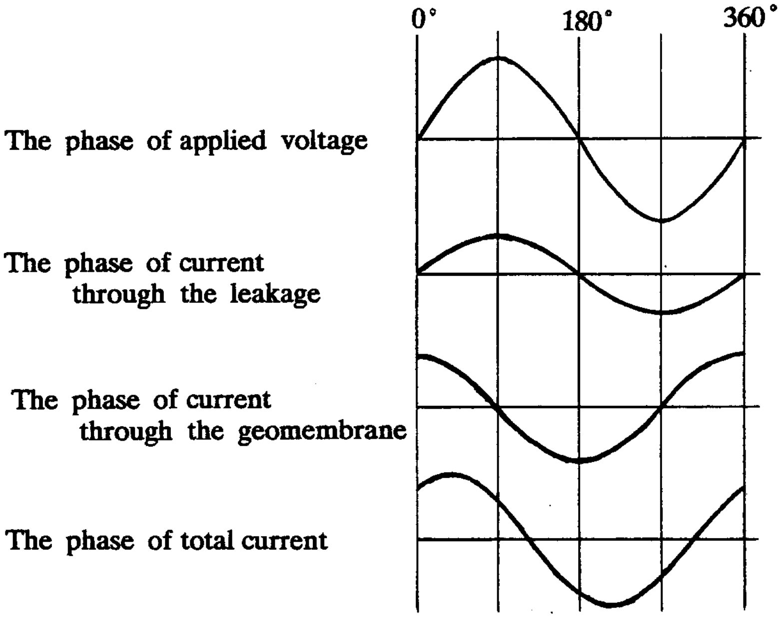


Figure 3. Phase of Voltage and Current.

2.2 Anisotropy of Conductivity

The electrical conductivity of soils are different depending on the water content and characteristics of the soil, but the direction of the conductivity is usually considered to have no special anisotropy. Therefore as shown in Figure 4, if linear electrodes are placed parallel and at equal intervals, the conductivity along the electrodes is higher than the conductivity orthogonal to the electrode axis. The electrode orientations above and below the geomembrane sheets are orthogonal, and as shown in Figure 5 one electrode is chosen respectively above and below the sheet and a voltage is applied between them. Where the point of intersection of the lines of conductivity above and below the sheet is near to a leakage position a large current will flow, and where it is far from a leakage position a small current will flow. Considering every conbination of elecdtrodes and the magnitude of each current, the leakage position can be determined.

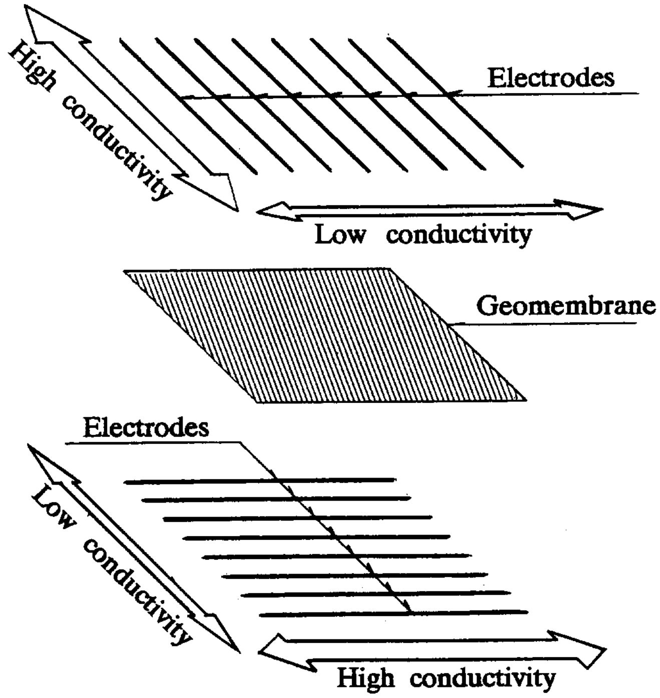
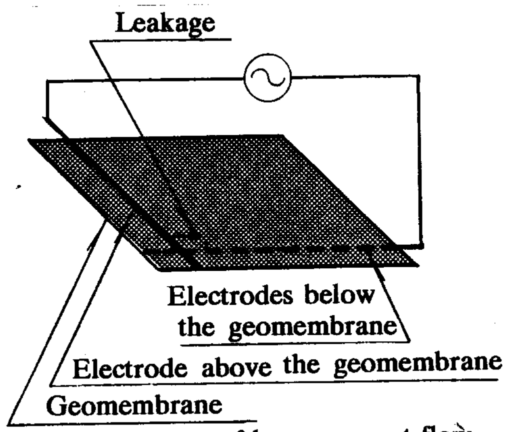
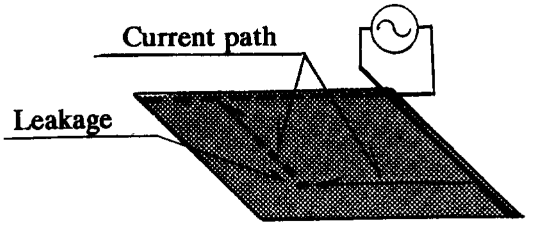


