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A STUDY OF THE REDEVELOPMENT POTENTIAL OF A LANDFILL CONTAINING IRON WASTES

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SYNOPSIS

This paper presents the results of the tests performed for examining the potential for re-developing the landfill site containing iron wastes. Test pile driving and the corrosion test both in the laboratory and the field were performed and the chemical substance of groundwater sample at the site were analyzed. The results showed that the site has highly heterogeneous soil properties with contamination in groundwater, which necessitates the use of high cost foundation such as pre-bored steel piles, and slurry walls for excavations. Corrosion of construction materials in the landfill appeared not to be significant, although more test are necessary for the remaining specimens.

INTRODUCTION

Anomalous soil properties of a landfill caused by the indiscriminate disposal of ironwork wastes at Pohang, Korea, and the corrosion characteristics of construction materials with respect to the wastes are investigated.

The waste landfill considered is located at the southeastern part of the Korean peninsula and is composed of dumped slags mixed with sludges, dusts and concrete fragments. Landfilling at this site was started in August, 1986 and is scheduled for completion at the end of 1996.

Re-development of this site was considered, and several tests were performed to examine the possible adverse effects that may occur while construction is going on. Standard penetration tests and test pile driving with piles of 40 cm diameter were performed. Soil resistivity, which is often considered as a basic criterion for evaluating the corrosivity of soils, was investigated using an electric resistivity test. In-situ corrosion tests were performed by installing concrete and metal specimens in the waste fill. Test specimens were tested after four month of installation, and will be tested periodically for 1, 2 and 4 years.

In this paper, the results of tests to evaluate the engineering and corrosion characteristics of the iron wastes are presented. Strategies to minimize the environmental impact, and the adverse effects of the soils on driven piles are also discussed.

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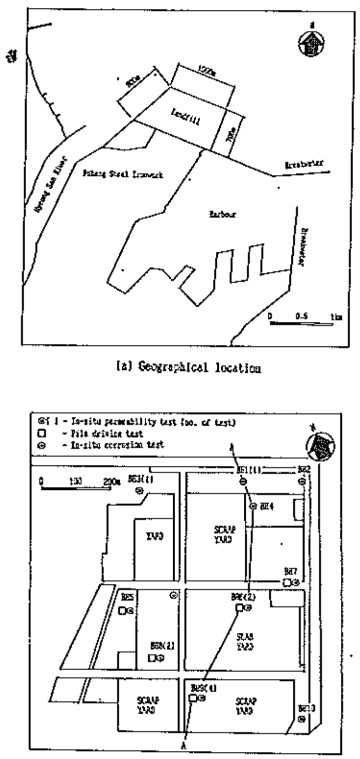
SITE CONDITIONS

The landfill investigated is in the Pohang ironwork and has a contact with the east sea (Fig. 1a). The distribution of iron waste and original subsurface material were investigated by drilling ten boreholes at the site (Fig. 1b). In-situ permeability tests were performed in five boreholes and test pile driving was performed at six points adjacent to the pre-drilled boreholes. Fig. 2 shows the distribution of iron wastes and the original subsurface for line A-A in Fig. 1.



(a) Geographical location

(b) Site plan with boring location

Fig. 1 Geographical Location and the Site Plan with Boring Locations

Wastes are mostly composed of slag, sand and gravel. However, some dust, sludge and concrete fragments can also be found. The average depth of the wastes is about 15 m and the size of slag is commonly that of gravel. Furnace brick, dust and sludge collected from the site have a similar size and shape to that of silty sand to sandy silt. The color of the slag is dark brown or dark gray. Chemical components of the slag are shown in Table 1.

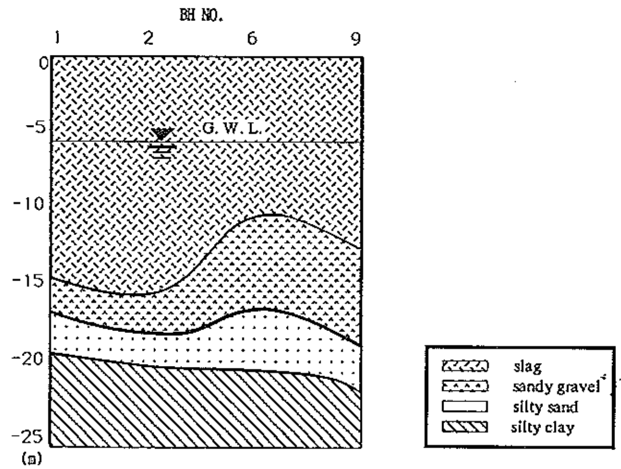


Fig. 2 Profile of the Landfill Based on the Drilling Log for Section A-A

Table 1 Chemical Components of Slag.

