A Report on the Performance of Stainless Steel Pipe for Water Supply in Underground Soil Environments

VOLUME ONE

Extensive data on
nickel-containing stainless steel,
carbon steel, copper and lead pipes tested
in 25 widely-separated geographic locations

JAPAN STAINLESS STEEL ASSOCIATION

and

NiDI

NICKEL DEVELOPMENT INSTITUTE

REPORT ON PERFORMANCE OF STAINLESS STEEL PIPE FOR WATER SUPPLY IN UNDERGROUND SOIL ENVIRONMENTS
VOLUME ONE

1988

Executive Summary

1. The corrosion behavior of metal in a soil environment differs considerably from the corrosion reaction that occurs in a homogeneous environment such as a solution.

   Statistical data obtained on the environment and the material, therefore, are important means in a practical evaluation of the corrosion resistance of stainless steel pipe in various soil conditions.

   With the co-operation of all the parties concerned with this subject, the Japan Stainless Steel Association set up a Committee on Soil Corrosion Test of Stainless Steel Pipe for Water Supply.

   In 1979 corrosion tests were begun on various types of stainless steel pipes, with and without fittings.

   Evaluation of the state of corrosion of the stainless steel, carbon steel, lead, and copper pipes used for testing is conducted every first, fifth and tenth year.

   This report contains a consolidation of the survey results obtained to that point, the fifth year since commencement of the test.

2. Principal method of evaluating the practical corrosion resistance of materials is to measure the loss of weight and thickness that have been caused by corrosion. That method is not suitable for evaluating the practical corrosion behavior of metal like stainless steels which develop corrosion resistance characteristics through the formation of a passive surface film.

   For stainless steel pipes it is necessary to inspect the surface for local corrosion–such as pitting, intergranular corrosion, crevice corrosion, and stress corrosion cracking.

   The results reported are intended to meet practical needs in other countries besides Japan, having similar soil conditions and constituents and where advantage may be taken of the corrosion resistance properties of stainless steel pipes.

3. Stainless steel and other pipes used for city water supply were subjected to the five-year underground installation test at 25 sites throughout the country. The results obtained are summarized.

Summary of Results

1) The SUS304 stainless steel pipes which were horizontally installed did not develop pitting corrosion or any other degradation at many test sites. Generally speaking, they exhibited excellent corrosion resistance although their surfaces were slightly discolored. Crevice corrosion was noted, however, underneath the vinyl tape wrapper at the test sites in an oceanic climate.
2) Horizontally installed SUS316 stainless steel pipes were almost free of discoloration or corrosion in all sites, except one in Okinawa, showing its superiority to the SUS304 pipes.
3) The potential of the above stainless steel pipes ranged from + 0.50 to -0.45 V (SCE) depending on soil conditions and other environmental factors.
4) Pitting corrosion was noted on the lower part of the vertically installed SUS304 stainless steel pipe at several test sites. The incidence of corrosion is higher for the pipes installed in undisturbed soil than for those in disturbed soil.
5) Cast copper alloy fittings or solder type fittings frequently corrode. In contrast, stainless steel press type fittings have excellent corrosion resistance.
6) Average corrosion rates of carbon steel and lead are 0.019 and 0.002 mm/y, respectively. Their maximum corrosion rates are five to six times as high as their average rates. On the other hand, the corrosion rate is nil for SUS304 and SUS316 stainless steels.
7) Modified SUS430 ferritic stainless steel has corrosion resistance comparable with that of the SUS304 and SUS316 stainless steels.

Contents

Preface

There are abundant data on the corrosion resistance of carbon steel pipe and cast iron pipe, buried underground and used for water supply.

The same can be said for the performance of various anticorrosive coating materials applied to them.

But data on the corrosion behavior and corrosion resistance of stainless steel pipe in a soil environment are scarce, except for United States National Bureau of Standards[1] data.

NBS data, however, are based on the special nature of soil in the United States and, therefore, are not entirely helpful when burying pipes in the soils of Japan.

The Corrosion behavior of metal in a soil environment differs considerably from the corrosion reaction that occurs in a homogeneous environment such as a solution. Statistical data obtained on the environment and the material, therefore, are important means in a practical evaluation of the corrosion resistance of stainless steel pipe in various soil conditions.

With the co-operation of all the parties concerned with this subject, the Japan Stainless Steel Association set up a Committee on Soil Corrosion Test of Stainless Steel Pipe for Water Supply.

In 1979 corrosion tests were begun on various types of stainless steel pipes, with and without fittings.

To collect data from as wide a geographical area as possible during the 10-year test project, 25 locations were selected throughout the country–from Hokkaido in the north down to Okinawa (please see Figure 1 and Table 1.)

Evaluation of the state of corrosion of the stainless steel, carbon steel, lead, and copper pipes used for testing is conducted every first, fifth and tenth year.

Volume One contains a consolidation of the survey results obtained to that point, the fifth year since commencement of the test.

Principal method of evaluating the practical corrosion resistance of materials is to measure the loss of weight and thickness that have been caused by corrosion. That method is not suitable for evaluating the practical corrosion behavior of metal like

stainless steels which develop corrosion resistance characteristics through the formation of a passive surface film.

For stainless steel pipes it is necessary to inspect the surface for local corrosion–such as pitting, intergranular corrosion, crevice corrosion, and stress corrosion cracking.

Photographs(volume two)show the surface conditions of stainless steel pipes, that were buried in 25 different selected sites in Japan, after a period of five years.

The results reported are intended to meet practical needs in other countries besides Japan–having similar soil conditions and constituents–and where advantage may be taken of the corrosion resistance properties of stainless steel pipes.

The tests were carried out by JSSA, and the English report was prepared with financial aid of Nickel Development Institute, to meet the above mentioned needs.

1) W.F. Gerhold, E. Escalante and B.T. Sanderson: The corrosion behavior of selected stainless steels in soil environments, NBSIR 81-2228(NBS) (1981).

1. Installation Sites and Periods

The specimen installation sites, their markings, test periods, and dates on which specimens were recovered, are set forth in Table 1.

Figure 1 shows the locations where specimens were installed.

Table 1 Installation Sites, Periods, and Recovery Dates

Marking	Installation site	Address	Installation	Recovery at 1 year	Recovery at 3 years	Recovery at 5 years
A*	Harumi Pumping Station of Tokyo Metropolitan Waterworks Bureau	1-12-20, Harumi, Chuo-ku, Tokyo	Nov. 20, '79	Dec. 17, '80	Nov. 18, '82	Dec. 21, '84
B	Toyozumi Pumping Station of Tokyo Metropolitan Waterworks Bureau	6-1-8, Toyo, Koto-ku, Tokyo	Dec. 10, '79	Dec. 9, '80	Nov. 24, '82	Dec. 4, '84
C	Kanamachi Purification Plant of Tokyo Metropolitan Waterworks Bureau	1-1, Kanamachi Jyosuijyo, Katsuhika-ku, Tokyo	Dec. 6, '79	Dec. 4, '80	Nov. 29, '82	Dec. 6, '84
Ⓓ	Misono Purification Plant of Tokyo Metropolitan Waterworks Bureau	2-10-1, Misono, Itabashi-ku, Tokyo	Dec. 13, '79	Dec. 11, '80	Dec. 9, '82	Dec. 10, '84
E	Suginami Purification Plant of Tokyo Metropolitan Waterworks Bureau	3-28-5, Zenpukuji, Suginami-ku, Tokyo	Dec. 3, '79	Dec. 2, '80	Dec. 13, '82	Dec. 13, '84
F	Wadabori Pumping Station of Tokyo Metropolitan Waterworks Bureau	2-30-43, Ohara, Setagaya-ku, Tokyo	Dec. 14, '79	Nov. 26, '80	Feb. 18, '83	Dec. 17, '84
G	Kinutashimo Purification Plant of Tokyo Metropolitan Waterworks Bureau	2-4-1, Kamata, Setagaya-ku, Tokyo	Dec. 17, '79	Nov. 28, '80	Dec. 20, '82	Dec. 19, '84
Ⓗ	Kushiro City Waterworks Bureau	67, Aza Toridori, Kushiro- mura, Kushiro-gun, Hokkaido	Oct. 31, '79	Sep. 26, '80	Oct. 1, '82	Sep. 26, '84
Ⓘ	Aomori City Waterworks Dept.	Harabetsu Haisuijyo, 14, Aza Honizumi, Ohaza Yadamae, Aomori City, Aomori Prefecture	Oct. 30, '79	Sep. 24, '80	Sep. 24, '82	Oct. 4, '84
Ⓙ	Nippon Stainless Steel Co., Ltd.	10-29, Kawara-cho, Jyoetsu City, Niigata Prefecture	Dec. 1, '79	Dec. 11, '80	Nov. 4, '82	Nov. 16, '84
Ⓚ	Nippon Benkan Kogyo Co., Molco Division, Yabuzuka Works	5, Higashiura, Ohaza Rokusengoku, Yabuzuka-honmachi, Nitta-gun, Gunma Prefecture	Dec. 22, '79	Dec. 13, '80	Dec. 22, '82	Dec. 12, '84

The 10-year test is under way at the installation sites whose markings are encircled. Specimens were tested for five years at other sites.
Standard and special specimens were embedded at the site marked with an asterisk.

