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Electrical Explorations in and around the Nanjido Waste Landfill

난지도 폐기물 매립장과 그 주변 지역에서의 전기탐사

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Abstract : Electrical soundings were conducted in and around the Nanjido waste landfill in August, 1994 and February, 1995. Schlumberger array was adopted and 37 and 22 soundings were performed around and in the Nanjido landfill, respectively. Besides, self potentials were measured at 50 points, in front of the right Nanjido landfill. Interpretations of the sounding data show low resistivity zones of about 10 Ω-m at depth ranging from 10 to 80 m from the surface in front of the landfill and of about 6 Ω-m at depth ranging from 37 m to 130 m in the landfill. It appears that these low resistivity zones are contaminated by or saturated with leachate, and their depths are deeper than those of boring data by 20~30 m. These results indicate the possibility of contamination of weathered zone and the upper part of the bed rock in these areas. But sounding data obtained at the back of the landfill reveal more resistive and thinner low resistivity zones than those in and in front of the landfill. Thus it is concluded that the degree of contamination by leachate in and in front of the landfill is greater than that at the back of the landfill.

요 약 : 난지도 매립지 주변지역과 매립지내에서 1994년 8월과 1995년 2월에 수직전기탐사를 실시하였다. 수직전기탐사는 슐럼버져 배열을 이용하였으며, 37점과 22점의 수직탐사가 매립지 주변과 매립지내에서 각각 수행되었다. 또한 우지도 앞쪽에서는 50개 지점에서 자연전위를 측정하였다. 자료의 해석결과, 난지도 앞쪽 지역에서는 좌지도와 우지도에 걸쳐서 대부분 지표하 10 m부터 지표하 80 m까지 10 Ω-m내외의 저비저항대가 나타나며, 매립지 내에서는 좌지도와 우지도 모두 평균적으로 지표하 37 m에서 지표하 130 m까지 약 6 Ω-m내외의 저비저항대가 나타난다. 이러한 저비저항대는 침출수에 의해 오염되었거나 포화된 층으로 판단되며, 그 층의 깊이는 매립지 앞쪽지역과 내부 등 양측 모두에서 시추자료의 기반암 깊이보다 20~30 m 정도 더 깊은 것으로 계산되었다. 이는 매립지 앞쪽과 매립지내에서 풍화대와 기반암 상부의 오염가능성을 시사하는 것으로 사료된다. 한편, 매립지 뒤쪽에서 실시한 수직탐사 자료는 매립지 앞쪽과 내부 자료에 비해 저비저항대의 비저항값이 높고 그 두께도 매우 얇은 양상을 보이는 것으로보아, 매립지 앞쪽과 내부에 비해서는 침출수에 의한 오염정도가 상대적으로 작다고 할 수 있다.

INTRODUCTION

From 1978 to 1992, industrial and domestic wastes of Seoul had been dumped in the Nanjido landfill which is located at Sangam-dong, Mapo-gu, Seoul. The maximum height of the landfill reaches about 80 m now. As the result of no proper management of wastes during and after waste reclamation, the leachate from the Nanjido landfill have contaminated groundwater around the landfill and flowed directly into the Han river located in the southwestern part of the Nanjido landfill.

In addition to such groundwater contamination, the problem of insufficient city life space caused by overpopulation and accelerating industrial development necessitates the stabilization and utilization of the landfill.

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The purpose of this study is providing the basic information on leachate distribution in and around the Nanjido landfill which is needed to prevent further groundwater contamination and build the effective plan of stabilization of the landfill.

Until 1980s, few hydrogeological and geophysical studies of the Nanjido landfill had been made. Recently, increasing concern of environmental contamination brought about quite a few hydrogeological and geophysical studies of the Nanjido landfill (Daewoo, 1992; Jang and Lee, 1994; Samsung, 1992; Segil, 1992). Generally, geophysical methods provide economic and convenient means to investigate contaminant plumes from landfills. Among the various geophysical methods, the electrical method is most commonly adopted in geophysical surveys of landfills (Cahyna, 1990; Carpenter *et al.*, 1990; Ross *et al.*, 1990).

In this study, 22 and 37 Schlumberger soundings were conducted in and around the Nanjido landfill, respectively, to elucidate landfill structure and the leachate level. Self potential (SP) measements were also made in the area in front of the Nanjido landfill.

OVERVIEW OF THE GEOLOGY

Detailed geology of the whole area of the Nanjido landfill is not known accurately because of the poorly developed outcrops in this area. Therefore, the information on geology mainly depends on some boring data in this area.

Precambrian banded biotite and granitic gneisses are distributed in the northeastern part of the landfill, Sangam-dong. In the southwestern part of tributary river which runs around the Nanjido landfill, alluvium is distributed along the side in the direction of the Han river. The gneiss shows coarse grained granoblastic texture and massive shape. Its essential minerals are quartz, biotite, and plagioclase and accessory minerals are garnet, muscovite, sericite, epidote, sillimanite, chlorite, and opaque (Hong *et al.*, 1982).

