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Annual Variation of Resistivity Structure in and around the Nanjido Waste Landfill

난지도 폐기물 매립장과 그 주변 지역에서의 연간 비저항구조 변화

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Abstract : Schlumberger soundings and dipole-dipole electrical surveys were carried out in and around the Nanjido waste landfill in August and December, 1995. Survey points were set to be identical as those in August, 1994 and February, 1995 as possible. To elucidate the annual variation of resistivity structure in and around the landfill, 50 electrical soundings and 2 lines of dipole-dipole surveys were conducted. Interpretations of these data show that mean resistivity values become lower and thicknesses of contaminated layers by leachate thicker than those of the previous year in and around the landfill. Especially, mean thicknesses of saturated layers with leachate increased by about 3~6 m and resistivities of bedrock decreased. Considering actual hydraulic conductivity, such increments of mean thicknesses are somewhat large. But resistivity variations in and around the Nanjido landfill clearly indicates contamination of layers by leachate is in progress even though some errors in measurements and interpretations are considered. On the other hand, sounding data in the back area of the landfill are almost identical to those of the previous year. From these results, it appears that contamination of weathered zone and bed rock is in progress mainly inside and in the front area of the landfill.

요　　약 : 난지도 매립지 주변지역과 매립지내에서 1995년 8월과 12월에 걸쳐 슐럼버져 수직비저항탐사와 쌍극자 전기비저항탐사를 실시하였다. 탐사지점은 1994년 8월과 1995년 2월에 실시했던 비저항탐사 지점과 가능한 한 동일하도록 노력하였으며, 모두 50점의 수직탐사와 2측선의 쌍극자탐사를 실시하여 매립지내와 그 주변지역의 연간 비저항구조 변화를 규명하고자 하였다. 자료의 해석결과 1년전에 비하여 매립지 내부와 주변지역의 평균비저항이 낮아지고, 침출수에 의해 오염되거나 포화된 층의 두께도 전반적으로 두꺼워진 경향을 보였다. 특히 좌지도 내부와 그 주변지역은 침출수에 의해 포화된 층의 평균두께가 3~6 m 정도 증가했으며 기반암의 비저항도 낮아진 것으로 나타났다. 이러한 저비저항대의 평균두께 증가폭은 현실적인 수리전도도를 고려할 때 다소 큰 것이어서, 자료측정시나 해석시 오차의 영향도 생각할 수 있으나 비저항값의 변화를 볼 때, 침출수에 의한 지층오염이 진행되고 있다는 것만은 분명하다고 판단된다. 한편, 매립지 뒤쪽에서의 수직탐사 자료는 이전의 자료와 커다란 차이를 보여주고 있지 않는 것으로 보아 침출수에 의한 풍화대와 기반암의 오염은 주로 매립지 내부와 전방 주변지역에서 활발히 진행되고 있다고 생각된다.

INTRODUCTION

Recently, environmental problems become big issues to people in everyday life. So, many people are giving much attention to these problems. Among other things, environmental problems related to waste landfill become the focus of public interest and various researches have been carried out to solve these problems. Because major factor of the ground contamination in and around landfill is leachate originated from landfill, it is very important to elucidate the details of its distribution and behavior.

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Since 1992 when waste reclamation was finished, the Nanjido landfill has been left untreated up to recently. However, recently many geophysical and hydrogeological studies have been made to stabilize the landfill (Jang *et al.*, 1994; Kwon *et al.*, 1995; Lee *et al.*, 1996; Lee and Yoon, 1995; Samsung, 1994; Segil, 1992) and especially slurry wall is under construction now by Dong-Ah construction company. According to these studies, the Nanjido landfill and its surroundings are contaminated by leachate and the possibility of bedrock contamination is indicated (Lee *et al.*, 1996; Lee and Yoon, 1995). The purpose of this study is to investigate variation of ground contamination and leachate distribution by comparing and analyzing the electrical survey data which were obtained in and around the Nanjido landfill with one year's interval. It