Continued

Marking	Installation site	Address	Installation	Recovery at 1 year	Recovery at 3 years	Recovery at 5 years
L	Riken Corp., Kumagaya Works	810, Kumagaya, Kumagaya City, Saitama Prefecture	Dec. 27, '79	Dec. 27, '80	Dec. 3, '82	Dec. 7, '84
M	Nippon Metal Industry Co., Sagamihara Works	1-30, Ohyama-cho, Sagamihara City, Kanagawa Prefecture	Nov. 27, '79	Jan. 10, '81	Dec. 17, '82	Dec. 20, '84
N	Nippon Yakin Kogyo, Kawasaki Works	4-2, Kojima-cho, Kawasaki-ku, Kawasaki City, Kanagawa Prefecture	Nov. 30, '79	Dec. 19, '81	Nov. 29, '82	Dec. 7, '84
O	Nippon Bulge Industries, Ltd., Ashikaga Works	306, Mamashita, Minami-Ashigara City, Kanagawa Prefecture	Dec. 20, '79	Dec. 16, '81	Dec. 7, '82	Dec. 13, '84
Ⓟ	Hitachi Metals Ltd., Kuwana Works	200, Kohinata, Asahi-cho, Mie-gun, Mie Prefecture	Dec. 20, '79	Dec. 20, '80	Dec. 23, '82	Jan. 17, '85
Q	Kawasaki Steel Corp., Nishinomiya Works	1-50, Asanagi-cho, Nishinomiya City, Hyogo Prefecture	Dec. 27, '79	Dec. 19, '81	Feb. 4, '83	Mar. 5, '84
Ⓡ	Sumitomo Metal Industries, Ltd., Wakayama Works	1850, Minato, Wakayama City, Wakayama Prefecture	Dec. 28, '79	Jan. 8, '81	Dec. 10, '82	Jan. 24, '85
S	Nippon Kokan K.K., Fukuyama Works	1, Kokan-cho, Fukuyama City, Hiroshima Prefecture	Jan. 23, '80	Dec. 3, '80	Dec. 17, '82	Nov. 30, '84
T	Nippon Steel Corp., Hikari Works	3434 Shimada, Hikari City, Yamaguchi Prefecture	Dec. 20, '79	Dec. 23, '80	Oct. 18, '82	Nov. 29, '84
Ⓤ	Nisshin Steel Co., Shunan Works	4976, Ohaza Tomita, Nanyo City, Yamaguchi Prefecture	Dec. 26, '79	Dec. 23, '80	Dec. 2, '82	Dec. 10, '84
Ⓥ	Nippon Steel Corp., Yahata Works, Nakatsu Factory	332, Higashihama, Nakatsu City, Ohita Prefecture	Dec. 21, '79	Dec. 18, '80	Oct. 19, '82	Feb. 6, '85
W	Okinawa Prefectural Misato Technical High School	1629, Aza Awase, Okninawa City, Okinawa Prefecture	Oct. 6, '80	Oct. 8, '81	Oct. 5, '83	Sep. 9, '85
Ⓧ	Okinawa Prefectural Nanbu Technical High School	1240, Aza Tomimori, Kochihira-machi, Okinawa Prefecture	Oct. 7, '80	Oct. 7, '81	Oct. 6, '83	Sep. 10, '85
Ⓨ	Matsuyama City Public Enterprise Bureau	4-7-2, Niban-cho, Matsuyama City, Ehime Prefecture	Oct. 2, '80	Oct. 1, '81	Oct. 13, '83	Nov. 14, '85
Z	Reference materials held by Japan Stainless Steel Association	Tekko Kaikan, 3-2-10, Nihonbashi Kayaba-cho, Chuo-ku, Tokyo				

The 10-year test is under way at the installation sites whose markings are encircled. Specimens were tested for five years at other sites.
Standard and special specimens were embedded at the site marked with an asterisk.

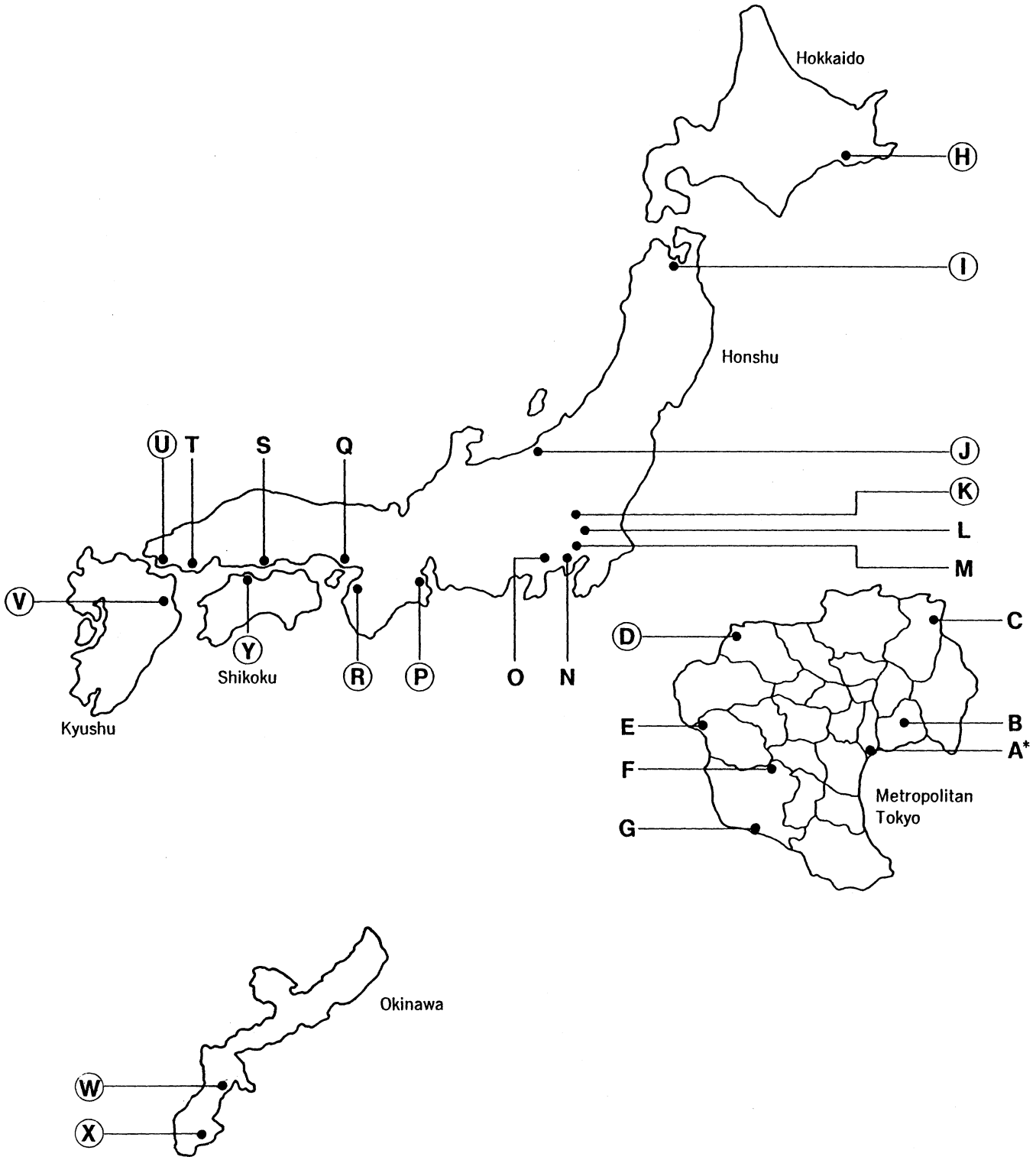


Figure 1 Specimen Installation Sites and Test Periods
Encircled markings indicate the sites where the 10-year test is under way.
The five-year test was made at other sites.

2. Test Methods

Test methods are classified as the Standard Test–in which water supply stainless steel pipe specimens, with and without four different kinds of fittings, are installed–and the Special Test–in which water supply stainless steel pipe specimens, connected to piping of differing metal materials– are mainly used.

2.1 Standard Test

2.1.1 Specimen Materials and Sizes

Table 2 Standard Specimen Materials and Sizes

(i) Stainless Steel Specimens

Material	Standard	Size (mm)
SUS 304 TPD-A	JIS G 3448	25Su (28.58ϕ × 1.0t) × 500ℓ, 1,800ℓ
SUS 304 TPD-E	JIS G 3448	25Su (28.58ϕ × 1.0t) × 500ℓ
SUS 316 TPD-A	JIS G 3448	25Su (28.58ϕ × 1.0t) × 500ℓ, 1,800ℓ

A: automatic arc welded pipe E: electric resistance welded pipe

(ii) Specimens with Fittings

Fitting	Standard	Pipe	
		Material	Size (mm)
Solder type	JWWA G 116	SUS 304 TPD-E	25Su (28.58ϕ × 1.0t) × 250ℓ
Press type	JWWA G 116	SUS 304 TPD-A	25Su (28.58ϕ × 1.0t) × 250ℓ
Compression type	JWWA G 116	SUS 304 TPD-E	25Su (28.58ϕ × 1.0t) × 250ℓ
Expansion and flexible type (A)	JWWA G 116	SUS 304 TPD-E	25Su (28.58ϕ × 1.0t) × 250ℓ
Expansion and flexible type (B)	——	SUS 304 TPD-A	25Su (28.58ϕ × 1.0t) × 250ℓ

(iii) Reference Specimens

Reference specimen	Standard	Size
SGP black (carbon steel pipe for piping)	JIS G 3452	20A (27.2ϕ × 2.8t) × 500ℓ, 1,800ℓ
Pb TW-2 (lead pipe for water supply)	JIS H 4312	28.4ϕ × 4.2t × 500ℓ
C1220T-H(M) (phosphorous deoxided seamless pipe)	JIS H 3300	28.58ϕ × 0.89t × 1,800ℓ

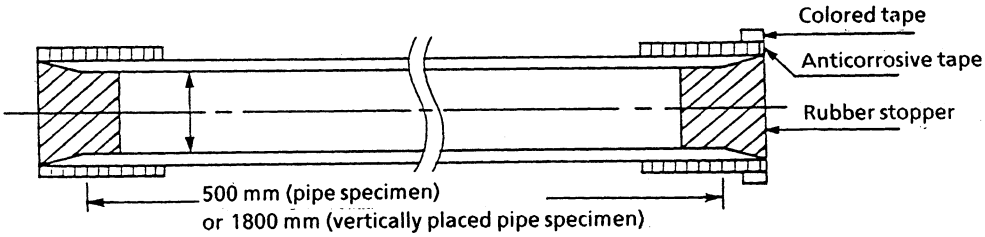
(iv) Specimen for Weight Measurement

Pipe type	Size (mm)
SUS 304 TPD-A	25Su (28.58ϕ × 1.0t) × 130ℓ
SUS 316 TPD-A	25Su (28.58ϕ × 1.0t) × 130ℓ
SGP black	15A (21.7ϕ × 2.8t) × 70ℓ
Pb TW-2	16.2ϕ × 3.1t × 60ℓ

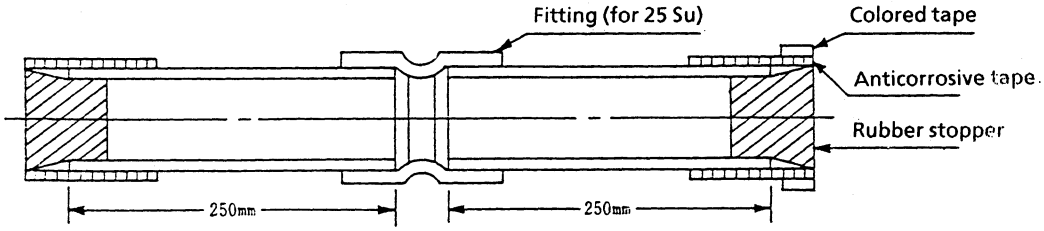
2.1.2 Cross Sections of Specimens

Cross sections of specimens are shown in Figure 2 below.