Figure 4. Forming Anisotropy of Conductivity.



(a)The case of large current flow



(b)The case of small current flow

Figure 5. Leakage Detection Method.

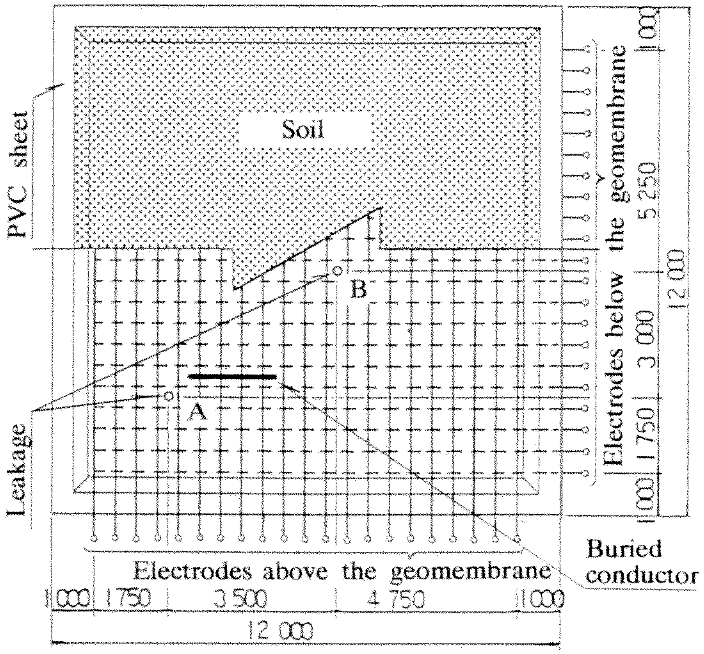


Figure 6. Test Yard.