Basically, geological layers of the study area are composed of top soil, alluvium, weatherd zone, and bed rock. The bed rock is mainly Precambrian biotite gneiss and its depth from the surface is about 30~40 m around the landfill (Daewoo, 1992). In the Nanjido landfill, considering that the height of waste reclamation is about 75~80 m, the depth of the bed rock from the surface is estimated about 110~120 m. Joints and fractured zones are well developed in the bed rock and they play an important role in the migration of leachate. The degree of bed rock weathering is quite intense in the whole area of this study.

ELECTRICAL EXPLORATIONS AND DATA INTERPRETATIONS

Schlumberger soundings were made with ABEM Terrameter SAS 300B. Maximum distances between measuring point and current pole are 146 m and 215 m around and inside the landfill, respectively. The interval of each SP measuring point is 10 m and measurements were made at 50 points.

Sounding data were interpreted using interactive forward modeling method (Kim and Lee, 1993). Interactive method is superior to inversion method in that existing known geological information can be included in interpreting process. The number of boring data which penetrate the weathered zone and bed rock is 10, but most of the boring holes are quite distant from the sounding point and limited to circumference of the landfill. So, these boring data were considered but not directly included in interpretation of sounding data.

Circumference of the Nanjido Landfill

The front area of the Nanjido landfill (Towards the Han river)

A total of 37 Schlumberger soundings and one line of SP survey were made along the circumference of the landfill (Figure 1). In the front area of the right and left Nanjido landfills toward the Han river, 14 Schlumberger soundings were carried out at regular intervals, respectively. The sounding points are arranged to lie closely along the Kangbyon-ro to delineate two dimensional resistivity structure of the area. The intervals of sounding points are 46 m in V1~V22 and 100 m in V23~V28. At some distance from V26 in the left Nanjido landfill, one sounding V37 was carried out for reference. Tentatively, SP values were also measured in the front area of the landfill.

Figure 2 and 3 show some typical interpretations among V1~V28 soundings taken in a straight line. Among 28 soundings, 17 soundings were interpreted as 4-layer structure. But most of the other soundings can also be interpreted assuming 4-layer structure neglecting thin layers within the shallow depth of about 2~4 m. The resistivities and thicknesses of the layers interpreted as 4 layers are shown in Table 1.

Judging from the boring data in the area, interpreted 4 layers can be regarded as top soil, alluvium, weathered zone and bed rock, respectively. From the interpreted results of sounding data, it is indicated that top soil having resistivities of about 50~500 Ω-m exists to the depth of about 1.7~4.5 m from the surface. Because the boring holes of this area are very close to the landfill, top soil in boring data contains large quantities of landfill materials. So, an exact correlation between top soils of sounding data and boring data is impossible.

The resistivities of the second layers considered as alluvium range from 76 Ω-m to 216 Ω-m and the mean is about 116 Ω-m. The mean thickness of this layer ranging from 4.7 to 18.6 m is 10.5 m. This agrees relatively well with the mean thickness, 20 m, of the boring data, considering that altitude difference between the