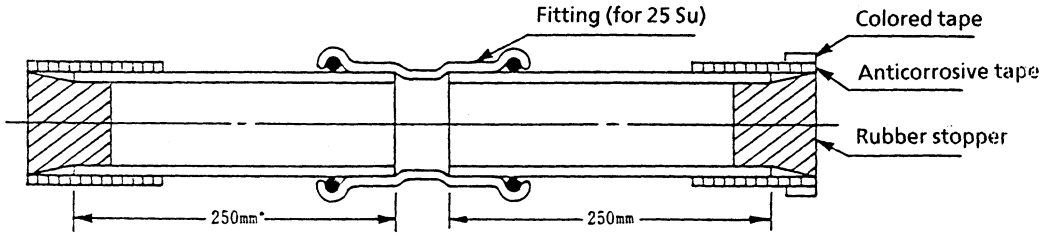
(i) Pipe or Vertically Placed Pipe



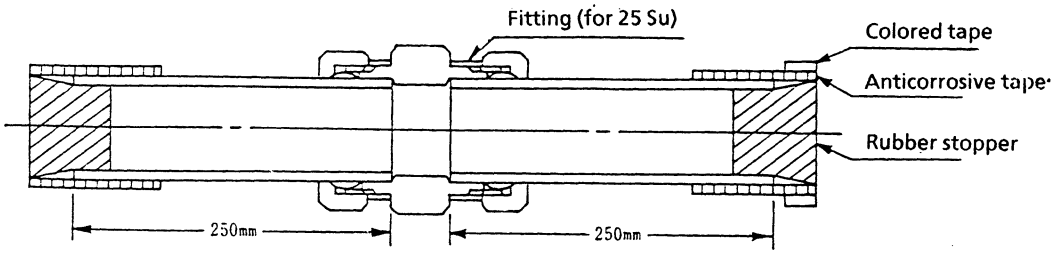
(ii) Pipes with Solder Type Fittings



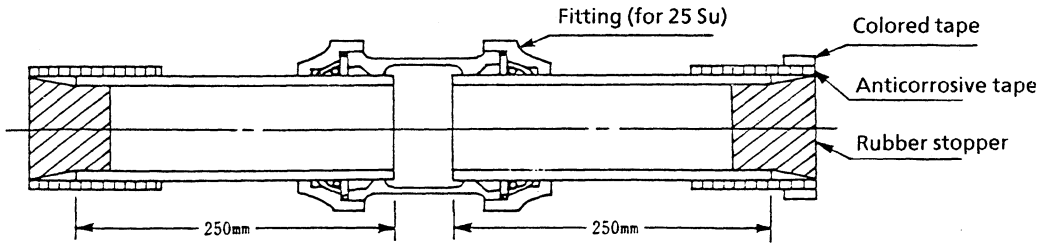
(iii) Pipes with Press Type Fittings



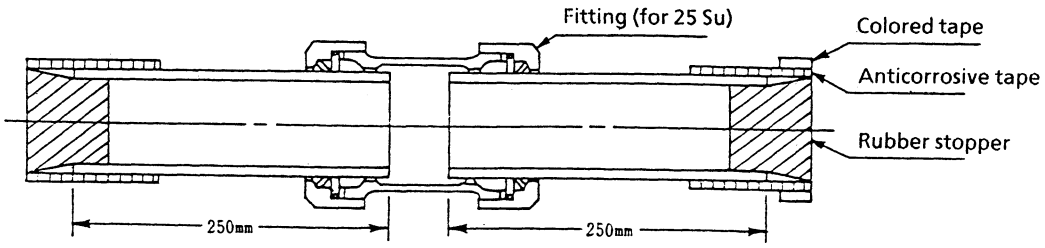
(iv) Pipes with Compression Type Fittings



(v) Pipes with Expansion and Flexible Type Fittings (A)



(vi) Pipes with Expansion and Flexible Type Fittings (B)



(vii)Pipe for Weight Measurement

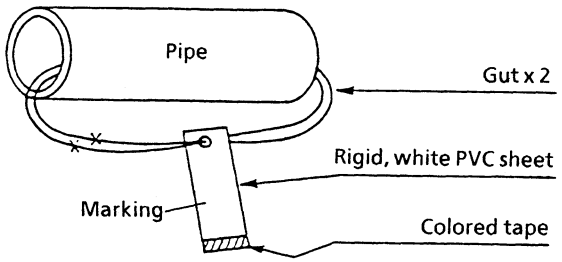
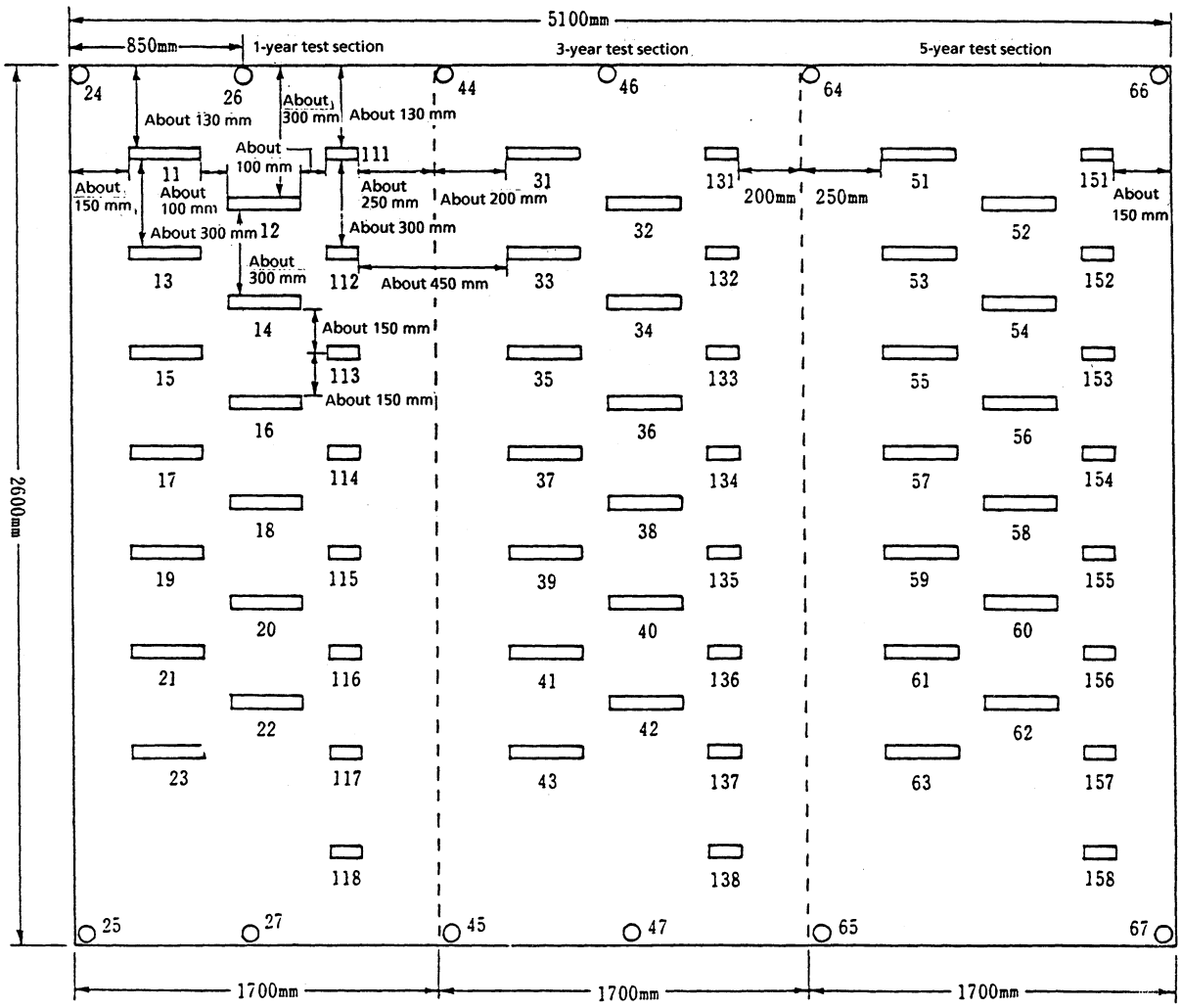


Figure 2 Cross Sections of Specimens

2.1.3 Installation Method

Figure 3 shows the arrangement of specimens in the standard test. A typical pipe installation is shown in Photo 1.



○ Open circles indicate the locations where specimens were vertically placed.