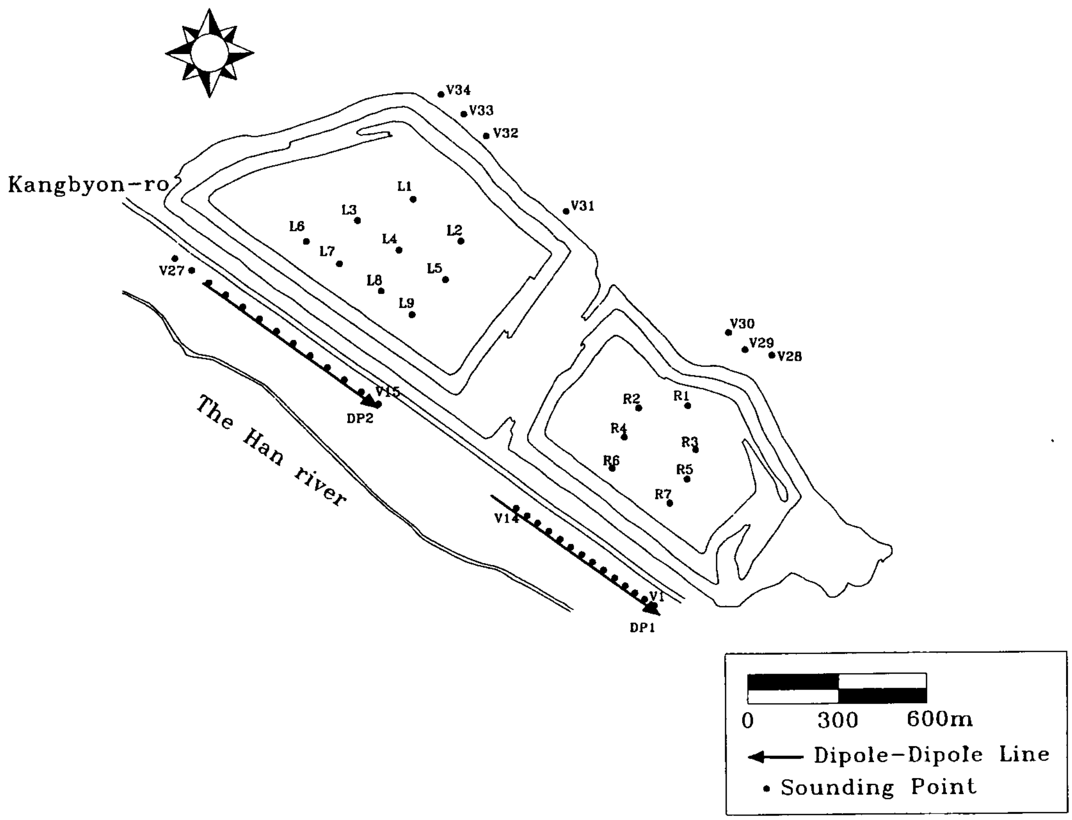

Figure 1. The location map of electrical surveys.

is thought that this study can provide useful data in dealing with the ground contamination problem at the Nanjido landfill.

In this study, a total of 50 Schlumberger soundings were made at the same places as those in August, 1994 and February, 1995 as much as possible. Also, to enhance the confidence of sounding data and better resolve the resistivity structure, two lines of dipole-dipole survey were carried out along the sounding lines in front of the landfill. Detailed location map of electrical surveys is shown in Figure 1.

COMPARISON AND ANALYSIS OF RESISTIVITY STRUCTURE

Electrical surveys were performed with ABEM Terrameter SAS 300B and OYO McOhm-meter. To increase the confidence of measured data, booster was used in the dipole-dipole surveys. In Schlumberger soundings, considering the bedrock depth, maximum distance between measuring point and current pole was set as 215 m and 145 m in and around the landfill, respectively. In the dipole-dipole surveys, electrode spacing and electrode separation coefficient were set as 30 m and 8.

Final resistivity structures of sounding data were determined by automatic interpretation method (Zohdy, 1989) and interactive method (Kim and Lee, 1993). Boring data and resistivity structures obtained by the automatic interpretation method were used in interactive interpretation process as possible. As a result, sounding data could be interpreted as 4-layer structure like the previous year. On the other hand, dipole-dipole survey data were interpreted by finite difference inversion method (Kim, 1987) which smoothness constraint is imposed on (Constable *et al.*, 1987; Inman, 1975). Smoothness constraint method makes the second derivatives of resistivity with space zero in order to prevent the abrupt change of the resistivity. This method gives a more reasonable resistivity structure in the geological sense.

Circumference of the Nanjido Landfill

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

In the front area of the right and left Nanjido landfills toward the Han river, 14 and 13 Schlumberger soundings were carried out at regular intervals, respectively. The intervals of sounding points are 46 m in V1~V14 and 68 m in V15~V27. The sounding points in front of the right Nanjido landfill were adjusted to be the same as those of August, 1994 in order to make the comparison of both data convenient. But in front of the left Nanjido landfill, sounding points were not exactly the same as those of the previous year due to the construction of the Gayang Great Bridge. Also dipole-dipole surveys were made along the sounding lines to enhance the confidence of interpreted resistivity structure.

Interpretations of V1~V27 are shown in Figure 2 and 3. Since the sounding points located in the front area of the right Nanjido landfill are the same as those of the previous year, interpreted resistivity structures of both sounding data are displayed simultaneously in Figure 2. It is indicated that the thicknesses of the third layers are increased than those of the previous year in soundings V5, V6, V13 and V14. The resistivities of the third layers suggest that weathered zones are contaminated by the leachate. So increase of the third layers' thicknesses indicates continuous leachate leakage from the landfill. Also judging from the fact that contaminated layers mostly thicken toward the second layers regarded as alluvium rather than the bedrock, it is believed that the leaked leachate from the landfill during the one year had not reached to the upper part of the bedrock yet. However, decrease of the mean resistivity of the bedrock in front of the right Nanjido landfill to about 2,000 Ωm, seems to indicate bedrock contamination by leachate is in progress continuously though slower than the weathered zone.