Types	Steelmaking slag (%)	Blast furnace slag (%)
FeO & Fe_2O^3	58.93	0.40
CaO	11.19	39.80
SiO_2	17.25	34.40
Al_2O_3	5.83	14.70
MgO	1.79	6.30
MnO	1.11	0.60
S	–	1.00
TiO_2	–	1.80
Miscellaneous	3.90	1.00

PHYSICAL AND ENGINEERING CHARACTERISTICS

Geotechnical laboratory experiments were performed on the remolded materials collected from standard penetration tests and the results are shown in Table 2.

Table 2 Physical Characteristics of In-situ Soils.

Characteristics	Landfill		Original soil	
	sand	clay	sand	clay
Specific gravity	2.64	2.68	2.65	2.70
Percent of passes to No. 200 sieve (< 0.072 mm)	33.0	80.0	31.0	89.0
Coefficient of uniformity (Cu)	94.4	3.7	15.6	10.1
Liquid limit (W_L)	N.A.*	42.7	N.A.	64.7
Plastic limit (W_p)		18.9		25.2
Plasticity index (I_p)		23.8		39.5
Shrinkage index (I_c)		0.35		0.64
Water content (W)	17.6	35.8	25.9	37.8

* data are not available

Table 3 Hydraulic Conductivity for the Soils Composed in the Landfill.

Soils	K (cm/sec)
slag and gravel	$1.48 \times 10^{-3} \sim 1.27 \times 10^{-1}$
sand	$6.60 \times 10^{-5} \sim 7.47 \times 10^{-2}$
sludge and dust	$9.24 \times 10^{-5} \sim 1.45 \times 10^{-4}$
clay	6.65×10^{-5}

There are no significant differences in the specific gravity and the fines content (< 0.072 mm) of the landfill and the original soil. However, sand in the landfill is far more uniform than the original subsuface material and the trend is reversed in clay. The liquid limit (W_L) and the plastic limit (W_p) of the filled clay show values lower than those of the original. The plasticity index is higher in the original ground, and the water content is similar between the fills and the original soils.

In-situ hydraulic conductivity tests were performed at five boreholes where in-situ SPT were taken (see Fig. 1). The average hydraulic conductivities for the soils in the landfill are shown in Table 3 and the distribution of hydraulic conductivity for the five boreholes is also shown in Table 4. The hydraulic conductivities of the sludge and dust are similar to clayey silt but are distributed over a wide range, even within the same soil level. This is because the fines content in the coarse materials (e.g. gravel, slag, sand) is different in different boreholes.

Table 4 Hydraulic Conductivity versus Depth.

Borehole	Depth (m)	Soil stratum	K (cm/sec)
1	6.0	sludge	1.45×10^{-4}
3	19.5	sand	6.60×10^{-5}
6	4.5	slag & dust	9.24×10^{-5}
	18.0	sand	7.47×10^{-2}
8	4.5	slag	5.60×10^{-2}
	15.0	gravel	8.77×10^{-2}
9	9.0	slag	1.05×10^{-1}
	13.5	slag	1.27×10^{-1}
	19.5	gravel	1.48×10^{-3}
	27.0	clay	6.65×10^{-5}

The results of the standard penetration test performed on the site are shown in Table 5. N values in the landfill are highly variable and an N value greater than 100 in the slag represents a stratum where the sampler cannot penetrate. It appeared from these results that pile driving may not be feasible for constructing the foundations of buildings.

Table 5 N Values Obtained from the Landfill of Ironwork.