Figure 3 Specimen Arrangement in Standard Test

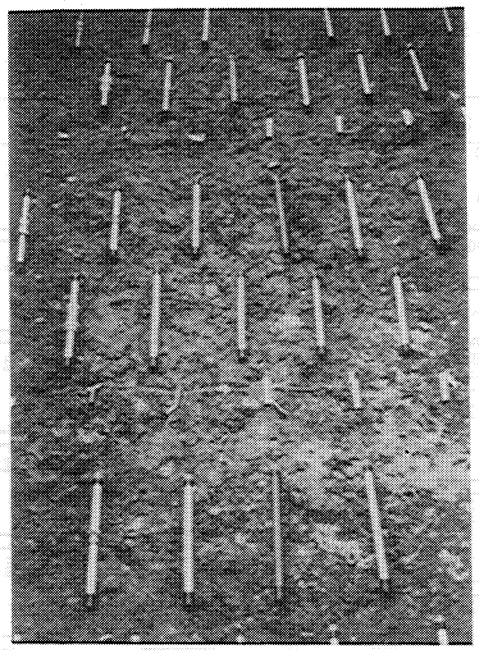
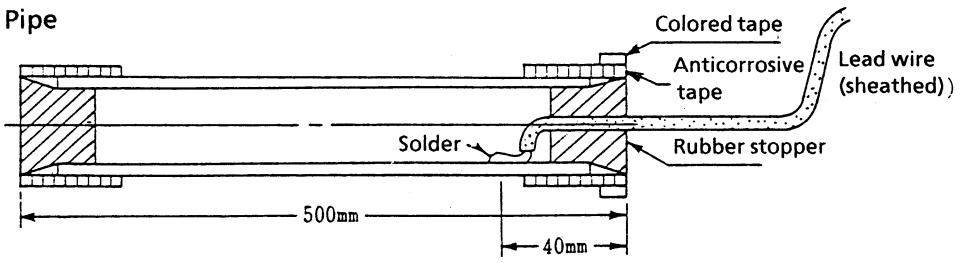


Photo 1 Installation of Standard Specimens
[at Kanamachi Purification Plant of Tokyo Metropolitan Waterworks Bureau (C)]

2.1.4 Specimens for Potential Measurement

To measure changes in natural potential with time, lead wires were attached to the 10-year test specimens excluding those which were vertically installed for weight measurement. Figures 4 and 5 show cross sections of the specimens and lead wire connections, respectively.

(i) Pipe



(ii) Pipes with Fittings (of Solder Type)

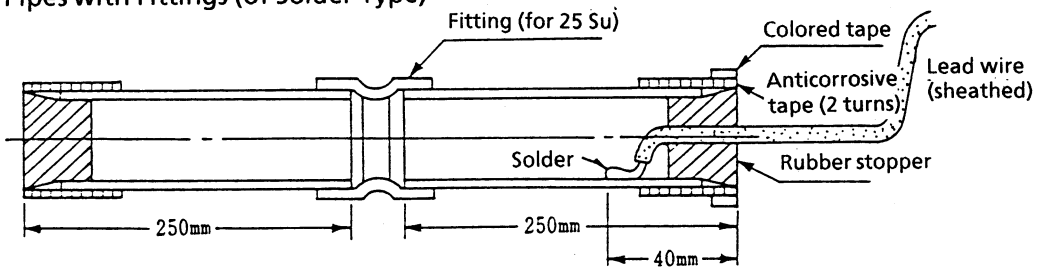


Figure 4 Cross Sections of Specimens for Potential Measurement

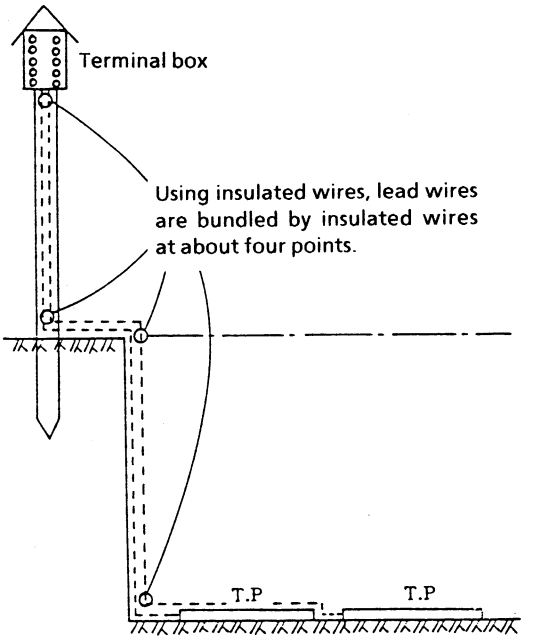


Figure 5 Connections of Lead Wires to Potential Measurement Specimens

2.2 Special Tests

In the special tests, specimens were connected to the pipes of the same or differing material, or tested as concrete macrocell pipes. The 430 modified specimen was used in this test. The test was conducted at only one site, the Harumi Water Supply Station (A) of the Tokyo Metropolitan Waterworks Bureau.

2.2.1 Specimen Types

Types of specimens are shown in Table 3. The number of specimens used was 40 for each test period.

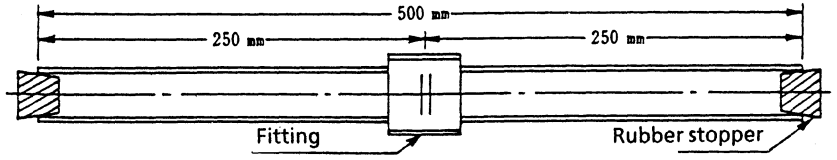
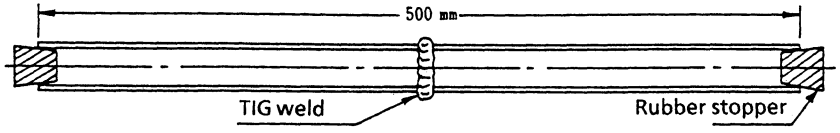
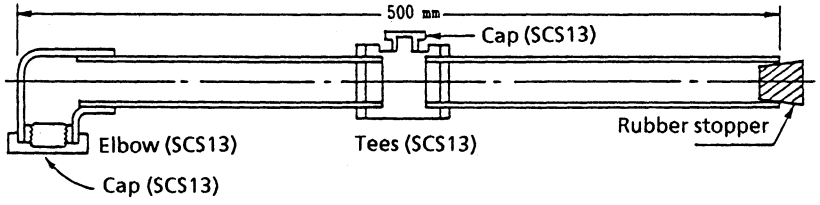
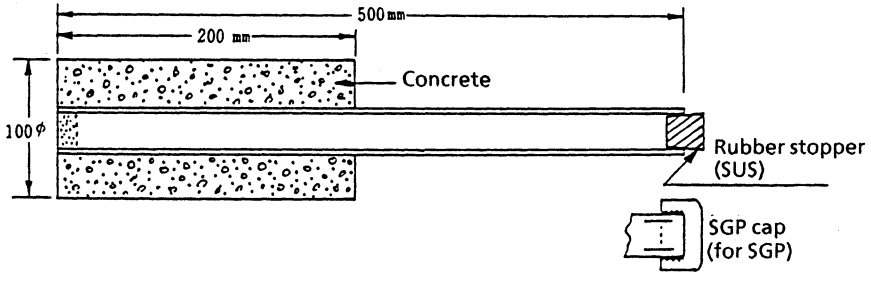
Table 3 Types of Specimens

Type of Specimens				* Shape	Remarks
Pipe coupled with device of same metal	C1220T-H (including fitting)			(1)	Screw type fitting
	SGPW (including fitting)			(1)	
	SUS304 TPD-A			(2)	TIG welded fitting
	SUS316 TPD-A			(2)	
	SCS13 cast steel fitting			(3)	Screw type fitting
Pipe coupled with device of different metal	SUS304TPD-A	Adapter (SUS)	BC quick close stop	(6)	Press type fitting
		Solder	PbTW-2	(7)	Solder type fitting
		Adapter (SUS)	Ductile cast iron	(8)	Press type fitting
		Adapter (SUS)	SGP black	(9)	Press type fitting
Macrocell pipe half-covered with concrete	SUS304 TPD-A			(4)	Concrete covering
	SUS316 TPD-A			(4)	
	SGP black			(4)	
430 Modified specimen (welded plate)	18 Cr – 0.5 Mo			(5)	TIG welding
	18 Cr – 1 Mo			(5)	
	18 Cr – 2 Mo			(5)	
	18 Cr – Ti or Nb			(5)	
	SUS304			(5)	
	SUS316			(5)	

* Parenthesized numbers indicate the specimen numbers in Figure 6.

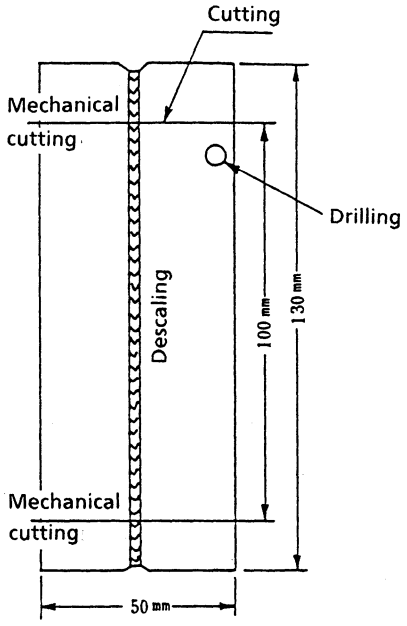
2.2.2 Cross Sections of Specimens and Fittings

Cross sections of specimens and fittings and shown in Figure 6.