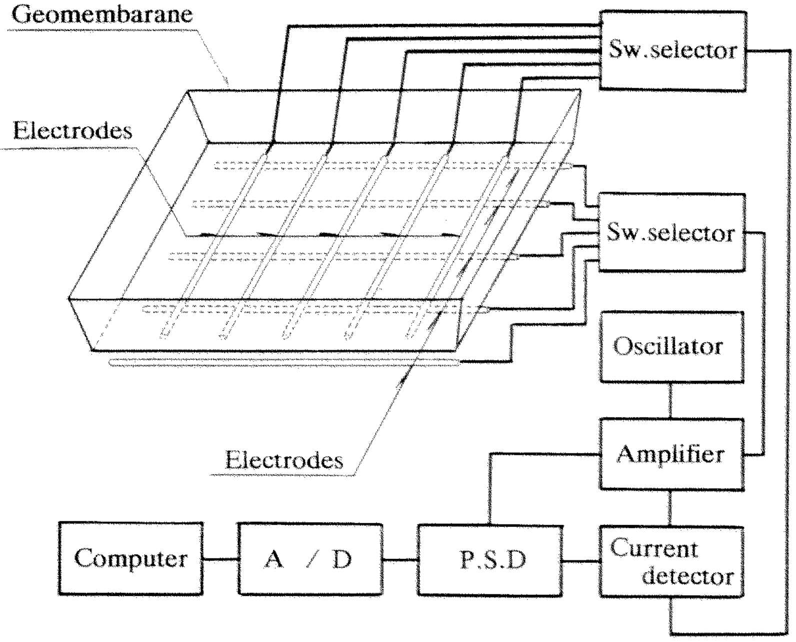


Figure 7. Layout of Measurement System.

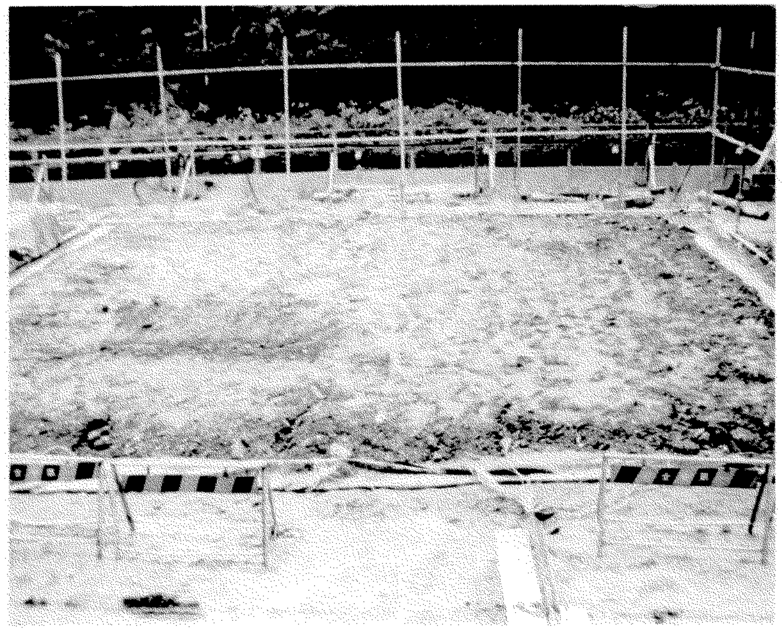


Figure 8. Test Yard.

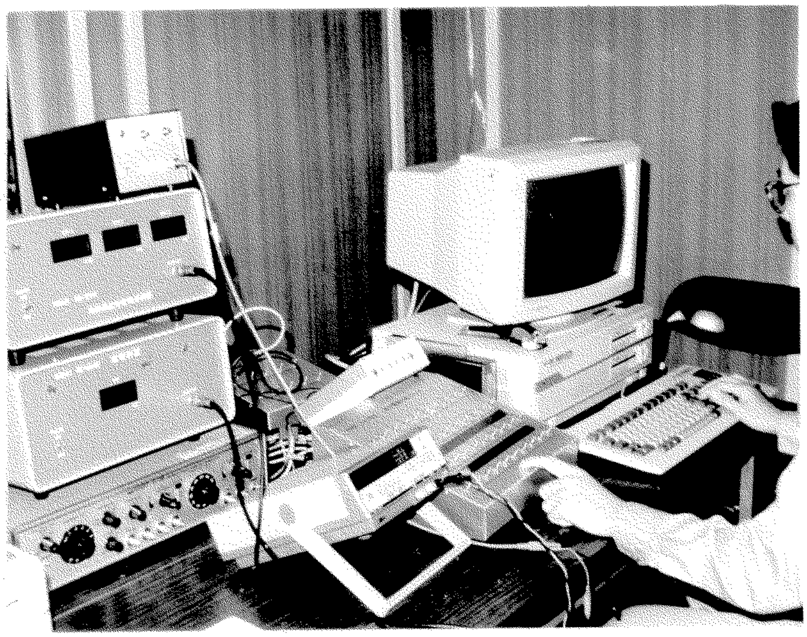


Figure 9. Measurement System.