Table 1 shows detailed interpretation results of soundings with the mean values of the previous year. Though each sounding data show some differences in resistivity structure, it is revealed clearly that average resistivity values reflect the progress of ground contamination in this area. In the front area of the right Nanjido landfill, average resistivities of alluvium and the weathered zone are lower than those of the previous year by about 30 Ωm and 2.5 Ωm, while the thickness of each layer does not show any significant change. Also, it is shown that mean resistivities of the bedrock decreased a lot. It is obvious that these decreases of mean resistivities have relation to the continuous leakage of the leachate from the landfill even though the errors in measurement and interpretation

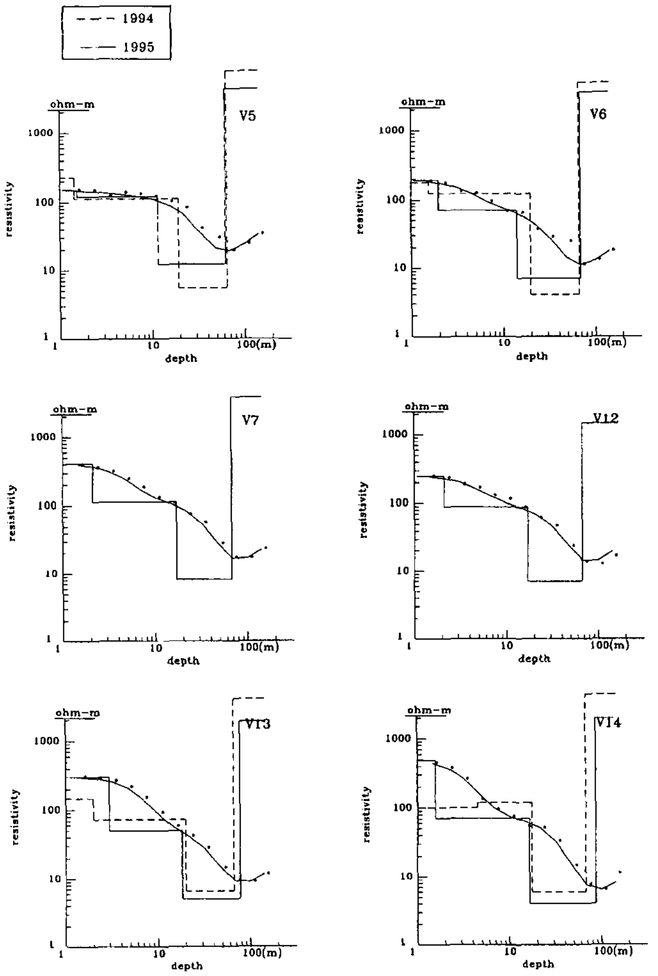

Figure 2. Interpretations of sounding data in front of the right Nanjido landfill (dot: observed value, solid line: theoretically calculated value, jagged line: interpreted resistivity structure).

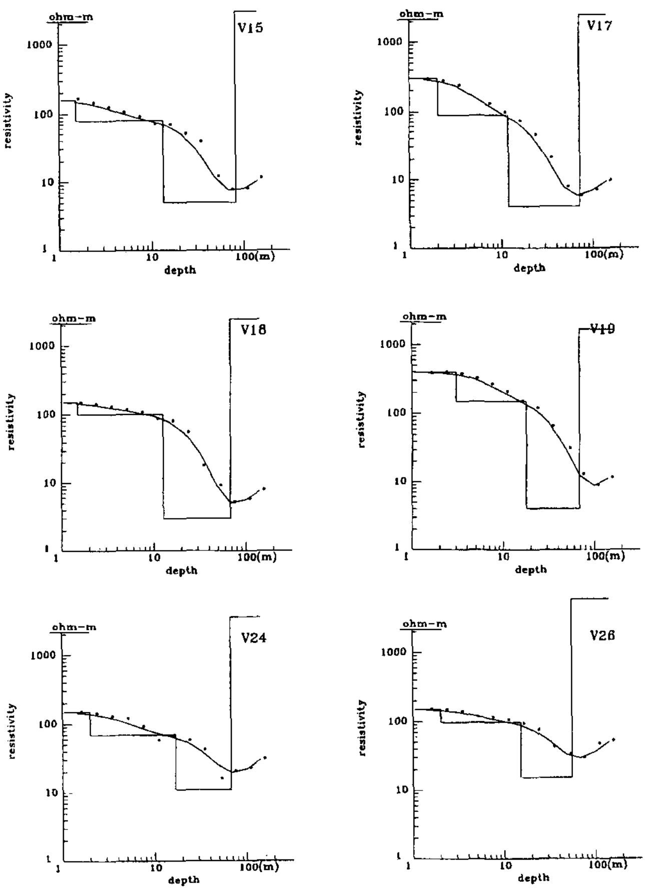

Figure 3. Interpretations of sounding data in front of the left Nanjido landfill (dot: observed value, solid line: theoretically calculated value, jagged line: interpreted resistivity structure).

Table 1. Resistivities and thicknesses of interpreted layers of sounding data around the landfill