Specimen number and material	Specimen cross section, size and connection
(1) C1220T-H(M) and SGPW	
(2) SUS304TPD and SUS316TPD	
(3) SUS304TPD + SCS13	
(4) SUS304TPD and SGP black	

(5)

Size of 430 modified specimen



430 modified specimen

Fig. 6 Cross Sections of Specimens and Fittings used in Special Tests

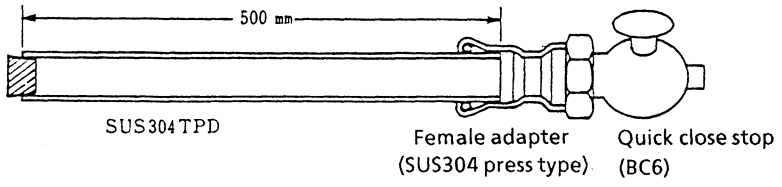
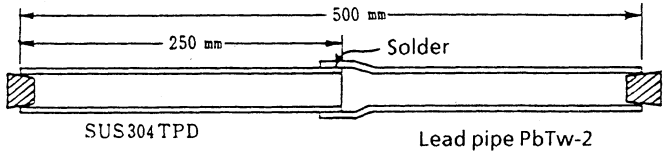
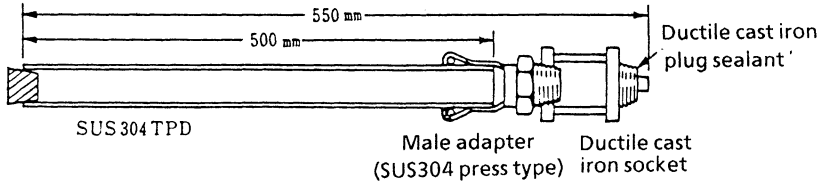
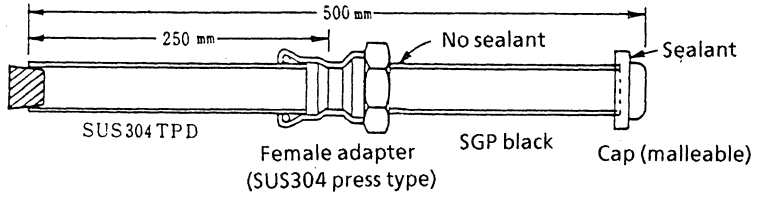
Specimen number and material	Specimen cross section, size and connection	Adapter and Fitting	Pipes and parts of different material
(6) SUS304TPD-A + BC6		SUS female adapter (press type) Size: 25 Su	Quick close stop Size: 25 Su
(7) SUS304TPD-E + lead pipe		Solder type fitting Material: Pb50-Sn50 Flux: for stainless steel	PbTW-2 lead pipe Size: 25 x 260 mm
(8) SUS304TPD-A + ductile cast iron		SUS304 male adapter (press type) Size: 25 Su	(1) Ductile cast iron socket SC Size: 1 (2) Ductile cast iron plug SC Size: 1
(9) SUS304TPD-A + SGP black		SUS304 male adapter (press type) Size: 25 Su	Carbon steel pipe for piping SGP black Size: 1 Malleable cap

Fig. 6 (con't)

3. Survey Method

Specimens and soil collected from the test site shall be tested before installation and after recovery as follows.

3.1 Specimens

3.1.1 Before Installation

- o Appearance
- o Measurement of specimen for weight measurement

  Weight measurement: in increments of 0.1 mg

  Size measurement: at three locations, one each for outer diameter, thickness, and length
- o Photographing appearance (color photos)

3.1.2 After Recovery

- o Visual inspection for appearance

  After washing

  After pickling (required when surface corrosion or corrosion product is found)
- o Observation with a magnifying glass or microscope (for stainless steel only)
- o Inspection of specimen inner surface (only for pipes with fittings)

  Cut the specimen in two, lengthwise. Photograph in color and check them for corrosion.
- o Weigh and calculate corrosion weight loss using the specimen for weight measurement.

  Wash or pickle the specimen. Weigh it and calculate the corrosion weight loss in mdd, a unit of corrosion rate.

3.2 Soil

Details of the soil test and analysis to be recorded before installation and after recovery, the methods of which are described below.

3.2.1 Tests

- o Visual inspection:

  Topography, soil profile, soil conditions, drainage, lime, coke, and other minerals

- o Soil resistivity (Ω-cm):
  By use of a soil probe, four- electrode method, or soil resistance box
- o Oxidation-reduction potential (mV-NHE):
  Convert the potential measured in accordance with the hydrogen electrode standard (by use of a high-sensitivity potentiometer or pH meter).
- o Water content (%):
  Measure the water content in accordance with JIS A1203 (Soil Water Content Test Method).

NOTE: For measurements, sampling method, time, and location, number of samples, and other information, refer to the Procedures for Corrosion Test of Stainless Steel Pipe for Water Supply (published by the Japan Stainless Steel Association).

3.2.2 Analyses

- o pH

  Sample:
  Air-dried (in accordance with JIS A1201, sample preparation for soil viscosity and physical property test)

  Sample weighing:
  Ratio of the sample to distilled water, 1 : 2.5

  Extraction method:
  Supernatant obtained after shaking and stirring (3 to 18 hr)

  Measurement:
  Glass electrode method in accordance with JIS Z8802 (pH measurement)

- o Water-soluble components

  Sample condition:
  Air-dried (sifting through a screen of 2-mm meshes after pulverization)

  Extraction method:
  Mix the air-dried specimen and distilled water at the ratio of 1 : 1 or 1 : 2. Vigorously shake the mixture and use the supernatant obtained through filtration or other method as an extract for analysis.

Analysis items:

Cl^-, SO_4^-, HCO_3^-, NO_3^-, M alkalinity, H_2S, sulfides, Ca_2^+, Mg^{2+}, Na^+, and K^+

Analytical method:

JIS K0101 (Industrial Water Testing Method)

Analysis value:

Ion concentration relative to the air-dried soil is expressed in mg/kg and M alkalinity in epm.

3.3 Natural Potential Measurement

3.3.1 Measurement

Measure the potential between the electrode of the specimen (only the one attached with a lead wire for the 10-year test) and the reference electrode.

Potentiometer:

A high-sensitivity potentiometer having an internal resistance of $10^{12}\Omega$/V

Example:

pH meter (mV measurement) and potentiometer

Reference electrode:

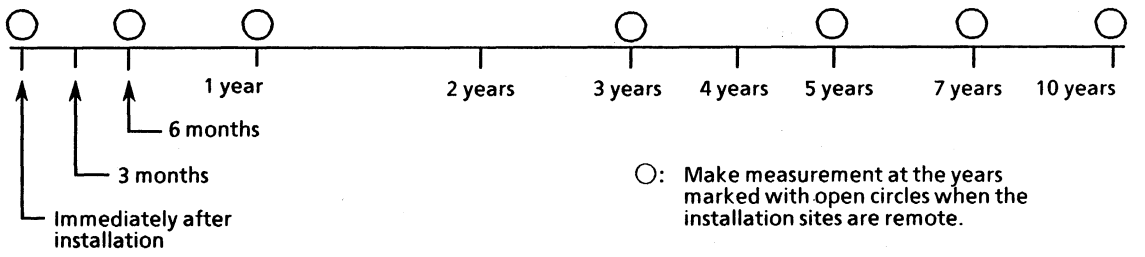
Saturated calomel electrode (with a 3 to 5-m lead wire) desirably accommodated in a plastic casing

3.3.2 Measurement Position

Place a calomel electrode at the center of the 10- year test section since the effect of the distance between the specimen and the electrode is almost negligible. Install the specimen at the position 10 and 15 cm below the ground surface. Pour a small amount of water around the electrode so that the soil is slightly moistened. Allow the electrode to stand for 5 to 10 min. After standing, measure the natural potential E (mV, SCE) of each specimen (at the terminal of the terminal box).

3.3.3 Measurement Periods

Make measurement referring to the schedule below. When the installation sites are in remote areas, such as Kushiro, Aomori, Okinawa and Shikoku, measurements should be made at the years marked with open circles.



3.3.4 Recording

Measure the potential to mV and record the data obtained in the specified form.

4. Test Results

4.1 Soil Survey

Soil samples collected from 25 test sites were examined for type, chemical property, resistivity, oxidation-reduction potential, and other factors–before they were installed underground. Other tests were made one, three, and five years after installation by recovering specimens.

4.1.1. Types of Soil

Figure 7 shows the geologic profiles down to a depth of 1 m from the ground surface at 25 test sites.

There is only one uniform soil layer at the test site in Kanamachi (C), Misono (D), Wadabori (F), Kinutashita, (G), Kushiro (H), Hikari (T), Nakatsu (V) and Okinawa (X).

The ground at other test sites consists of two to three different soil layers. At most test sites in the suburbs, the ground is composed of natural soil, while the greater part of test sites in urban areas and industrial areas are in artificially backfilled or reclaimed ground.

One peculiar example, the test site in Kushiro (H), is in peat marshland where ditch reed grows and water abundantly seeps at the depth at which specimens were installed. The test site in Kawasaki (N) is in a typical reclaimed land which contains wet, slurry mud. Fukuyama (S) test site is in the littoral industrial zone where there is a mixture of soils collected from mountain and sea- bottom, and water seeps at the installation depth. At Okinawa (W) test site, located in land filled with beach sand, the shoreline is 500 m away so that seawater seepage is likely to occur.