3. TESTS

3.1 Test Equipment

The test yard was constructed as shown in Figure 6 and Figure 8, 30 cm thickness of soil on top of PVC sheet (12 m by 12 m, 1 mm thick). The linear electrodes (3.2 mm ϕ copper wire) were oriented orthogonally at 0.5 m intervals above and below the sheet. A 48.6 mm ϕ (2.4 mm thick) steel pipe was placed at a 15 cm depth, crossing level with the linear electrodes. The layout of the measuring instruments was shown in Figure 7 and Figure 9; a 7.5 V voltage of frequency 20 Hz was applied to the test yard.

4. TEST RESULTS AND DISCUSSIONS

(1) Accuracy of Measurements

As shown in Figure 10 Graphs (a)-(d), the current becomes maximum for leakages up to 2 cm^2 and leakage positions can be determined. However as shown in Figure 10 (e), in the vicinity of 1 cm^2 leakages there are the same maximum values but the position can not be pinpointed. Under the no-leakage condition as shown in Figure 11, the graph was totally flat, and the minimum value of current, 0.43 mA, is very small, compared with the minimum value of current, 12.93 mA, measured with 1 cm^2 leakage ,as shown in Figure 10 (e).

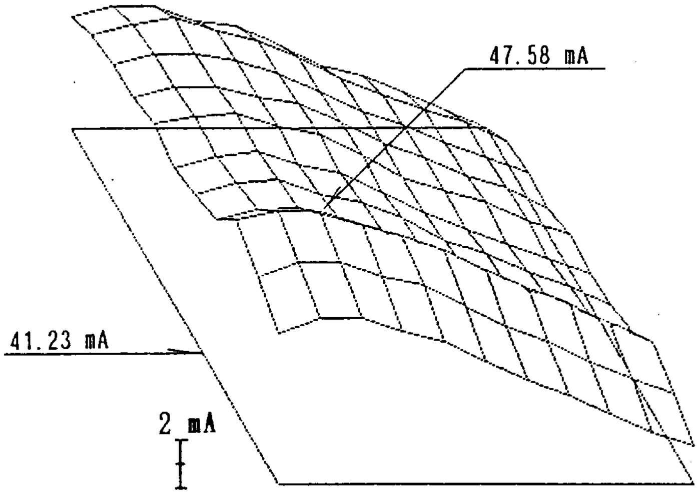


Figure 10 (a). Measurements of 16 cm^2 of Leakage A.

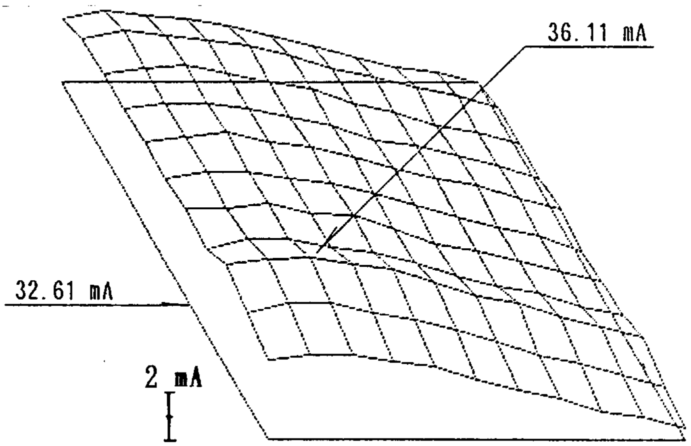


Figure 10 (b) Measurements of 8 cm^2 of Leakage A.