Soils		Ranges	Averaged
Landfill	slag	3 ~ 100 <	–
	gravel	10 ~ 49	26
Original soil	gravel	8 ~ 25	15
	sand	11 ~ 33	22
	clay	8 ~ 11	9

TEST PILE DRIVING IN SITU

In order to confirm the S.P.T. results, and to analyze the feasibility of using driven piles, six test driven piles were installed. The points selected for this test were located 2 ~ 3 m away from the places where the S.P.T.s were taken.

The diameter of the test piles was ϕ = 406 mm and the length was 14 m. An IDM-25 driver with a ram and hammer weight of 7.5 tonnes was used. The piles were marked at 10 cm intervals to measure the number of blows.

The number of blows is recompiled for a penetration depth of 20 cm and plotted with respect to depth in Fig. 4. Mostly, the number of blows is in the range of 5 ~ 25. However, at Boreholes 6 and 9, the blow number increased at the depths of 3 m and 1 m, respectively, and the piles failed to penetrate the full 14 m. It seems that the failure of pile driving may come from the inclusion of hard materials produced from the factories (e.g. concrete fractions and scrap iron). The behavior of the piles diven at the 5 points, including the two failed points 6 and 9, is summarized in Table 6.

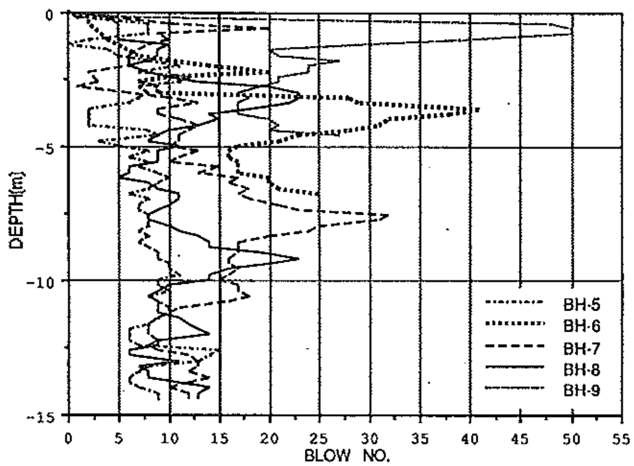


Fig. 3 Number of Blows versus Penetration Depth

Table 6 Behavior of Test Piles at Five Test Points.

No. of borehole	Behavior
BH-5, 7, 8	The piles were driven without any interruption.
BH-6	The ground adjacent to the test pile settled about 15 cm and formed a hole of radius 40 cm.
BH-9	The pile hit hard stratum at the depth of 0.5 ~ 1.0 m. It inclined 6° at the depth of 4 m and driving was stopped.

ESTIMATION OF CORROSIVITY

The corrosion characteristics of the construction materials in the earth can be found in several texts (e.g. Headon and Chan, 1985; Cross, 1979; Choi and Kwon, 1987). Headon and Chan (1985) performed in-situ test for the metal specimens in the flyash backfills. They estimated the degree of corrosion of the metal specimens in the compacted fly ash and bottom ash after two years of burial. Cross (1979) performed an in-situ experiment to investigate the corrosion of metal reinforcing elements. The soils used in this test were London clay and uniformly graded sand. Choi and Kwon (1987) analyzed the characteristics of leachate from blast furnace slag and estimated the corrosion of the specimens in the leachate solutions by measuring the weight loss of the specimens with one or two weeks intervals.

The corrosion characteristics of iron wastes may also influence the capacity of construction materials such as steel pipes, pipe sand concrete panels. In this section, the corrosion environment is estimated by measuring the electric resistivity of iron waste in the laboratory, and the in-situ corrosivity test is performed by burying the test specimens in the iron wastes.

Electric resistivity test

Corrosivity of the soils in the landfill is estimated qualitatively using the electric resistivity test. The test was performed by the following procedure.

(1) Five kilograms of materials which pass No. 4 sieve are mixed with water to an optimum water content.
(2) To ensure that the water is distributed uniformly in the materials, the soil is left for 16 hours.
(3) The materials are compacted in three layers in the resistivity cell.
(4) Distilled water is poured into the water compartments located at the two sides of the cell.
(5) The resistivity between the two plates is measured. The circuit diagram for the measurement of electric resistivity is shown in Fig. 4.

The inherent resistivity of the soils measured from this experiment is shown with the maximum dry density and the optimum water content in Table 7.