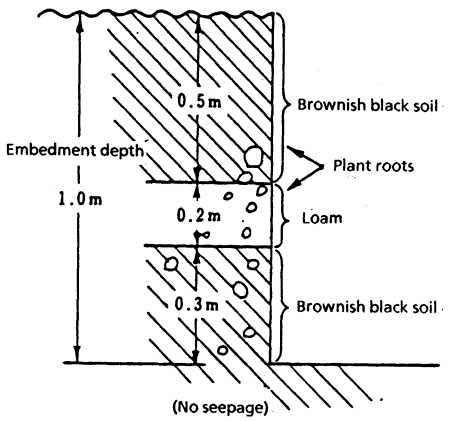
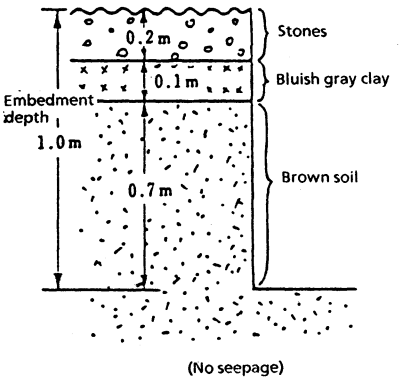
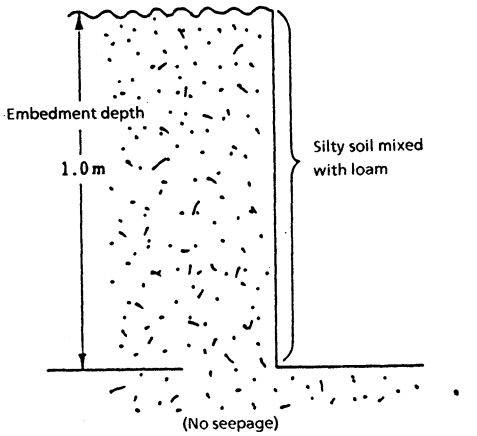
Installation	Soil Profile	Remarks
A. (Harumi, Tokyo)		This reclaimed land contains pebbles, wooden chips, and cobblestones in large amounts.
B. (Toyozumi, Tokyo)		The ground consists of about three soil layers with the surface layer containing stones in large amounts. The intermediate and lower layers are composed of bluish gray clay and wet, brown soil, respectively. This reclaimed land is free of lime, coke, or other minerals. No odor.
C. (Kanamachi, Tokyo)		The site is on the filtration plant premises and about 5 m higher than a nearby road. Earth collected from a mountain in Matsudo City is used as banking. Small plant roots are contained.

Figure 7 Soil Profile

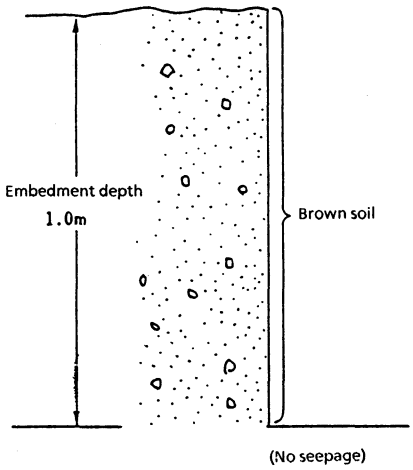
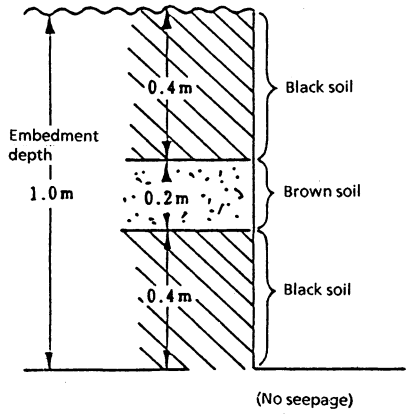
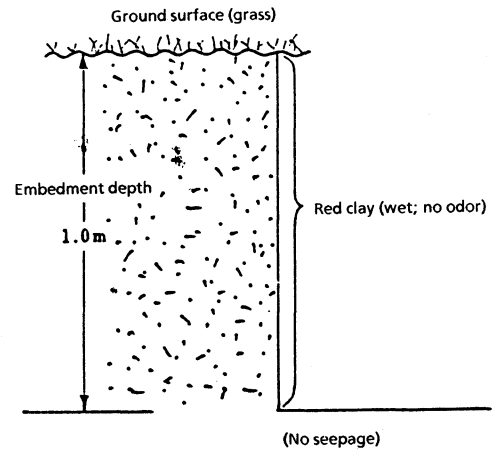
Installation	Soil Profile	Remarks
D. (Misono, Tokyo)		The ground is composed of virtually one soil layer. No seepage.
E. (Suginami, Tokyo)		The ground has three soil layers. The surface layer down to 40 cm from ground surface consists of black soil, the intermediary layer is 10 to 20 cm thick, and the lower layer consists of brown soil mixed with pebbles and uniform black soil, respectively. There is no seepage although the site is near a park pond. No lime, coke, or odor.
F. (Wadabori, Tokyo)		The ground consisting of only red clay is free of stones or gravel. There is no seepage although the site is slightly wet.

Figure 7 Soil Profile (cont'd)

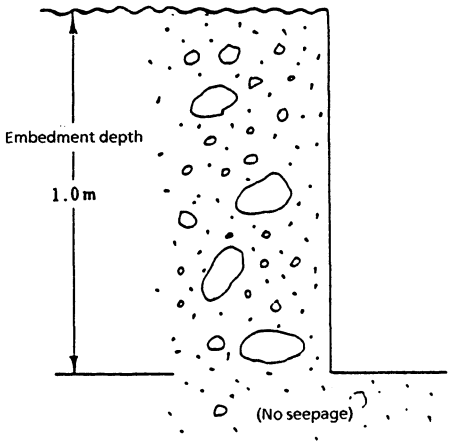
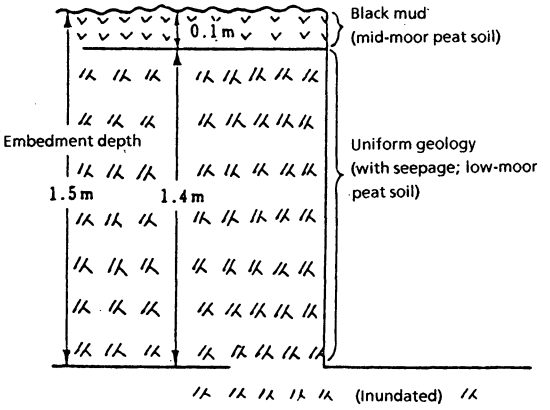
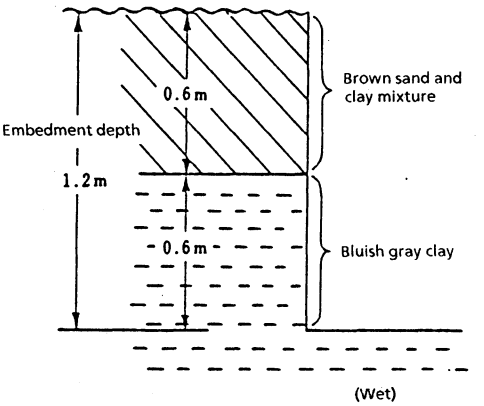
Installation	Soil Profile	Remarks
G. (Kinutashita, Tokyo)		The ground is composed of bed-sand containing much cobblestones.
H. (Kushiro)		The ground consists of peat soil (uniform geology; part of the Kushiro Moor with abundant ditch reed growth). Much seepage. Inundated. There is a smell of hydrogen sulfide.
I. (Aomori)		The ground is composed of two soil layers; a brown sand and clay mixture prevails to a depth of about 60 cm from the ground surface and it is underlain by bluish gray clay. Wet. There is a smell of hydrogen sulfide.

Figure 7 Soil Profile (cont'd)

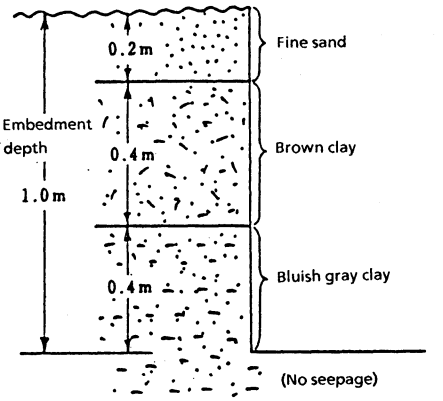
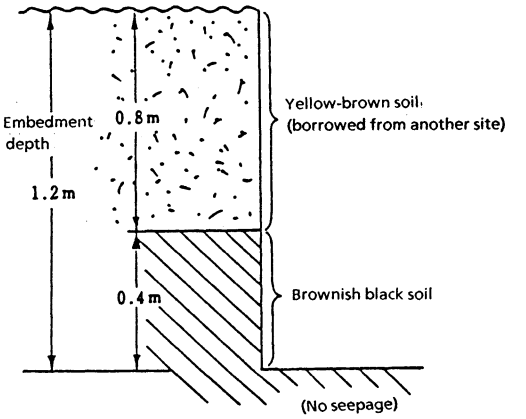
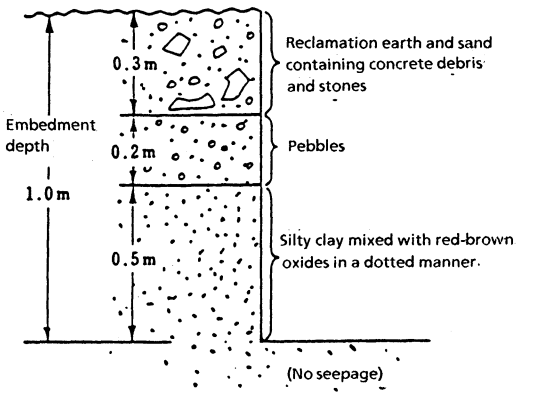
Installation	Soil Profile	Remarks
J. (Naoezu)		The ground consists of three soil layers. No lime, coke, or odor. No seepage.
K. (Yabuzuka, Gunma Prefecture)		Soil, borrowed from another site, is the same as Kanto loam. No seepage.
L. (Kumagaya)		This site is on the factory premises. It does not drain well since it was once in a paddy field.