Location of VES	No. of VES	First Layer thickness (m)	First Layer resistivity (Ωm)	Second Layer thickness (m)	Second Layer resistivity (Ωm)	Third Layer thickness (m)	Third Layer resistivity (Ωm)	Fourth Layer resistivity (Ωm)
Front Area of the Right Nanjido Landfill	V1	3.5	597.5	14.0	203.8	45.2	49.9	6400.7
	V2	2.0	299.9	9.8	150.5	33.7	13.3	4005.4
	V3	1.6	395.1	13.0	77.6	40.0	20.1	4005.4
	V4	1.7	254.1	7.0	111.1	45.1	20.7	4994.0
	V5	1.5	150.5	10.0	120.7	50.3	12.2	4232.5
	V6	2.0	192.9	12.2	69.5	55.0	7.1	3587.1
	V7	2.1	406.1	14.8	111.1	50.2	8.1	3790.5
	V8	1.6	247.2	14.0	91.6	59.0	11.0	2576.5
	V9	2.0	308.3	11.9	79.8	53.2	5.1	1703.7
	V10	3.5	300.0	15.0	49.9	49.7	4.9	1568.5
	V11	1.5	395.1	17.0	99.5	45.1	14.8	2010.3
	V12	2.1	247.2	15.1	89.1	50.0	7.1	1484.3
	V13	2.9	300.0	15.2	50.0	59.0	5.1	1902.4
	V14	1.6	492.6	15.0	71.5	70.0	4.1	2010.3
Mean		2.1	327.6	13.1	98.3	50.4	13.1	3162.3
Previous Mean		2.5	231.9	13.9	129.7	50.6	15.6	5040.2
Front Area of the Left Nanjido Landfill	V15	1.5	159.0	12.2	79.8	69.1	5.1	3040.1
	V16	1.6	247.2	14.9	49.9	59.6	2.1	1525.8
	V17	2.0	300.0	9.9	89.1	60.0	4.1	2506.5
	V18	1.5	150.5	11.1	99.5	55.4	3.0	2506.5
	V19	3.0	395.1	14.9	150.5	50.2	4.1	1703.7
	V20	1.5	247.2	10.0	69.5	50.3	11.9	3489.5
	V21	2.1	150.5	10.0	108.1	45.5	7.1	3040.1
	V22	2.0	198.3	11.9	20.7	46.1	2.1	2010.3
	V23	1.5	441.2	10.0	40.1	50.3	7.1	4005.4
	V24	2.0	150.5	15.0	69.5	50.2	11.0	3489.5
	V25	1.5	203.8	12.0	79.8	49.3	10.1	3040.1
	V26	2.0	150.5	13.1	96.8	40.1	15.3	6057.3
	V27	3.1	550.4	15.0	15.5	29.4	20.1	7147.2
Mean		1.9	257.2	12.3	74.5	50.4	7.9	3350.9
Previous Mean		2.0	165.1	8.9	102.0	47.4	6.8	4525.3

are considered. Similar trends of these changes in resistivity structures are also revealed in the front area of the left Nanjido landfill and inside of the landfill. These facts indicate survey data are very reliable.

The interpretation results of the soundings in front of the left Nanjido landfill are shown in Table 1 and Figure 3. Sounding data of this area indicate that ground contamination by leachate is in progress more rapidly than in front of the right Nanjido landfill. Since the locations of soundings V15~V17 are somewhat different from those of the previous year, it is difficult to compare the resistivity structures with those of the previous year one to one. However, because the differences in locations are not so large, it is reasonable to analyse the whole resistivity structures in comparison with those of the previous year. As shown in Figure 3, all soundings were interpreted as 4-layer structure. On the whole, mean resistivities of each layer decreased compared with those of the previous year like the case of the front area of the right landfill (Table 1). But the thicknesses of the weathered zone and alluvium contaminated by the leachate increased by 3 m and 3.4 m on the average unlike in front of the right Nanjido landfill. Especially, soundings V15 and V17 located in the middle of the right and left Nanjido landfill show thicker contaminated weathered zone than those of the other soundings (Figure 3). Also, it is revealed that mean resistivities of alluvium and weathered zone is lower than those of the right Nanjido landfill by about 24 Ωm and 5 Ωm, respectively. Therefore, it seems that ground contamination is severer in this area than in front of the right landfill. This is due to the fact that the quantity of the leachate from the left landfill is large owing to larger dump volume of waste in the left landfill than in the right landfill.

In Figure 4, two pseudo-sections of two dimensional resistivity structure of the area in front of the Nanjido landfill are shown. The pseudo-sections are constructed based on the sounding data interpreted in terms of 4 layers. These sections do not represent the real subsurface structure but can be used

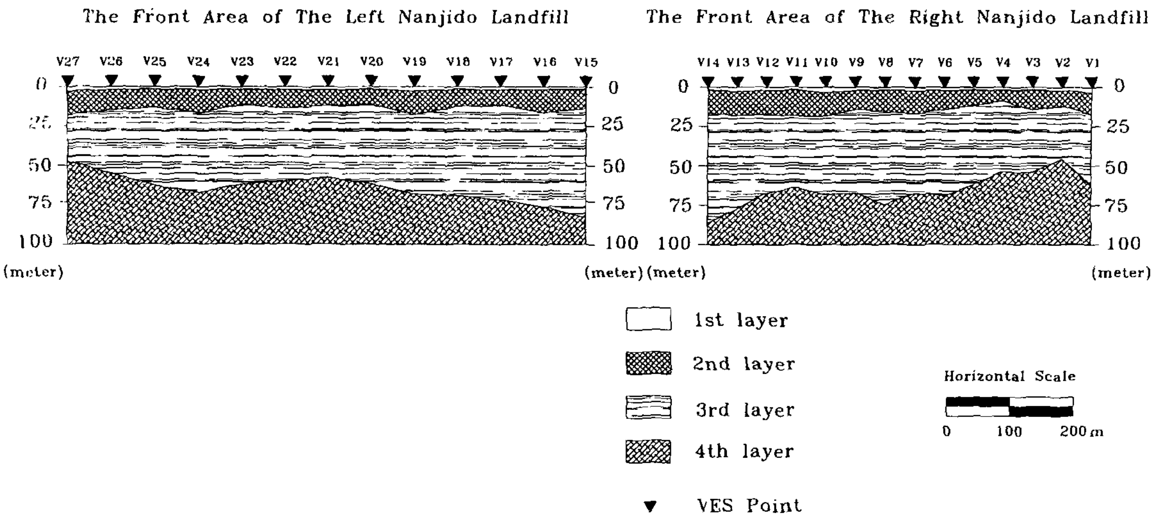

Figure 4. Pseudo-sections of two dimensional resistivity structure in front of the Nanjido landfill.