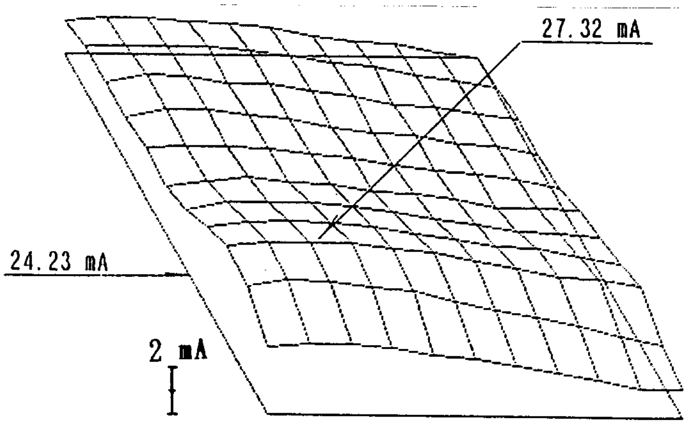


Figure 10 (c). Measurements of 4 cm^2 of Leakage A.

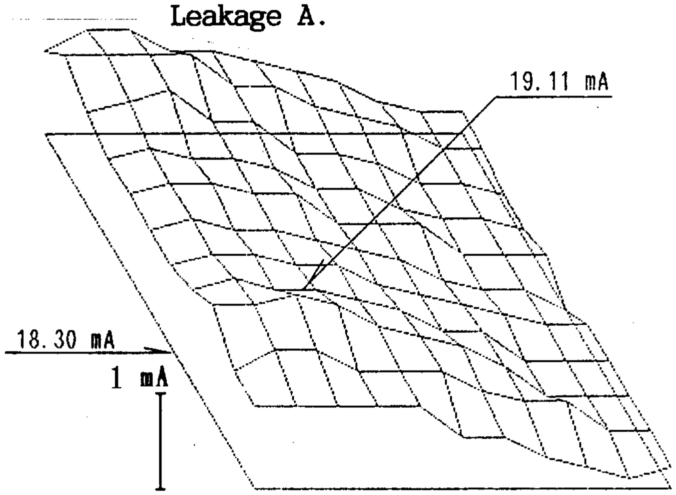


Figure 10 (d). Measurements of 2 cm^2 of Leakage A.(4 x Magnification)

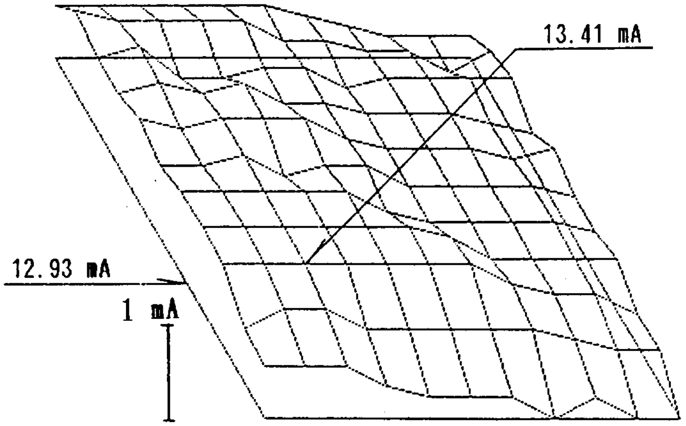


Figure 10 (e). Measurements of 1 cm^2 of Leakages A.(4 x Magnification)

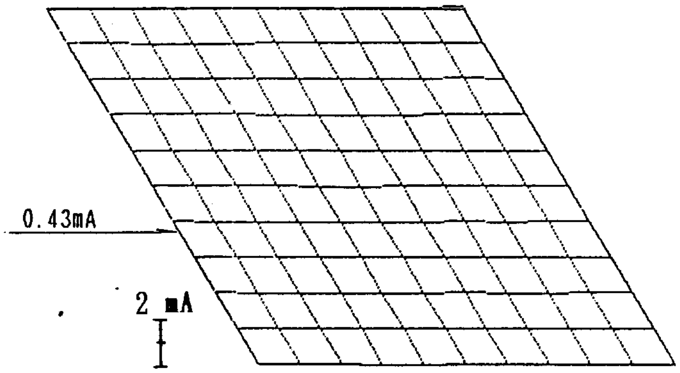


Figure 11. Measurements of No-Leakage Condition.