The reason we used optimum water content instead of natural water content is to investigate the possibility of using the ironwork wastes as fill materials in the reclamation site. In many cases, the reclaiming land should be compacted to the optimun water content, otherwise further soil improvement methods may be needed later for loosely deposited sites if a reclaimed landfill is usable as a construction site. Therefore, in order to generalize the results of the resistivity test for iron wastes, the optimum water content is used rather than the natural water content at a specific site.

The corrosivity of soils which have a resistivity less than 2,000 Ω cm and a water content greater than 20% is classified as high by many researchers, (e.g. Uhlig and Revie, 1985). The materials produced from ironwork such as steelmaking slag, sludge, dust and the blast furnaced slag have electrical resistivities that are less than 2,000 Ω cm, and the steelmaking dust has the lowest resistivity. The optimum water content of the steelmaking sludge has a water content in which the corrosivity of the material is high.

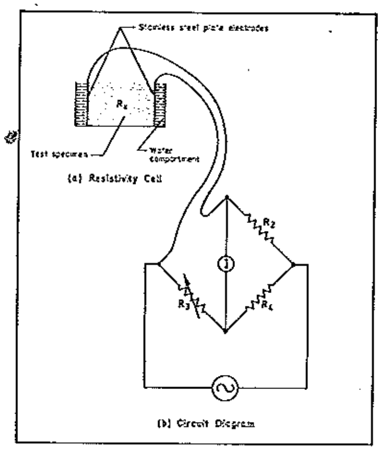


Fig. 4 The Circuit Diagram for the Electrical Resistivity Test

Table 7 Engineering Characteristics and Electric Resistivity of the Reclamated Soil

Type of soils	W(1)	γdmax (g/cm³)	Wopt(2) (%)	Electric resistivity (Ωcm)
weathered granitic soils	–	1.73	15	13,300
sand	–	–	–	11,509
steelmaking slag	0.6	2.57	8.2	1,509
blast furnaced slag	0.7	2.11	9.6	967
steelmaking sludge	19.5	1.99	28.3	653
steelmaking dust	1.5	2.25	11.5	200

(1) W Natural water content measured in the Lab.
(2) W Optimum water content for compacted soils.

In-situ corrosivity test

This test is carried out to measure the degree of corrosion of test specimens with time. The selected time intervals are 4 months, 1 year, 2 years and 4 years. Construction materials most frequently used in the ironwork are selected as specimens. The type and size of the specimens is shown in Table 8. The initial weight and thickness of the specimens is carefully measured and placed at depth of 1.5 m. Two samples of the same type are buried to obtain an averaged data from each group. A schematic view of arrangement of the specimens in the landfill is shown in Fig. 5.

Table 8 Types and Size of the Specimens.

Materials	Size (cm)	Remarks
unreinforced concrete	10 (D) × 20 (H)	cured for 28 days
reinforced concrete	10 (D) × 20 (H)	cured for 28 days
copper bar	0.6 (D) × 15 (H)	
stainless steel bar	0.6 (D) × 15 (H)	D : diameter
aluminum plate	2.5 (W) × 15 (H) × 0.6 (t)	H : height
carbon steel plate	2.5 (W) × 15 (H) × 0.6 (t)	W : Width
galvanized steel plate	2.5 (W) × 15 (H) × 0.6 (t)	t : thickness

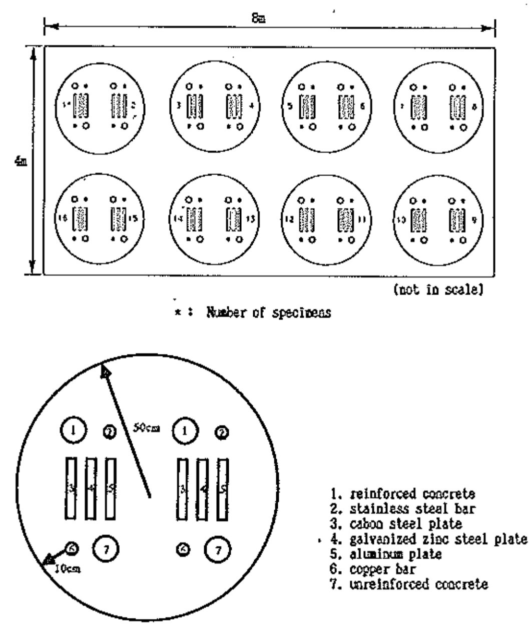


Fig. 5 Schematic View of the Arrangement of Specimens in the Landfill

Analyses and results

After 4 months of burial, a group of specimens was excavated. The site excavated for colleciton of test specimens after 4 months, of burial is shown in Fig. 6 and the specimens excavated at this time are shown in Fig. 7.