for understanding 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 right landfill and between the right and the left landfill. While mean thicknesses of the third layers are about 50 m both in front of the left and the right Nanjido landfill, in the area between the both landfills the thicknesses of these layers reach about 60~70 m. Also their resistivities in this portion is lower than mean resistivity by about 2~9 Ωm. This is the evidence that the leachate from the landfill moves mainly along the valley between the both landfills. This evidence is also indicated in the sounding data of the previous year (Lee and Yoon, 1995) and the dipole-dipole data obtained in the vicinity of this area (Lee *et al.*, 1996).

Compared with the pseudo-sections of the previous year, the overall resistivity structures of this study are similar, but detailed structures somewhat different (Lee and Yoon, 1995). Particularly in the center of the right Nanjido landfill, the thickness of the third layer decreased and in the left edge of the left Nanjido landfill, the thickness increased much compared with that of the previous year. However, it is unreasonable to give any significance to these differences because the number of soundings that were used in making the pseudo-sections of the previous year is deficient. However, since the number of soundings of this study is more than two times as that of the previous year, pseudo-sections in this study are more reliable.

To verify the confidence and exactness of the pseudo-sections, two lines of dipole-dipole surveys were made along the sounding points in front of the right and the left Nanjido landfill. Figure 5 and 6 show the interpretation results of dipole-dipole surveys. Like the results of soundings, thick low resistivity zone appears near the center of the right Nanjido landfill and between the landfills. But the size of the block used in inversion of the dipole-dipole data is too large for thin top layer to appear in the inverted resistivity sections. Besides, since the resistivities of the second and the third layers are too

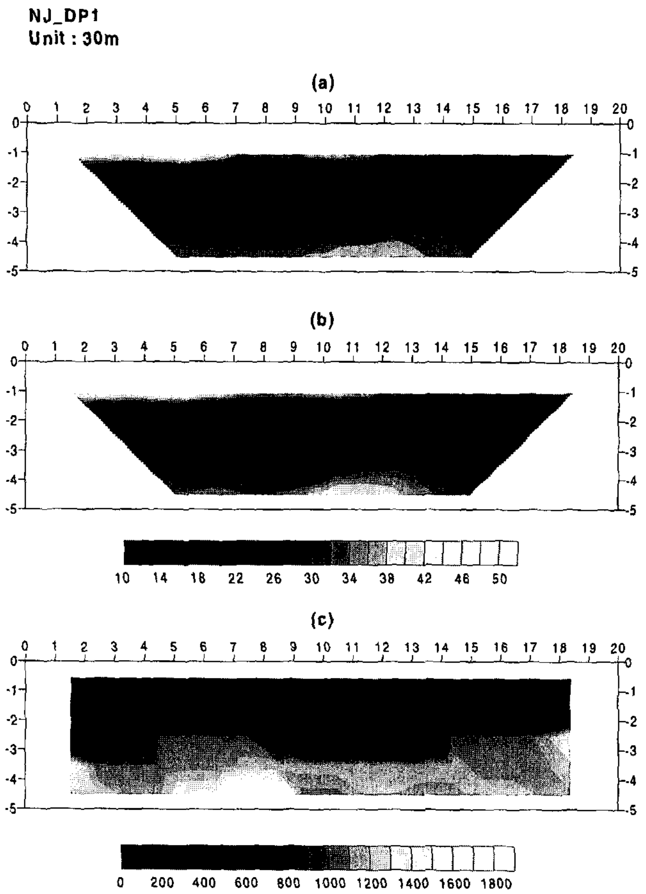

Figure 5. Interpretation of dipole-dipole survey in front of the right Nanjido landfill: (a) pseudo-section of observed apparent resistivity (b) pseudo-section of theoretically calculated apparent resistivity (c) inverted block model.