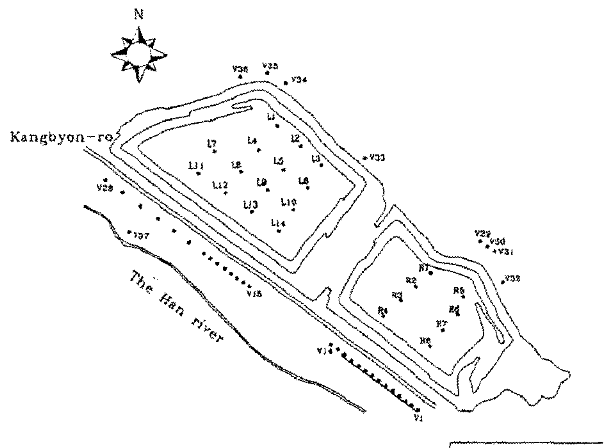

Figure 1. The location map of the electrical sureve

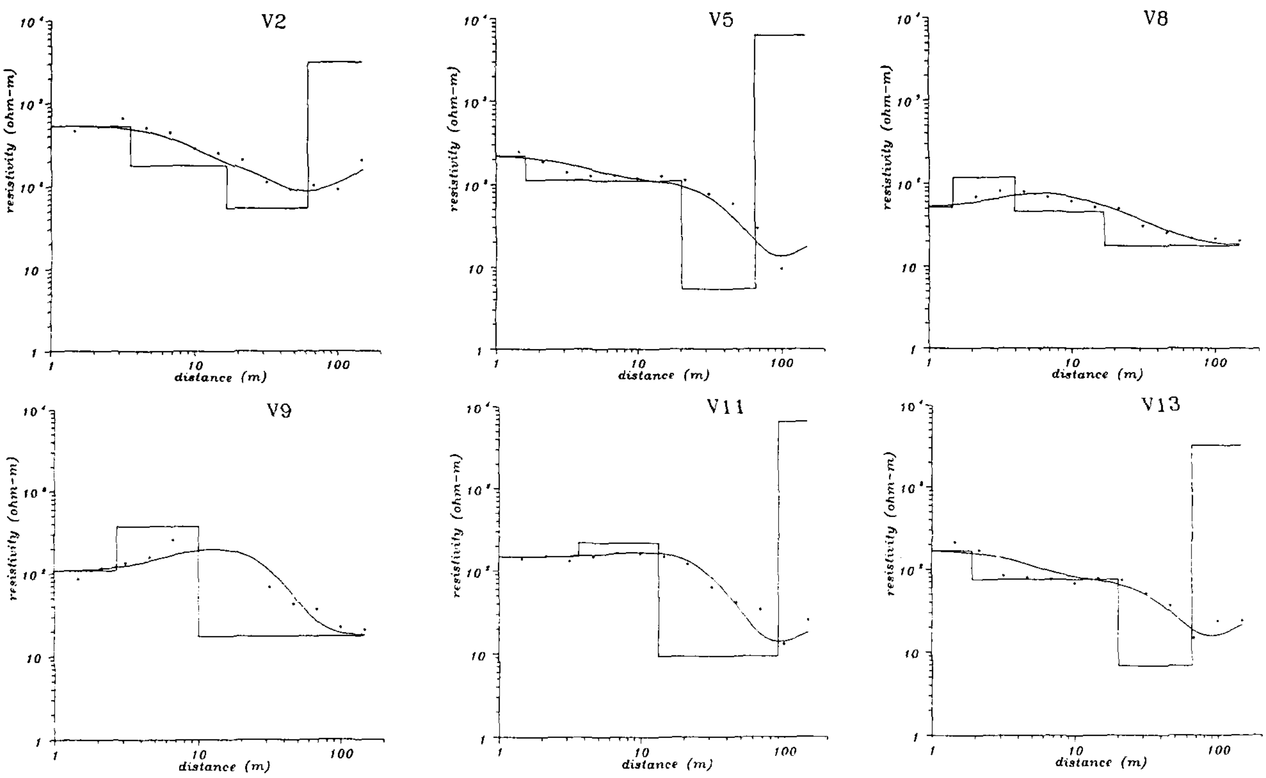

Figure 2. Electrical soundings and their interpretations in front of the right Nanjido landfill. Observed data and theoretically computed values are marked by dots and solid lines. Jagged lines represent imterpreted resistivity structure.