Therefore it is considered that the existence of 1 cm^2 leakages may be determined.

(2) Effects of Electrode Intervals

Figures 12 (a) and (b) show the measurements for the leakage positions in the centre of the test yard with a 2.5 m interval between linear electrodes, and short-circuited sheet surfaces in rain. The existence of the 8 cm^2 leakages can be seen from Figure 12 (a), but the existence of 4 cm^2 leakages can not be confirmed from Figure 12 (b). Where the interval between electrodes is 0.5 m the measurements in rain are as shown in Figures 13 (a) and (b). The position of the leakages can be determined more accurately than when the interval is 2.5 m, but it was seen that 4 cm^2 leakages can not be detected so clearly when the interval is 2.5 m. Then a smaller interval between the linear electrodes makes the leakage positioning more accurate. But it is not effective for improving the sensitivity to the leakage size.

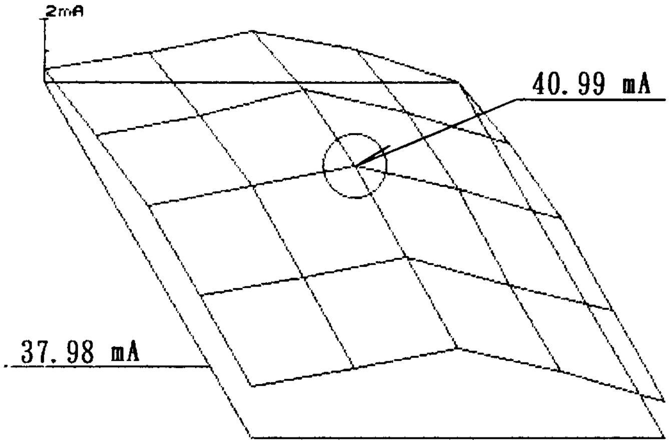


Figure 12 (a). Measurements of 8 cm^2 of Leakage B.(Electrode Interval 2.5 m)

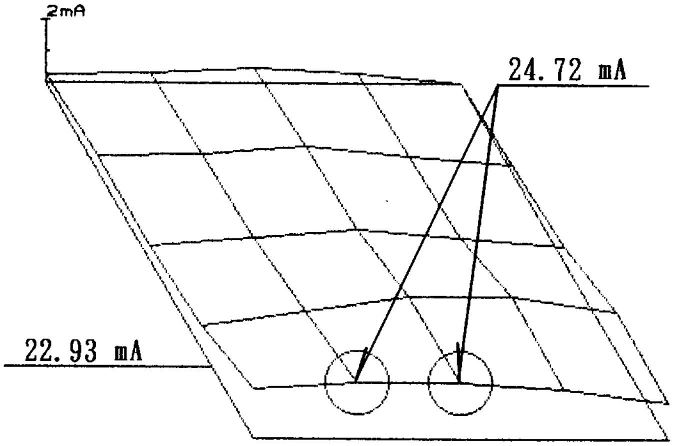


Figure 12 (b) Measurements of 4 cm^2 of Leakage B.(Electrode Interval 2.5 m)

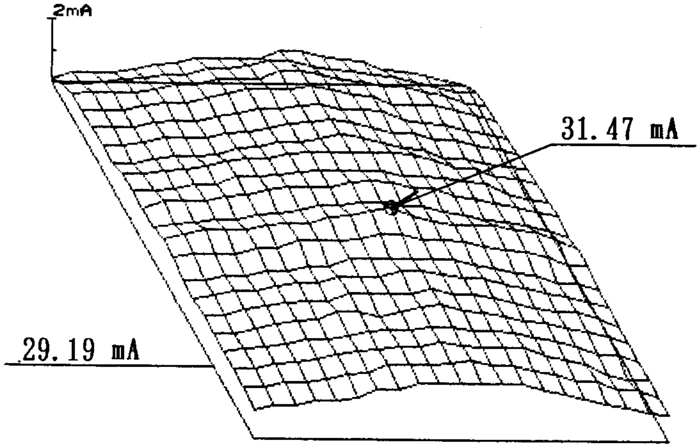


Figure 13 (a) Measurements of 8 cm^2 of Leakage B.(Electrode Interval 0.5 m)