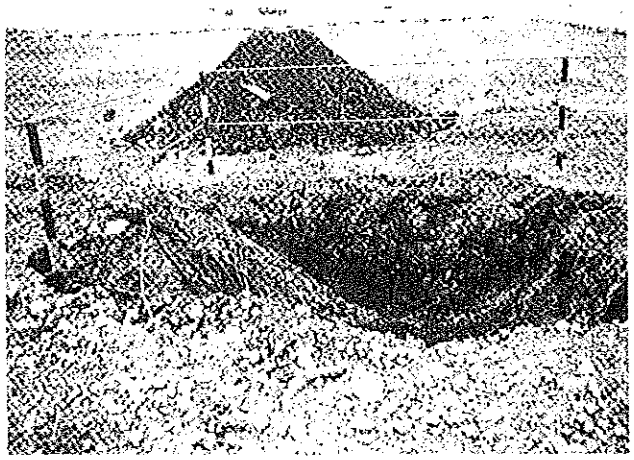


Fig. 6 The Site Excavated for Collection of Specimens

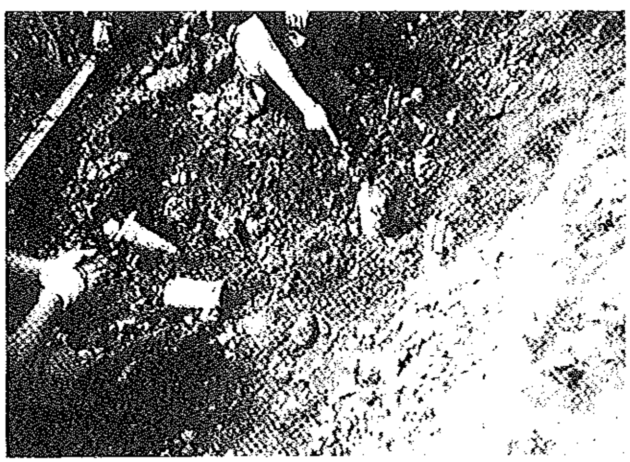


Fig. 7 The Specimens Collected after 4 Months of Burial

The specimens were brushed and put into a boiled solution of 10% NaOH for 5 minutes. After the samples were cleaned and dried out by acetone, the weight loss was measured. The degree of corrosion of the specimens was determined from the following formula suggested by Sohn (1980).

$$\text{mm/year} = 87.6 \frac{W}{D.A.T.}$$

Where W is the weight loss (mg)
D is the density of the specimen (g/cm^3)
A is the exposed area of the specimen (cm^2)
T is time (hr)

The standards of NACE (National Association of Corrosion Engineers) in Table 9 are used as a basis for determining the degree of corrosion and the results are shown in Table 10.

Table 9 NACE Standards (1976).

Thickness loss	Degree of corrosion
< 0.03 mm/year	Low
0.03 ~ 0.13 mm/year	Moderate
0.13 ~ 0.25 mm/year	Severe
> 0.25 mm/year	Very severe

Table 10 The Results of the Corrosion Test for Metal Specimens.

Type	Initial weights (g)	Weights after 4 month (g)	Weight loss (g)	Corrosivity (mm/year)
aluminum	48.27	48.27	0.00	0.00000
plate	48.46	48.45	0.01	0.00126
copper bar	38.15	38.10	0.05	0.00529
	38.55	38.54	0.01	0.00105
carbon steel	155.20	154.89	0.31	0.01276
plate	153.52	153.38	0.14	0.00576
stainless	33.64	33.64	0.00	0.00000
steel bar	33.78	33.77	0.01	0.00120
galvanized	177.47	177.17	0.30	0.01111
zinc plate	174.36	174.10	0.26	0.00980

The weight loss of the carbonated steel plate and the gavanized zinc plate is significant. It can be recognized that the resistance of carbon steel and zinc to corrosion seems relatively lower than that of the other materials. Comparision of the corrosion characteristics of the metal specimens with NACE standards shows that the degree of corrosion of all the metal specimens used in this experiment is still classified as low.