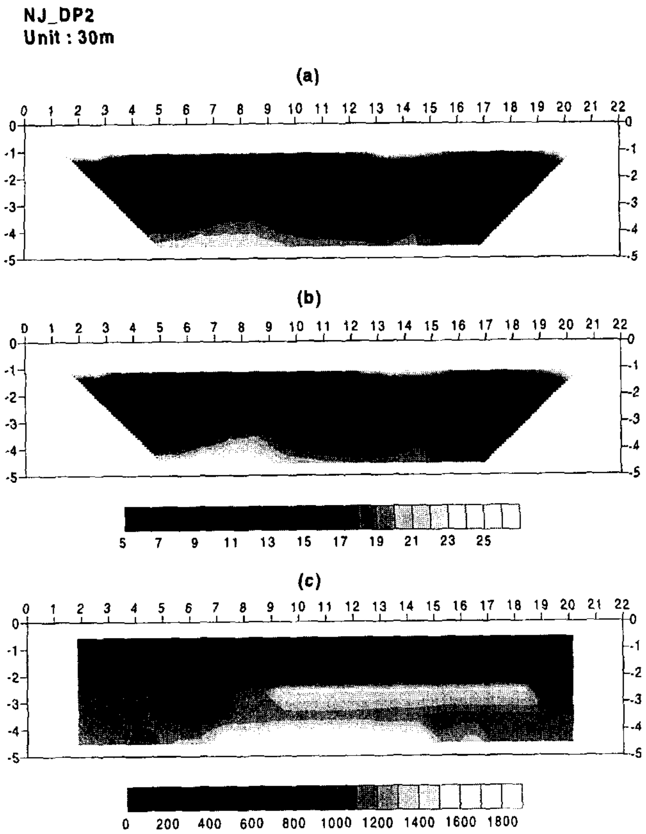

Figure 6. Interpretation of dipole-dipole survey in front of the left Nanjido landfill: (a) pseudo-section of observed apparent resistivity (b) pseudo-section of theoretically calculated apparent resistivity (c) inverted block model.

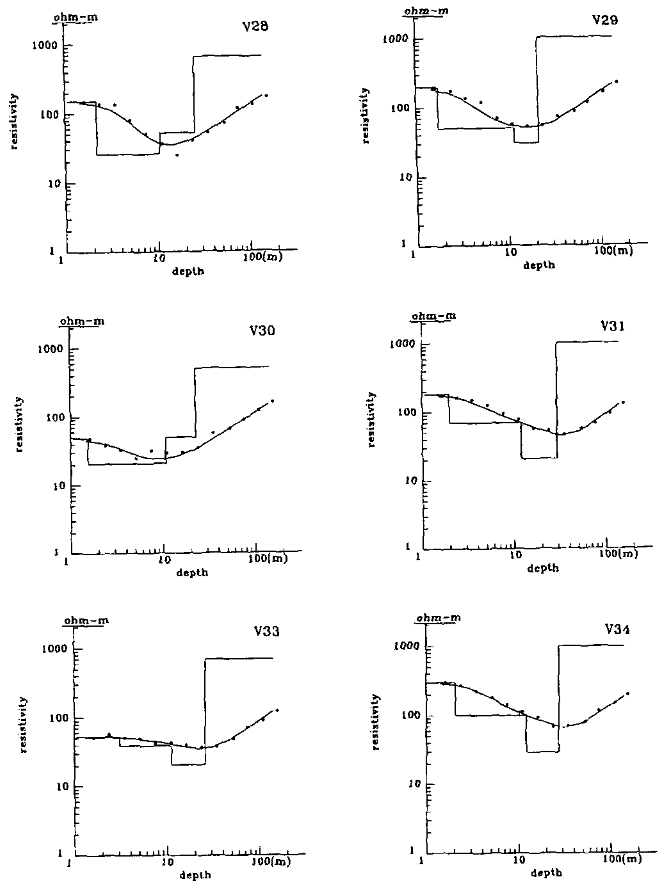

Figure 7. Interpretations of sounding data at the back of the Nanjido landfill (dot: observed value, solid line: theoretically calculated value, jagged line: interpreted resistivity structure).

small compared with those of the bedrock, those layers are indistinguishable from each other in the sections. However the bedrock depths of dipole-dipole data are in good agreement with those of pseudo-sections.

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

Interpretations of six soundings obtained in the back area of the landfill are shown in Figure 7. Soundings V28~V30 and V31~V34 are at the back areas of the right and the left Nanjido landfill, respectively. The locations and the interpreted resistivity structures of soundings are somewhat different from those of the previous year in this area. Sounding data were interpreted in terms of 4 layers while previous soundings 3 layers. But both resistivity structures are similar to each other on the whole. In Figure 7, the bedrock appears at the depth of about 20~30 m from the surface. Thus there is no evidence that contamination of the bedrock in this area had progressed for one year. Like the results of the previous year, in the back area of the left landfill low resistivity zone of about 10~30 Ωm is thicker than that in the back area of the right landfill.

Inside of the Nanjido Landfill

Considering the depth of the bedrock is 110~120 m from the surface in the landfill, 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 (The 1st landfill)

A total of 9 soundings were carried out and four interpretations of these data are shown in Figure 8. Like the previous year, all soundings were interpreted as 4-layer structure having similar trends. In this area, average thickness of the saturated layer with leachate is 98.7 m and increased by about 6 m. Compared to the previous year also mean resistivity of the bedrock decreased by about 40 Ωm. Considering that the thicknesses and resistivities of the top and the second layers change little, it seems that the thickness of the saturated layer with leachate increases toward the bedrock. Especially, in the interpretations of L4 and L5 which are located near the center of the left landfill, resistivities of the bedrock ranging from 48 Ωm to 57 Ωm are much lower than those of the other soundings in this area. This phenomenon indicates that continuous bedrock contamination due to the downward movement of the leachate is in progress and the degree of contamination is severest near the central portion of the landfill.