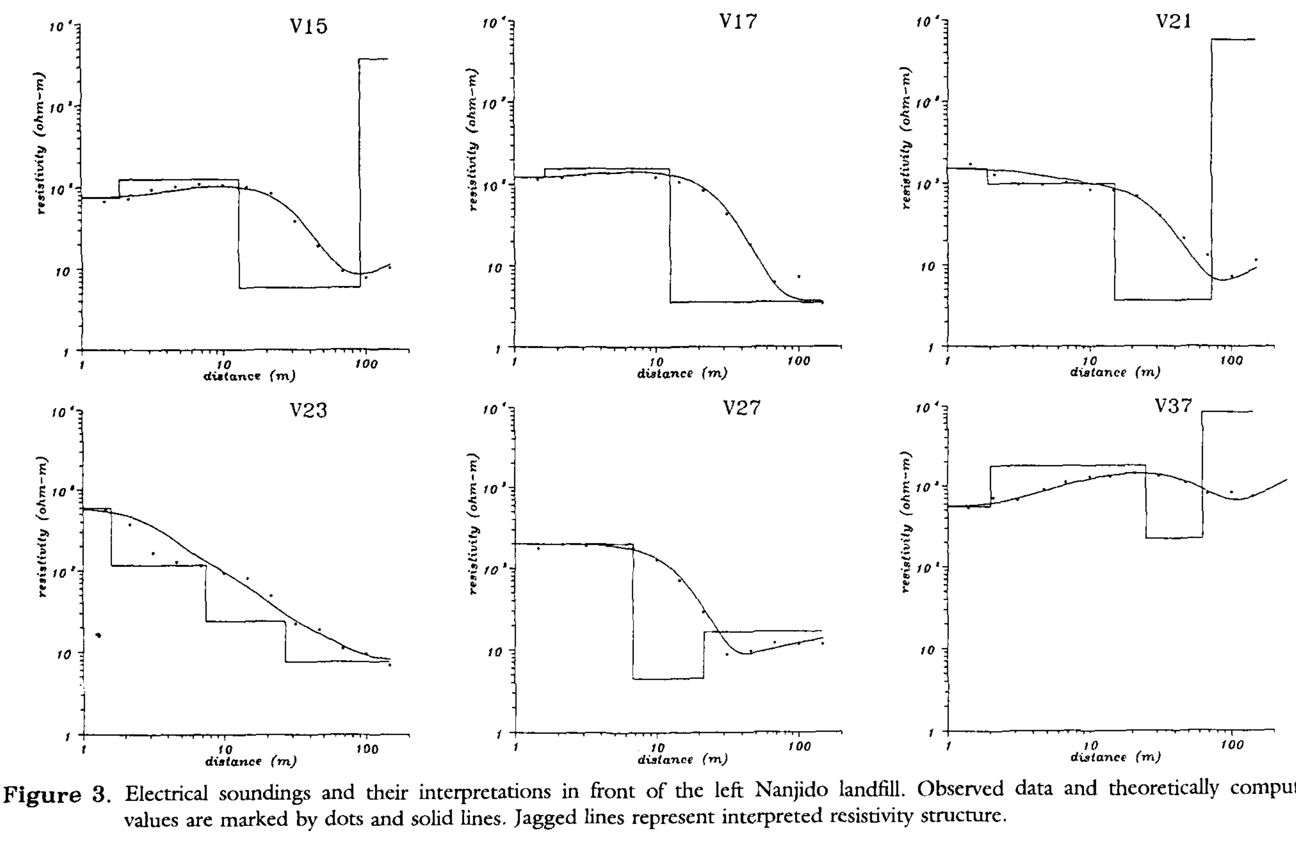

Figure 3. Electrical soundings and their interpretations in front of the left Nanjido landfill. Observed data and theoretically computed values are marked by dots and solid lines. Jagged lines represent interpreted resistivity structure.

Table 1. Resistivities and thicknesses from interpretations of sounding data as 4 layers.

Location of VES	No. of VES	First Layer		Second Layer		Third Layer		Fouth Layer
		thickness (m)	resistivity (Ω-m)	thickness (m)	resistivity (Ω-m)	thickness (m)	resistivity (Ω-m)	resistivity (Ω-m)
The Left Lanjido Landfill	L 1	6.3	60.6	29.1	20.2	88.4	7.1	151.5
	L 2	11.3	126.7	34.2	21.0	92.9	8.1	362.7
	L 3	10.0	72.4	31.3	19.8	102.7	6.8	138.6
	L 5	9.1	60.6	29.9	13.8	104.9	5.3	105.9
	L 6	13.4	35.4	26.8	18.1	103.8	9.5	36.2
	L 7	9.1	99.1	33.9	15.8	53.4	5.8	169.5
	L 8	8.7	37.0	21.7	10.8	104.2	6.2	56.6
	L 9	10.7	26.5	30.6	8.6	102.7	4.6	24.2
	L10	11.5	75.7	26.5	21.0	106.0	8.6	189.5
	L11	11.0	77.5	34.5	15.1	87.3	5.7	1037.9
	L13	8.0	119.5	26.5	22.1	48.4	6.5	33.8
	L14	9.7	8148.2	25.2	28.9	109.0	7.9	158.5
Mean		9.9	78.3	29.2	17.9	92.0	6.8	205.4
The Right Nanjido Landfill	R1	10.7	207.3	25.7	37.9	90.9	11.6	742.0
	R2	11.3	75.7	28.8	15.8	116.7	4.8	742.9
	R3	13.8	66.2	28.7	16.1	101.5	5.1	379.3
	R5	9.7	148.2	32.7	27.7	65.3	8.1	33.1
	R6	10.3	55.4	32.2	15.5	101.5	4.8	54.1
	R7	11.3	118.5	30.5	18.1	100.5	5.4	742.9
	R8	10.3	118.5	27.2	21.0	106.5	6.6	379.3
Mean		11.1	112.8	29.4	21.7	97.6	6.6	439.1
Front Area of the Right Lanjido Landfill	V2	3.6	538.7	13.0	180.7	45.0	54.6	3162.3
	V3	2.3	460.8	13.4	139.3	54.1	4.2	9173.4
	V4	1.7	320.2	13.5	113.1	69.3	14.9	6714.1
	V5	1.6	222.5	18.6	113.1	45.4	5.4	6210.1
	V6	1.7	180.7	18.6	128.8	47.9	3.9	3990.9
	V8	1.5	51.8	2.5	119.2	13.0	45.5	17.8
	V11	3.6	146.7	9.7	216.8	77.5	9.3	6541.7
	V12	2.6	128.8	17.6	82.8	60.1	5.5	8267.0
	V13	1.9	167.1	18.3	74.6	45.4	6.8	3162.2
	V14	4.5	101.9	14.1	128.8	47.9	6.1	3162.3
Mean		2.5	231.9	13.9	129.7	50.6	15.6	5040.2
Front Area of the Left Nanjido Landfill	V15	1.9	74.6	11.0	125.5	78.0	5.8	3691.4
	V16	1.7	122.3	10.6	154.6	69.1	4.4	3162.3
	V19	2.7	72.7	11.5	110.2	61.1	2.1	7646.5
	V21	1.9	154.6	13.1	99.3	57.6	3.7	5744.0
	V23	1.6	597.7	5.8	116.1	19.4	23.8	7.6
	V24	2.7	80.7	4.7	18.8	20.4	3.6	8267.0
	V26	1.7	53.2	5.8	89.5	25.9	4.1	3158.0
Mean		2.0	165.1	8.9	102.0	47.4	6.8	4525.3