The uniaxial strength test for concrete specimens was also performed for two conditions (i.e. pre-buried and post-buried). The results of the strength tests given in Table 11 show that the average loss of strength during 4 months burial is 22% for reinforced specimens, and 26% for unreinforced specimens. Although it is difficult to figure out the causes of significant strength loss, it appears that the different type of device used for strength testing at pre-and post-burial and inadequate care in the handling of specimens may have influenced the measured strength of the specimens.

Table 11 Uni-axial Strength of Concrete Specimens for Pre-and Post-burial.

	Specimens	
	pre-burial	post-burial
reinforced	225.0	176.1
unreinforced	213.3	158.0

Discussion on the results of laboratory and in-situ corrosivity test

According to the electric resistivity data, the corrosivity of wastes produced from the steelmaking process is high. However, the results of in-situ testing show that the degree of corrosion of the specimens in the landfill is low. This apparent anomaly may result for the following reasons.

- o The landfill site contains large amounts of sand and weathered granitic soils which are not highly corrosive.
- o The groundwater level in this landfill is located between 6 and 7 m below from the surface and the in-situ water contents of the soil samples were in the range of 3 to 7%. The specimens were located 1.5 m from the surface and in-situ water content was significantly lower than the one that would cause significant corrosion of the specimens.
- o Although electric resistivity is a major factor that influences the degree of corrosion, other factors (e.g. pH, void ratio, biological activity, rainfall, temperature, etc.) are not favorable for the specimens to corrode.

More tests on the remaining specimens and complementary tests on the influence of other factors are needed to confirm the results of these experiments.

THE CHEMICAL ANALYSIS OF WATER SAMPLE FOR THE SITE

The quality of groundwater was analyzed by sampling water from the boreholes. Table 12 shows the depth of the boreholes where the samples were taken.

Table 12 The Depth of the Boreholes in the Landfill.

Borehole No.	depth (m)
BH-2 and 7	18.5
BH-5	22.5
BH-8	27.5
BH-9	32

Each borehole is sealed by P.V.C. pipes of the radius 1.5 inch and the upper part of the pipes are capped in order to prevent the infiltration of rainwater. Five litres of water samples were collected twice and the amounts of chemicals in each borehole were measured. Table 13 shows the results of the chemical tests and the table 14 shows the standards of heavy metal contents allowed for the discharge water established by the environmental preservation act of Korea.

Table 13 The Results of Chemical Tests for the Water Samples Collected.

(Unit : mg/litres)

month	boreholes	Cd	Cr^{6+}	Cu	Fe	Mg	Mn
'91 May	sea water	0.0233	0.1814	0.0430	ND*	8.1676	0.0826
	BH2	0.0233	0.3626	0.0428	ND	8.1593	ND
	BH5	0.0259	0.1845	0.0440	ND	8.1277	0.2299
	BH7	0.0315	ND	0.0397	ND	8.1027	ND
	BH8	0.0233	0.1319	0.0357	ND	8.1311	0.3988
	BH9	ND	ND	0.0022	ND	7.0721	0.2554
'91 June	sea water	0.0170	0.1206	0.0370	0.0595	4.4353	0.0300
	BH2	0.0171	0.1434	0.0610	0.0869	4.3975	0.0500
	BH5	0.0181	0.1614	0.560	0.3667	4.3708	0.8739
	BH7	0.0168	0.1458	0.0580	0.0102	4.3298	0.0563
	BH8	0.0185	0.1149	0.0720	1.6213	4.3664	1.4276
	BH9	0.0072	0.310	0.0440	2.5153	4.0426	0.7951

* Not detected

Table 13 (con.)