Figure 7 Soil Profile (cont'd)

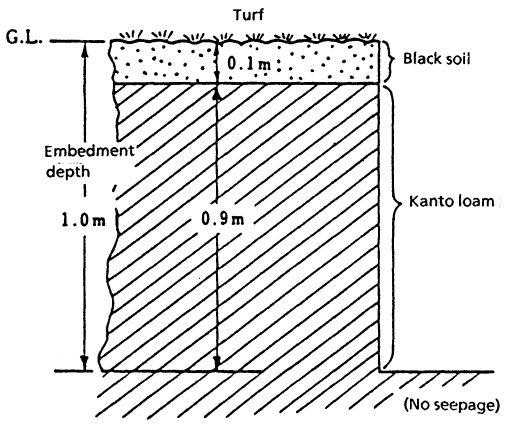
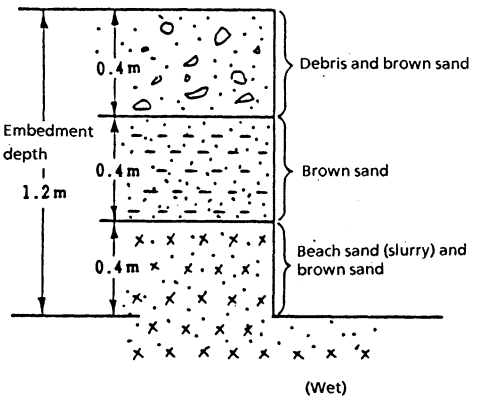
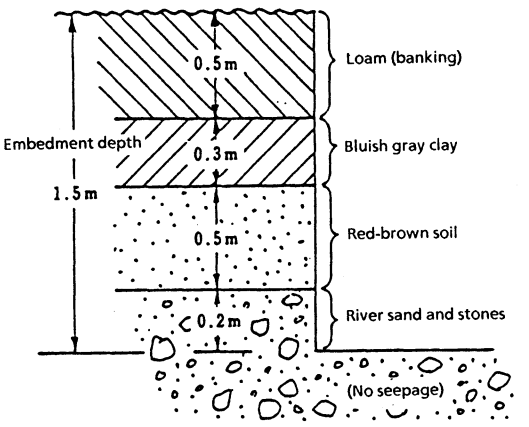
Installation	Soil Profile	Remarks
M. (Sagamihara, Kanagawa Prefecture)		Kanto loam (black soil to a depth of 0.1 m below the ground surface, and underlying Kanto loam 0.9-m thick)
N. (Kawasaki)		The site is located on reclaimed land consisting of sand with the surface layer containing debris, and the lower layer blue slurry sediments. The ground is wet and the slurry soil has a slight odor.
O. (Ashigara, Kanagawa Prefecture)		The ground contains stones in large amounts, allowing good drainage. No seepage. No lime, coke or other minerals. No odor.

Figure 7 Soil Profile (cont'd)

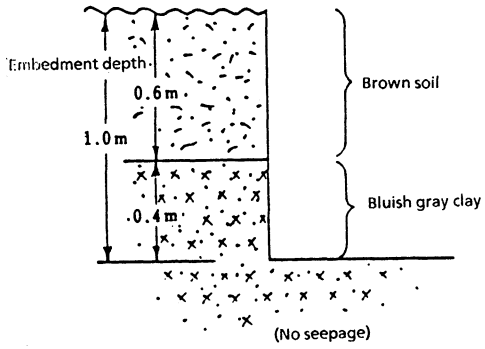
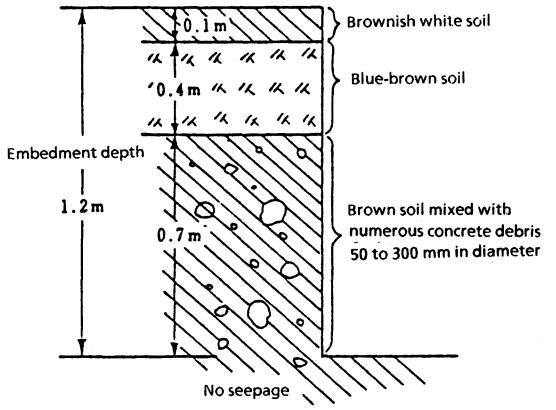
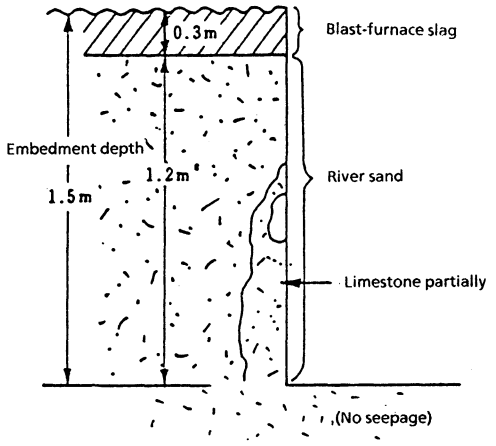
Installation	Soil Profile	Remarks
P. (Kuwana)		Brown soil prevails to a depth of about 0.6 m below the ground surface. It is underlain by wet, bluish gray clay. No lime, coke, or other minerals. No seepage.
Q. (Nishinomiya)		Surface layer: brownish white soil; second layer: blue-brown soil; third layer: brown soil mixed with stones 50 to 300 mm in diameter. No lime, coke, or other minerals. No odor. No seepage.
R. (Wakayama)		Blast-furnace slag prevails to a depth of 10 to 30 cm and is underlain by river sand.

Figure 7 Soil Profile (cont'd)

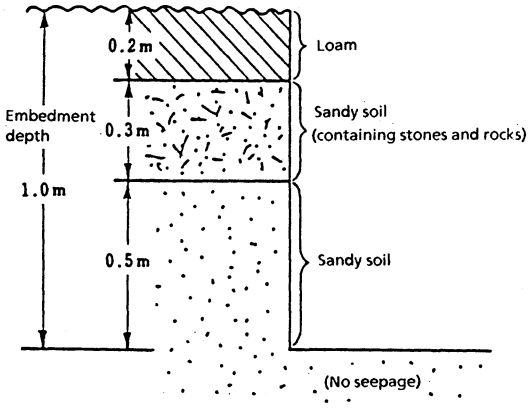
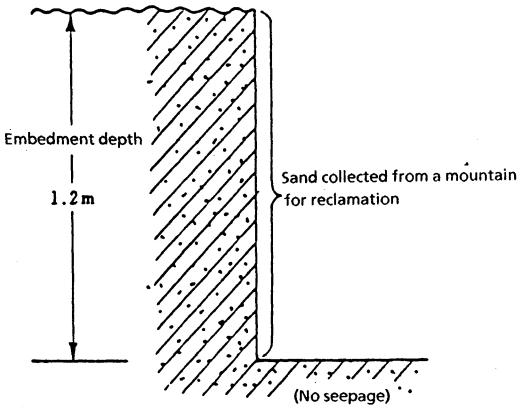
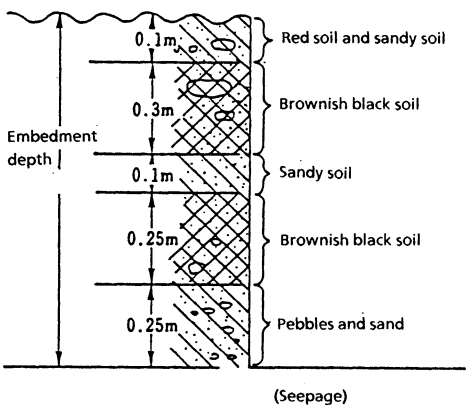
Installation	Soil Profile	Remarks
S. (Fukuyama)		The site was once located near the sea.
T. (Hikari, Yamaguchi Prefecture)		The site is on the reclaimed land consisting of red-brown sandy soil brought from a mountain. It is now part of a green district. No odor.
U. (Shunan, Yamaguchi Prefecture)		The ground consists of layers of brownish black and sandy soils which are underlain by soil containing large amounts of pebbles and sand. There is seepage. The embedment site was changed on January 29, 1982.

Figure 7 Soil Profile (cont'd)

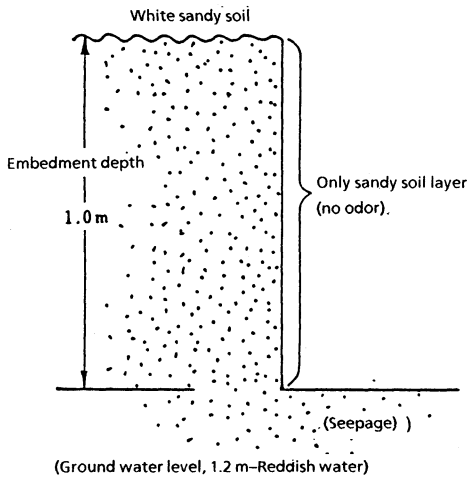
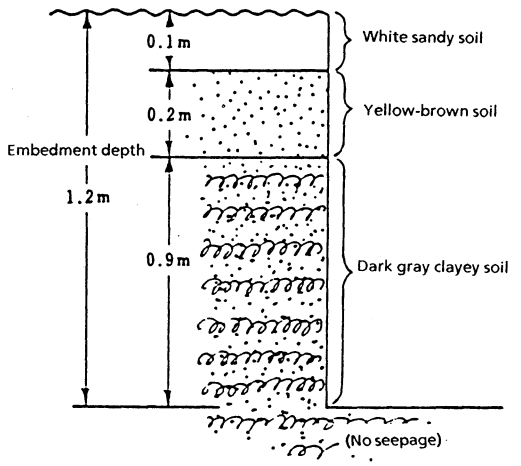
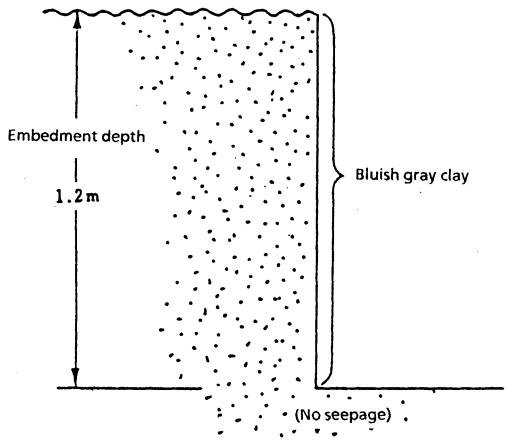
Installation	Soil Profile	Remarks
V. (Natatsu, Ohita Prefecture)		The ground consists of sandy soil layer only. Ground water level is 1.2 m below the ground surface. There is seepdge of reddish water, and there is a layer of dumped carbide, 4 cm thick, in the surface layer above the specimen. No odor.
W. (Misato, Okinawa)		The ground consists of three soil layers. White sandy soil contains remains of coral. Although there is no ground water, seawater level probably reaches the embedded specimen during high tides.
X. (Nanbu, Okinawa)		The ground consists of bluish gray clay only, clay called kuchana in Okinawa.