sites of Schlumberger soundings and boring holes is about 10 m.

However, there exists no good correlation between the boring and sounding data in the case of the third layer. The resistivities of the third layers which correspond to weathered zone range from 2 Ω-m to 55 Ω-m and the mean value is about 12 Ω-m. These values are extremely low compared with those of ordinary weathered zone. Besides, the interpreted mean depth of the bed rock from the surface is about 62m and this value is very large in comparison with 30 m of boring data. This seems to result from contamination of the upper part of bedrock by leachate, considering the bedrock in this area is very permeable (Daewoo, 1992). The evidence of bedrock contamination is also clearly shown in the interpretations of soundings V8, V9, V17, V23, and V27 (Figure 2 and 3). In these interpretations, layers of very low resistivity values of about 3-20Ω-m extend down to depths exceeding 100 m.

In Figure 4, a pseudo section of two dimensional resistivity structure of the area in front of the right Nanjido landfill is shown. The pseudo section is constructed based on the sounding data interpreted in terms of 4 layers. This section does not represent the real subsurface structure but can be used for und-

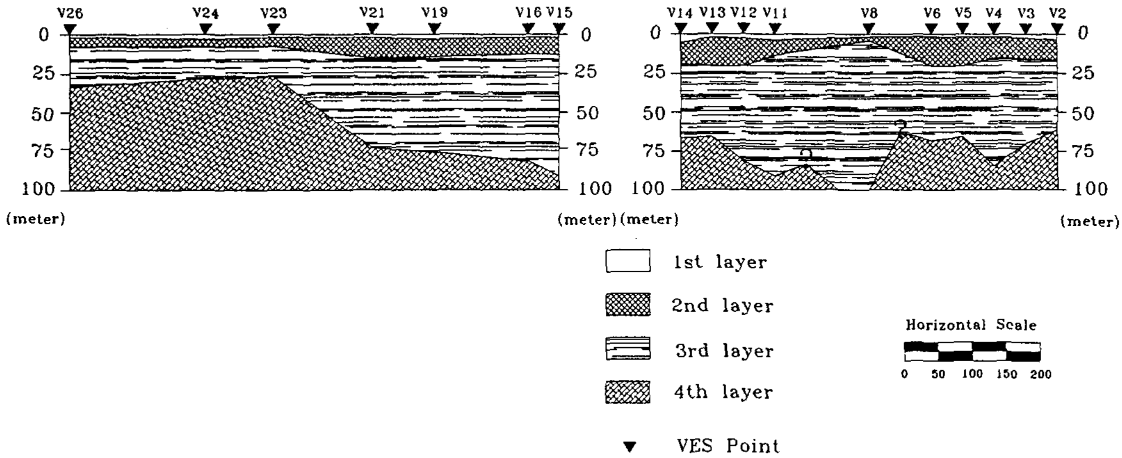

Figure 4. Pseudo section of two dimensional resistivity structure in front of the Nanjido landfill.

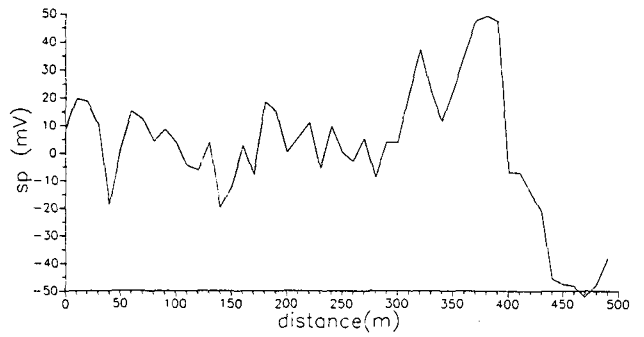

Figure 5. Self potential values measured in front of the right Nanjido landfill.

erstanding the general resistivity structure of the area. Low resistivity zone which corresponds to the third layer in the pseudo section appears thick, especially in the central portion of survey line in front of the left Nanjido landfill and at the right edge of survey line in front of the right landfill. Summing up, it appears that the weathered zone is contaminated by leachate from the landfill and contamination of the upper part of bedrock is considerable.