Detailed interpretation results of all soundings are shown in Table 2. It is shown that the resistivities of the second and the third layers corresponding to the partially and fully saturated layers with leachate changed very little from the previous year. This seems to result from the horizontal movement of the leachate.

The right Nanjido landfill (The second landfill)

Soundings R1~R7 were made in the right Nanjido landfill.

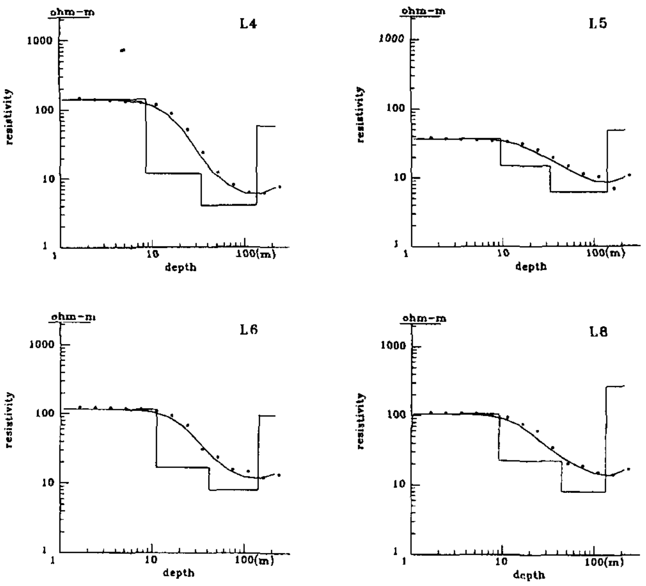

Figure 8. Interpretations of sounding data in the left Nanjido landfill (dot: observed value, solid line: theoretically calculated value, jagged line: interpreted resistivity structure).

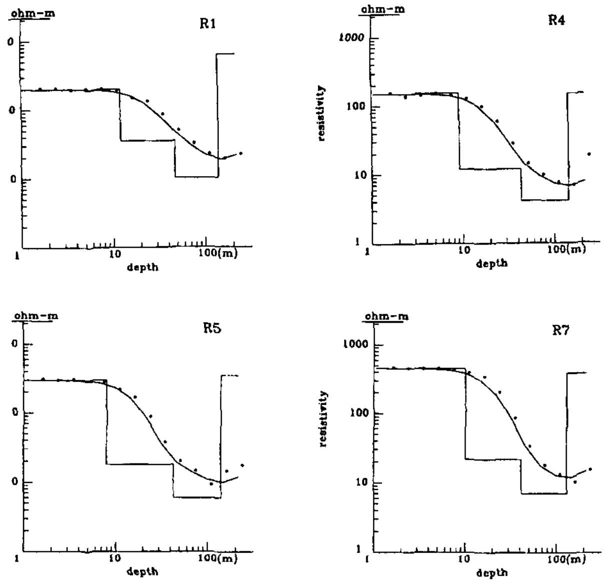

Figure 9. Interpretations of sounding data in the right Nanjido landfill (dot: observed value, solid line: theoretically calculated value, jagged line: interpreted resistivity structure).

Table 2. Resistivities and thicknesses of interpreted layers of sounding data in the landfill.

Location of VES	No. of VES	First Layer thickness (m)	First Layer resistivity (Ωm)	Second Layer thickness (m)	Second Layer resistivity (Ωm)	Third Layer thickness (m)	Third Layer resistivity (Ωm)	Fourth Layer resistivity (Ωm)
The Right Nanjido Landfill	R1	12.0	198.3	34.0	34.9	91.6	10.1	631.4
	R2	13.0	99.5	27.7	15.3	111.9	5.4	299.9
	R3	15.2	60.6	26.7	17.0	102.5	7.9	441.2
	R4	9.1	150.5	33.9	11.9	99.3	4.1	150.5
	R5	8.0	300.0	35.0	18.0	97.3	6.0	353.8
	R6	12.0	114.2	27.1	20.1	91.9	5.1	441.2
	R7	10.1	453.5	31.1	21.8	89.7	7.1	395.1
Mean		11.3	196.7	30.8	19.9	97.7	6.5	387.6
Previous Mean		11.1	112.8	29.4	21.7	97.6	6.6	439.1
The Left Nanjido Landfill	L1	9.6	71.5	35.3	21.2	95.5	7.5	150.5
	L2	11.2	131.1	31.9	12.9	99.3	6.3	308.3
	L3	10.0	96.8	24.0	11.0	110.3	5.2	154.7
	L4	8.6	142.4	24.9	12.0	101.1	4.1	57.3
	L5	9.5	36.9	23.1	14.8	105.8	6.1	48.6
	L6	11.2	117.4	30.7	17.0	100.5	8.1	96.8
	L7	11.0	316.9	33.9	18.5	97.5	7.1	203.8
	L8	9.1	105.2	35.1	22.5	90.4	8.1	276.1
	L9	10.0	215.4	31.3	15.3	87.8	7.2	203.8
Mean		10.0	137.1	30.0	16.1	98.7	6.6	166.7
Previous Mean		9.9	78.3	29.2	17.9	92.0	6.8	205.4

All the data are interpreted as 4-*layer structure and four of* them are shown in Figure 9. On the whole, interpretations of these data show similar resistivity structures to those of the left Nanjido landfill as expected. However, compared with those of the left Nanjido landfill, the resistivities of the bedrock are higher by about 200 Ωm while the first, second and third layers differ little in thicknesses and resistivities (Table 2). Thus it is thought that the contamination of the bedrock in this area is less than in the left Nanjido landfill. Soundings R4 and R5 situated at the central portion of the landfill show thicker saturated layers with leachate than the other soundings in this area.