month	boreholes	Pb	Zn	CN	pH	Cl^-	SO_4^{-2}
'91 May	sea water	0.1574	ND	0.0502	8.0000	20,968.5	2,126.96
	BH2	0.3314	ND	ND	9.3000	20.368	2,368.5
	BH5	0.2222	ND	ND	8.1000	21.967.5	2,315.6
	BH7	0.1714	ND	ND	9.7000	19,693	1,741.5
	BH8	0.1587	ND	ND	8.2000	13,258	1,507.5
	BH9	0.0174	ND	ND	8.6000	524.9	95.8
'91 June	sea water	0.1644	0.0116	ND	8.4000	18,719.2	2,216.96
	BH2	0.2064	ND	ND	8.9000	19,469	2,360.5
	BH5	0.2010	ND	0.0106	7.2000	20,469	2,430.2
	BH7	0.1813	ND	0.0526	10.1000	19,119	2,007.9
	BH8	0.2170	0.1854	0.0165	7.7000	17,069	2,036.6
	BH9	0.0495	0.2712	ND	7.8000	449.9	101.98

Table 14 Standards of Heavy Metal Contents for the Discharge Water.

(Unit : mg/liter)

Items	CN	Cr	Fe	Zn	Cu	Cd	Pb	Cr^{+6}
standard	1	2	10	5	3	0.1	1	0.5

The results of chemical analyses of water samples show similar trends with those of the seawater. pH ranges for the samples collected at different periods are similar to those of seawater (pH 8.3 ~ 8.6) except at BH 2 and 7. This means that the water in the landfill is exposed to seawater quite a long time and mixed well with sea water. The amounts of heavy metals in the water samples are lower than the standards of the discharge water quality in Table 14.

CONSIDERATIONS IN PLANNING CONSTRUCTIONS ON THE LANDFILL

The following problems are recognized from the tests in planning constructions on this landfill. The waste filled in this site has large size fractions of scrap iron and concrete debris and it is difficult to install pile foundations by driving. Water samples taken from the boreholes are contaminated and the crew performing this investigation has experienced skin allergies after contacting the water samples, although the quality of water sample appears to satisfy the discharge water quality standards. Concerns arising are how to treat the excavated material and seepage

water produced during the construction, and how to maintain a safe environment for construction workers.

Soil-Cement Injected piling (S.I.P.), which is a preboring method, was considered initially for the installation of pile foundations in this landfill. This method is relatively inexpensive and efficient compared with other preboring method and the area adjacent to the pile itself has significant bearing capacity after installation due to the smearing of soil cement. However, S.I.P. is weak to lateral stresses, because soil-cement is not strong in tension. This was thought to be a significant defect for the foundation of structures which need provision for vibration and seismicity. Hence, prebored steel piling was selected instead of S.I.P. Prebored steel piles can support both compressive and tensile stresses and can also encourage the consumption of iron in the steelmaking factory.

The analyses of chemical substances in the iron wastes showed that the substances were diluted to a certain extent due to the contact of waste with seawater for a long period of time. However, a slurry wall type construction was recommended for excavations, because it can cut off water during excavation and is efficient for construction in soils containing rubble.

It is expected that, when the construction begins, dust and sludge above the water table would flow down to the groundwater and the colloidal substances formed by the contact of waste with the wate would increase. Therefore, the installation of a chemical treatment facility was recommended. Waste materials produced from the construction process are to be placed in the containment where the geomembrane is installed.

CONCLUSIONS

The geotechnical properties of a landfill containing iron wastes were investigated to determine the suitability of the site for foundations of structures. The following conclusions can be made from the investigations.

1. The landfill site at Pohang, was highly heterogeneous. Construction rubble and scrap iron buried indiscriminately in the past necessitate the use of high cost foundation, such as pre-bored steel piles. Also, the construction of slurry walls are required for excavations.

2. Special treatment of groundwater and the excavated material may be needed during the construction stage, because the chemical substances contained in the excavated soils and groundwater may have an adverse effect on the construction workers and the peripheral environment.

3. Corrosion of construction materials in the landfill appeared not to be significant, although the qualitative assessment of corrosivity of iron waste from the laboratory electrical resistivity test showed a high level of corrosivity. More tests are necessary for the remaining specimens. In addition, the investigation of other

factors that may have an influence on the corrosivity of the soils would be useful to confirm the results of these analyses.

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