Sounding V37 were made to be used for reference data. In Figure 3, interpreted result of sounding V37 is shown. No evidence of groundwater contamination by leachate is indicated in this data. But it is difficult to confirm that groundwater is not contaminated in the distant area from the the landfill because of scarcity of sounding data.

The result of SP survey is shown in Figure 5. Measured values fluctuate remarkably. It seems that this fluctuation is caused by rainfall having continued during two days before the day of SP survey. Generally SP data is apt to be easily corrupted by external noise, such as rainfall, humidity, topography, chemical fertilizer etc (Telford *et al.*, 1990). Furthermore, SP data is difficult to interpret quantitatively. Therefore, it appears unreasonable to put great importance to the SP data.

The back area of the Nanjido landfill (Sangam-dong)

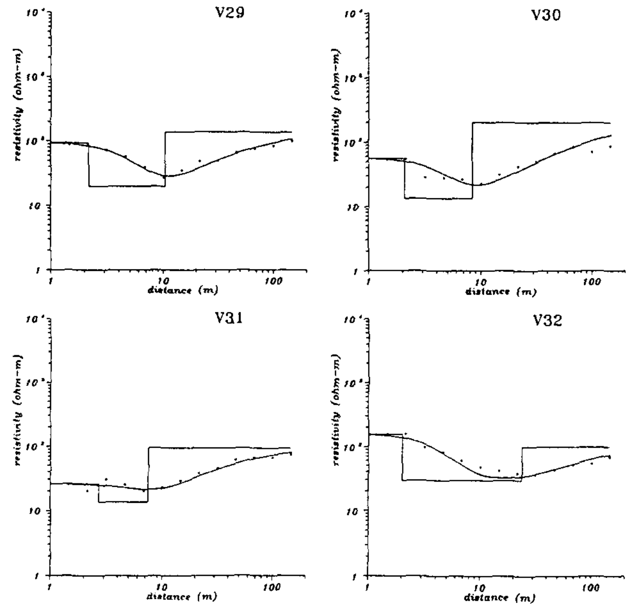

Figure 6. Electrical soundings and their interpretations at the back of the right Nanjido landfill. Observed data and theoretically computed values are marked by dots and solid lines. Jagged lines represent interpreted resistivity structure.

Soundings V29~V32 and V33~V36 were made in the back areas of the right and left Nanjido landfill, respectively. Because of poor field condition, many Schlumberger soundings were not made. The interpretations of sounding data at the back of the right Nanjido landfill is shown in Figure 6. All the data are interpreted as 3-layer structure. Below the top layer lie low resistivity zones of about 13~29 Ω-m at the depth of 8~24 m with mean thickness of 10.3 m. The resistivity structures of this area are quite different from those in the areas in front of the landfill which have more conductive and thicker low resistivity zones. Relatively resistive and thin low resistivity zones of this area appear to be related to the fact that the survey points in this area are somewhat far from the landfill and hydrogeologically this area belongs to up-gradient area. Actually, following sounding data near the back of the left Nanjido landfill show more conductive and thick low resistivity zones than those of this area.

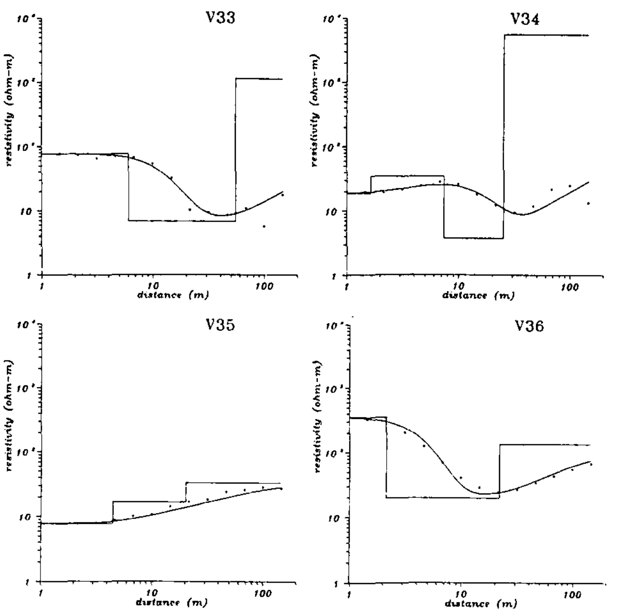

Figure 7. Electrical soundings and their interpretations at the back of the left Nanjido landfill. Observed data and theoretically computed values are marked by dots and solid lines. Jagged lines represent interpreted resistivity structure.

Adjacent to the back edge of the left Nanjido landfill, soundings V33~V36 were carried out. These data also shows low resistivity zones of about 3.8~19 Ω-m with mean thickness of 25.6 m (Figure 7). Especially, V35 shows very conductive top soil having resistivity of 7.7 Ω-m. It appears that this result from leachate drained on the surface through outlet existing near the measuring point.