In comparison with the sounding data of the previous year there are no much differences in the resistivities and thicknesses of each layer except bedrock whose mean resistivity decreased by about 40 Ωm. Accordingly, it can be concluded that the right Nanjido landfill is more stabilized than the left landfill. However, judging from the resistivity decrease of bedrock, continuous bedrock contamination is in progress and prolonged resistivity monitoring is needed.

CONCLUSIONS

In this study, to elucidate the annual variation of resistivity structure in and around the Nanjido landfill, electrical survey data have been analyzed. As a result, followings are concluded.

1. In front of the Nanjido landfill the weathered zone is thought to be considerably contaminated by the leachate from the landfill. The mean thickness of this layer is 50.4 m in this area. Also the mean resistivity of this layer is 7.9 Ωm and 13.1 Ωm in the left and the right landfill, respectively. Comparing these values with those of the previous year, mean thickness of this layer increases by 3 m and the mean resistivity decreases by 2.5 Ωm in front of the left and the right landfill, respectively (Figure 10). On the other hand the mean resistivities of the bedrock in the front areas of both landfills decrease by about 1,200~2,000 Ωm. Thus it appears that the contamination of the weathered zone and the bedrock is in progress in front of the Nanjido landfill. Besides, in front of the Nanjido landfill, soundings and dipole-dipole survey data indicate that contamination of the weathered zone is most intensive between the landfills and in the middle of the right Nanjido landfill.

2. Soundings made in the back area of the Nanjido landfill do not show any indication of further ground contamination by leachate compared with those of the previous year.

3. In the left Nanjido landfill, mean thickness of fully saturated layer with leachate increased by about 6 m and mean resistivity of the bedrock decreased by about 40 Ωm compared with those of the previous year (Figure 10). Considering actual hydraulic conductivity, such increment of mean thickness is somewhat large. But considering the resistivity variations, it is obvious that bedrock contamination by leachate is in progress rapidly in this area.

4. In the right Nanjido landfill, the differences of mean thicknesses and resistivities of each layer from those of the previous year are not large but mean resistivity of bedrock decreases by about 50 Ωm. It seems that bedrock contamination is going on in this area, probably slower than in the left Nanjido landfill.

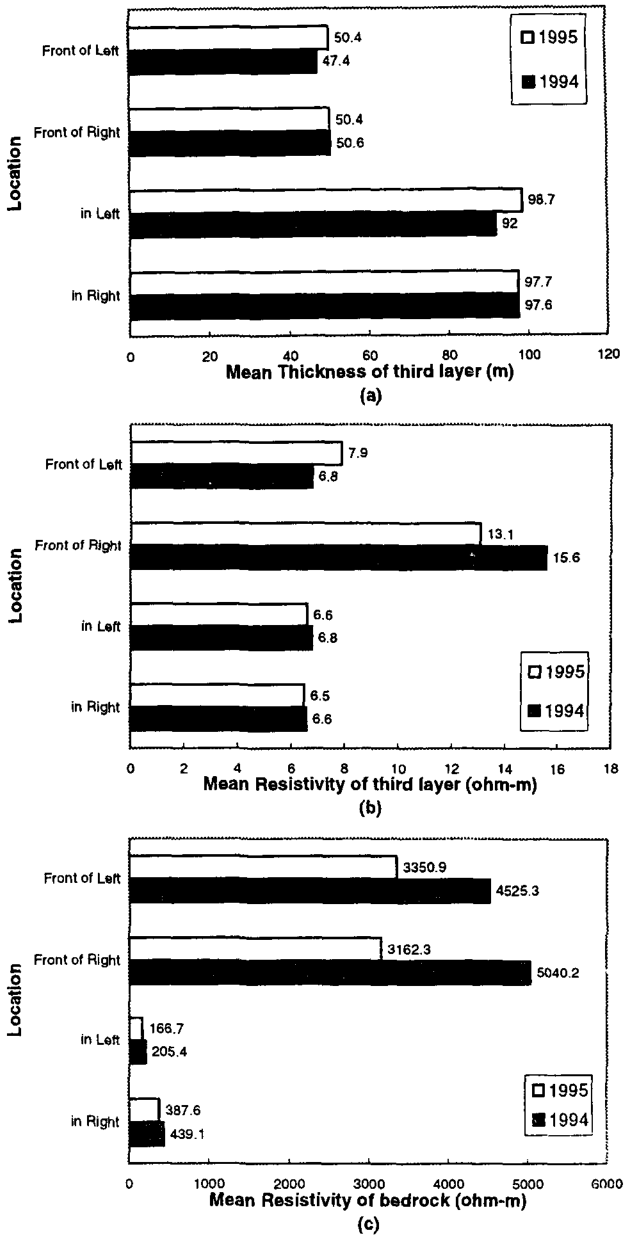

Figure 10. Comparison of interpreted resistivity structures in and around the landfill. (a) mean thickness of third layer (b) mean resistivity of third layer (c) mean resistivity of bedrock.

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