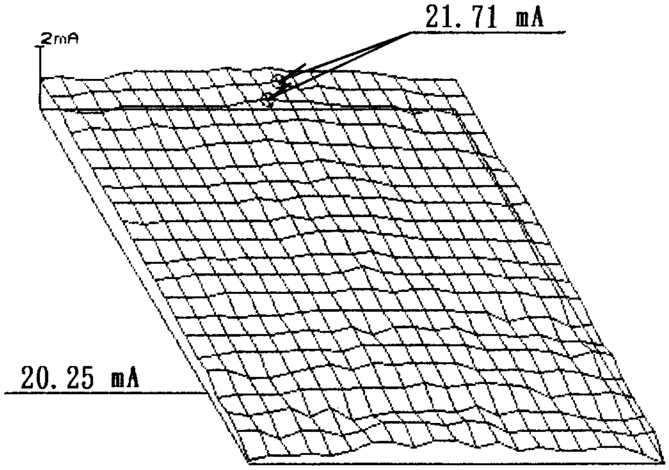


Figure 13 (b). Measurements of 4 cm^2 of Leakage B.(Electrode Interval 0.5 m)

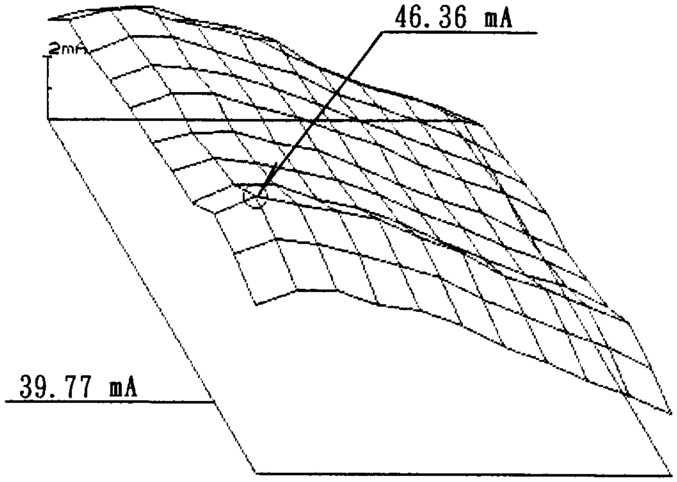


Figure 14. Effects of Buried Steel Pipe. (on Leakage A)

(3) Effects of Buried Conductor

Where the buried conductor as steel pipe was placed in the test yard the measurement for 16 cm^2 leakage is shown in Figure 14. When the measurement for Figure 13 and Figure 10 (a) (no buried pipe) are compared, it is expected that there would be a uniform current in the vicinity of the buried pipe, but both sets of measurements are almost the same and within this test experiment no hindrance to measuring was observed.

5.CONCLUSION

Tests were conducted on the accuracy performance of the conductivity anisotropy and phase sensitive detection measurement system, and the conclusions obtained are as below.

(1) Measurement Accuracy

In dry condition the position of 2 cm^2 leakages can be detected, and the existence of 1 cm^2 leakages can be determined. However with rain the detection accuracy was lowered to 8 cm^2 leakages.

(2) Effect of Electrode Intervals

The smaller interval between the linear electrodes is more effective to improve the accuracy of the leakage positioning than to improve the sensitivity to smaller leakages.

(3) Effect of Buried Conductor

Within this experiment, buried electrical conductor may not privent to detect and locate the leakage positions in this electrical method.

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