On the whole, the sounding data in the area in front of the landfill show more conductive and thicker low resistivity layers than those at the back of the landfill. Moreover, the sounding data around the left Nanjido landfill show a little more conductive low resistivity zones than those around the right Nanjido landfill.

Inside of the Nanjido Landifll

Because maximum waste reclamation reaches about 80 m, the depth of bed rock is 110~120 m from the surface in the landfill. For this reason, the maximum distance between measuring point and current pole is controlled to be 215 m in this area. The directions of soundings are parallel to the long axis of the landfill.

The left Nanjido landfill

A total of 14 Schlumberger soundings were conducted. Most of these data can be interpreted in terms of 4 layer structure having similar trends except L4 and L12. Six of these soundings are

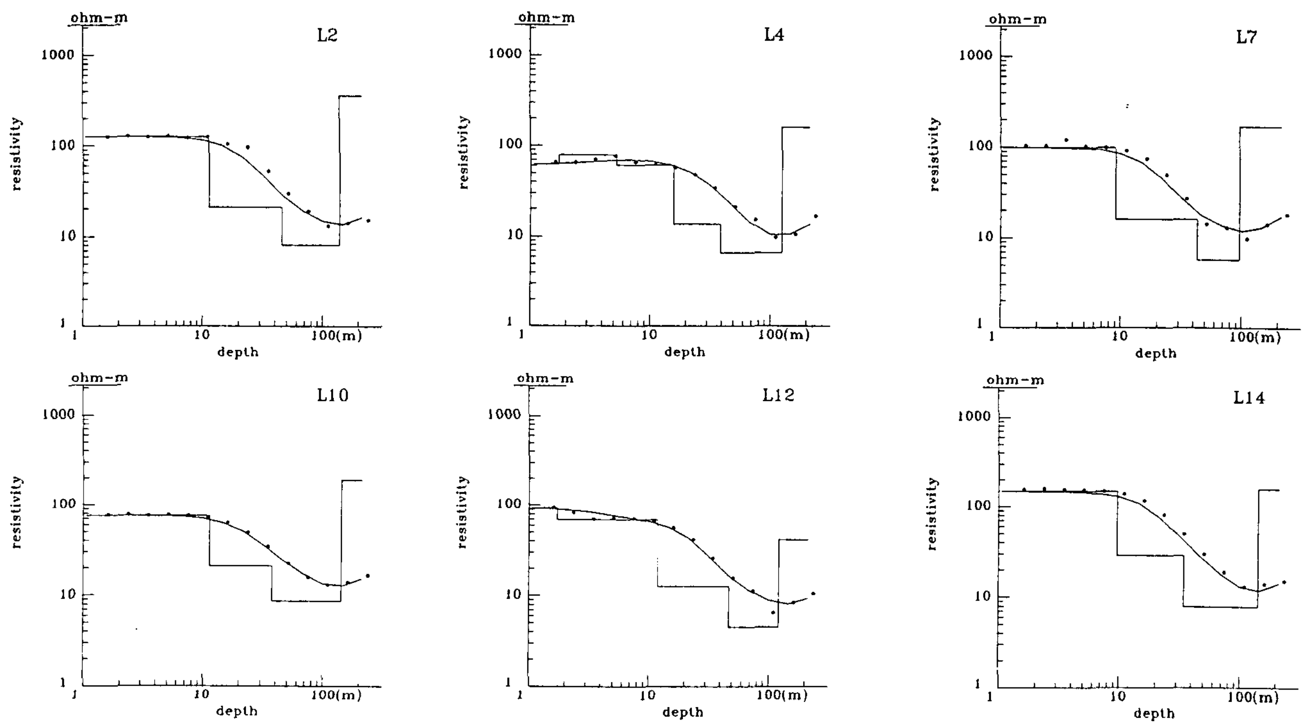

Figure 8. Electrical soundings and their interpretations in the left Nanjido landfill. Observed data and theoretically computed values are marked by dots and solid lines. Jagged lines represent interpreted resistivity structure.

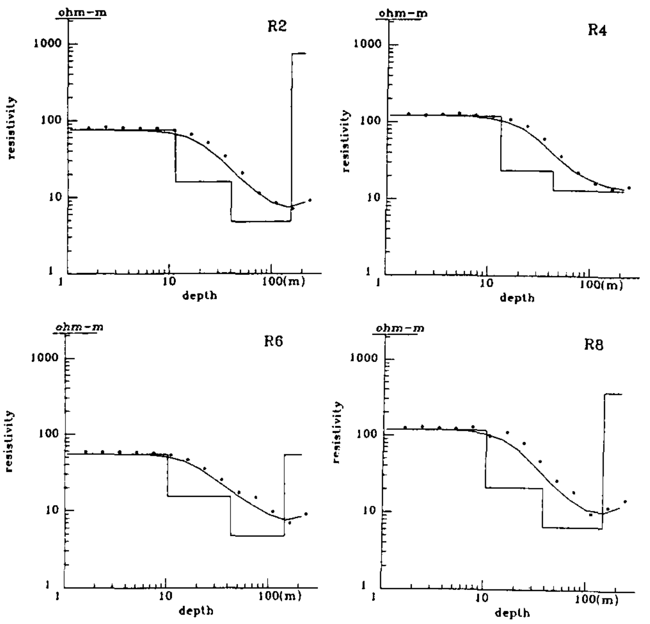

Figure 9. Electrical soundings and their interpretations in the right Nanjido landfill. Observed data and theoretically computed values are marked by dots and solid lines. Jagged lines represent interpreted resistivity structure.

shown in Figure 8. Most of the soundings in the right Nanjido landfill can also be modeled as 4-layer structure. Thus, these soundings are interpreted assuming 4-layer structure.

In Table 1, resistivities and thicknesses of interpreted layers are given. Because of inhomogeneous landfill materials, the first layers having resistivities of 26~148 Ω-m show a relatively large deviation of resistivity values with mean thickness of about 10 m. Considering their resistivities, the first layers can be assumed as unsaturated landfill layers with leachate. The resistivities of second layers are lower than those of the first layers. Also, the deviation of resistivities is much less than that of the first layers. Such decrease of resistivity deviation, despite of inhomogeneity of the landfill materials, indicates the saturation of this layer with leachate. But mean resistivity of this layer is 18 Ω-m and this is higher than that of leachate which generally has values below 10 Ω-m (Samsung, 1992). Thus the second layer can be assumed as partially saturated zone with leachate.

The third layer shows the typical characteristics of fully saturated zone with leachate. The resistivities of this layer range from 4.6 Ω-m to 9.5 Ω-m with the mean value of 6.8 Ω-m. These relatively homogeneous and very low resistivities indicate that this layer is fully saturated with leachate. Thus the top of the third layer can be regarded as leachate level. The mean leachate level of this area is 39 m down from the surface. Especially, the mean leachate levels of L4, L5, L8, and L9 located in the center of the left Nanjido landfill is 37 m from the surface. This means that the leachate level is formed high in the central area.

The mean depth of bed rock is 131 m from the surface. Considering the height of waste reclamation is about 75~80 m, this mean depth of bed rock is converted to 51~56 m from the surface before reclamation. Exact depth of the bed rock is not known because there is no boring hole which penetrates the bed rock in the landfill. But, assuming that the depth of bed rock in this area is similar to that of the circumference of the landfill, the mean interpreted depth is deeper than that of boring data by about 20~25 m. This is suggestive of contamination of the upper part of the bed rock in this area like around the landfill. The possibility of the bed rock contamination is supported by relatively low mean resistivity of the bed rock, too. The mean resistivity of the bed rock is 205 Ω-m and this is very low compared with that of gneiss forming bedrock in this area.

The right Nanjido landfill

Soundings R1~R8 were made in the right Nanjido landfill. Interpretations of these data show similar resistivity structures as those of the left Nanjido landfill as expected. Some of these interpretations are shown in Figure 9. The mean thicknesses of the first and the second layer are 11m and 29 m, respectively, which are close to those of the left Nanjido landfill. But the mean resistivities of these layers are somewhat high in comparison with those of the left Nanjido landfill. Besides, the mean leachate level from the surface is lower than that of left landfill by about 2 m. From these facts, it can be concluded that the right landfill is somewhat less saturated by leachate than the left landfill. Such discrepancy in the degree of leachate saturation between the left and the right landfill seems to result from different geology and hydrology of landfill areas. The mean depth of the bed rock is 130.4 m close to 131 m of the left landfill. However, the mean resistivity of bedrock is about two times as much as that of left landfill but still the value is much lower than that of gneiss. It appears that the upper part of the bed rock in the right landfill is considerably contaminated, too.

CONCLUSIONS

1. The weathered zones of the areas in front of and back of the Nanjido landfill are contaminated with leachate from the landfill. Considering the resistivities and thicknesses of interpreted sounding data, the degree of contamination of the area in front of the landfill is more severe than that at the back of the landfill.

2. The interpreted mean depth of the bed rock in front of the landfill is about 62 m and this is larger than that of boring data by about 20~30 m. This indicates the contamination of the upper part of bedrock in this area, the same phenomenon occurring in the landfill. Contamination of the bedrock will continue in these areas without proper management such as installation of slurry

wall, cap, drainage facilities, etc. But at the back of the landfill, no evidence of bedrock contamination is indicated.

3. Depths of mean leachate levels from the surface are 39 m and 41m in the left and right Nanjido landfills, respectively. Such difference of leachate levels seems to result from the different geology and hydrology of waste reclamation areas of the left and right Nanjido landfills.

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