Fig. 7 Soil Profile (cont'd)

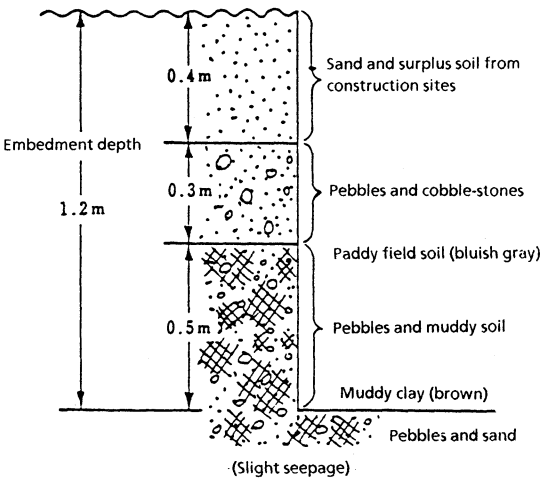
Installation	Soil Profile	Remarks
Y. (Matsuyama)		The ground consists of two to three soil layers. Paddy field soil is found in the intermediate layer.

Figure 7 Soil Profile (cont'd)

4.1.2 Analyses of Soil

Tables 4.1 and 4.2 show the analyses of soil which were obtained before installation and five years after installation. Resistivity and oxidation-reduction potential of soil are shown Table 5.

a) Water Content

The water content slightly changes with time. Of 24 test sites, 21 show a water content of 40% or less. In particular, the water content is no more than 20% at Misono (D), Kinutashita (G), Wakayama (R), Fukuyama (S), Hikari (T), and Nakatsu (V).

On the other hand, the soil has high water content at the Kushiro (H) test site located in marshland. Water content of over 80% is noted at Suginami (E) and Sagamihara (M) situated in the Kanto loam formation.

b) pH

The pH values measured at most test sites range from 6 to 8, indicating the soil is neutral.

At some test sites of sandy soil, the pH is over eight, indicating that the soil is mildly alkaline. On the other hand, the soil at Aomori (I) in the Tohoku region, and at Kushiro (H), has weak acidity, the pH measuring below six.

c) Water-soluble Components

Concentrations of two water-soluble components–Cl^- and SO^{2-}_4–are closely related to corrosion.

Concentrations of these two components are remarkably high at the Okinawa test site (W) which is in an oceanic climate. The concentration of Cl^- is relatively high at Kushiro (H) and that of SO^{2-}_4 is high at Kushiro (H), Kawasaki (N) and southern Okinawa (X). At other test sites, corrosive salt content of soil is low since the Cl^- concentration is lower than 25 mg/kg, or the SO^{2-}_4 concentration is below 100 mg/kg.

d) Resistivity

Resistivity is one of the criteria by which soil corrosiveness is evaluated. Soil, the resistivity of which exceeds 10,000 Ω-cm, is almost free of corrosiveness.

On the other hand, soil with a resistivity of 5,000 Ω-cm or less is considered liable to cause metal corrosion.

Test sites where the resistivity is lower than 5,000 Ω-cm are at Aomori (I), Naoezu (J), Yabuzuka (K), Kumagaya (L), Kawasaki (N), Kuwana (P), Okinawa (W) and southern Okinawa (X). In particular, the soil at the test sites in Okinawa (W) and southern Okinawa (X) is considered corrosive since its resistivity is comparatively low.

Table 4-1 Chemical Analysis of Soil (Before Embedment)

Installation \ Analyses	Water content (%)	pH (H_2O)	Organic content (%)	Water-soluble component (mg/kg) * epm										
				Cl^-	SO_4^{2-}	HCO_3^-	NO_3^-	M alkalinity*	H_2S	Sulfides	Ca^{2+}	Mg^{2+}	Na^+	K^+
A. Harumi Pumping Station	33.5	7.93	—	59.3	766.6	187.7	328.7	2.33	0.6	0.6	188.2	18.8	11.3	30.2
B. Toyozumi Pumping Station	30.9	7.6	—	20.2	173	492	9.6	2.12	—	2.2	51	159	56	—
C. Kanamachi Purification Plant	47.9	6.16	—	34.6	295.6	<1	2.2	0.54	<0.1	<0.01	37.4	23.8	20.0	—
D. Misono Purification Plant	17.2	7.3	—	<1	79	32	5	0.26	—	<1	81	20	6	2
E. Suginami Purification Plant	121.2	5.9	11.2	6	45	12	56	0.1	<1	<1	17	9	5	4
F. Wadabori Pumping Station	48.6	6.1	—	7.3	11.4	5.3	0.9	0.09	0.00	0.00	2.2	1.9	2.4	—
G. Kinutashimo Purification Plant	4.6	8.4	0.1	6.8	—	—	3.4	0.2	<0.03	<0.03	4.3	0.6	5.4	—
H. Kushiro City Waterworks Bureau	708.6	3.9	91.6	87	7200	—	1.8	3.51	<0.1	<0.1	1317	220	100	—
I. Aomori City Waterworks Dept.	47.5	5.3	1.4	7.0	23.0	—	<1	0.02	<1	—	2.6	0.8	12.2	0.9
J. Nippon Stainless Steel Co., Ltd.	24	7.1	0.4	8	36	44	22	0.6	<1	<1	8	6	23	3
K. Nippon Benkan Kogyo Co., Molco Division, Yabuzuka Works	55.3	5.5	1.8	13.2	—	—	131	0.2	<0.03	<0.03	26.4	3.2	13.8	—
L. Riken Corp., Kumagaya Works	26.9	7.57	—	8.8	64.0	77.0	3.5	1.26	<0.1	<0.01	17.2	6.2	14.0	—
M. Nippon Metal Industry Co., Sagamihara Works	128	6.9	3.8	4.9	14.7	—	0.7	<0.1	<0.1	<0.1	2.6	1.7	5.5	—
N. Nippon Yakin Kogyo, Kawasaki Works	38.0	8.2	1.2	9.0	159	—	<1	0.86	<1	—	47	19.0	16.0	14.0
O. Nippon Bulge Industries, Ltd., Ashikaga Works	19.2	6.86	—	1.3	12	7.9	19	0.2	—	<0.1	18	10	2.3	—
P. Hitachi Metals Ltd., Kuwana Works	21.1	6.9	—	32	72	14.1	3	0.68	—	1.5	6.8	14.8	28	—
Q. Kawasaki Steel Corp., Nishinomiya Works	11.3	8.2	—	15	182	95	13	0	<1	—	204	42	58	13
R. Sumitomo Metal Industries, Ltd., Wakayama Works	—	7.5	—	9.5	22.5	16.6	3.0	0.29	—	<0.5	28.3	1.2	6.3	—
S. Nippon Kokan K.K., Fukuyama Works	14.0	7.25	—	31.0	19.7	91.5	0.3	1.08	0	—	8.7	3.9	43.5	—
T. Nippon Steel Corp., Hikari Works	8.0	8.2	—	6.1	10.0	87.9	7.9	0.6	<0.02	<0.02	10	24	6.3	—
U. Nisshin Steel Co., Shunan Works	21.2	6.48	—	16.2	56.0	268.8	2.0	0.1	0.2	0.2	19.4	2.4	6.3	5.0
V. Nippon Steel Corp., Yahata Works, Nakatsu Factory	10.4	8.1	—	2.8	5.6	33.6	0.0	0.54	0.00	0.00	5.9	0.1	1.2	—
W. Okinawa Prefectural Misato Technical High School	31.8	7.8	—	1540	2710	—	—	—	—	—	546	405	1520	—
X. Okinawa Prefectural Nanbu Technical High School	52.1	7.4	—	50	872	—	—	—	—	—	325	127	87	—
Y. Matsuyama City Public Enterprise Bureau	19.9	6.53	—	39.0	56.8	21.8	450.0	0.2	0.6	0.5	11.4	3.2	8.7	2.0

Analyses of seeping water (mg/ℓ)	pH	Cl^-	SO_4^{2-}	HCO_3^-	NO_3^-	M alkalinity (epm)	H_2S	Ca^{2+}	Mg^{2+}	Na^+
At Harumi (A)	7.19	58.31	386.9	–	311.0	0.5	–	187.2	35.5	35.9
At Nippon Yakin Kogyo, Kawasaki Works (N)	7.8	43	368	–	–	–	–	–	–	–

Table 4-2 Chemical Analysis of Soil (After Five years)

Installation \ Analyses	Water content (%)	pH (H_2O)	Organic content (%)	Water-soluble component (mg/kg)										
				Cl^-	SO_4^{2-}	HCO_3^-	NO_3^-	M alkalinity (* epm)	H_2S	Sulfides	Ca^{2+}	Mg^{2+}	Na^+	K^+
A. Harumi Pumping Station	36.5	7.60	--	5.8	36.2	218.8	3.10	3.50	0.30	0.30	83.8	5.8	9.80	11.1
B. Toyozumi Pumping Station	35.2	7.80		8.5	--	52.0	6.30	0.50		--	73.0	126.0	40.00	
C. Kanamachi Purification Plant	31.6	6.70		10.2	44.6	9.6	1.90	0.16	0.1>	0.01>	13.0	7.8	5.40	
D. Misono Purification Plant	25.5	7.80	--	2.3	20.0	40.0	1.90		<0.01			3.5	2.30	4.3
E. Suginami Purification Plant	85.0	6.10	11.0	4.0	41.0	35.0	20.00	0.10	<1.0	<1.0	14.0	4.0	3.00	3.0
F. Wadabori Pumping Station	36.5	7.50	--	4.2	14.7	7.3	2.20	0.66	<0.02	<0.02	32.0	5.0	1.60	0.8
G. Kinutashimo Purification Plant	7.3	8.20	--	4.0	<10	--	8.40	1.55	--	<0.2	13.4	6.4	3.20	
H. Kushiro City Waterworks Bureau	426.0	5.60	44.3	53.0	7230.0	--	3.40	7.40	<1.0	<1.0	2030.0	26.1	253.00	
I. Aomori City Waterworks Dept.	31.3	5.10	2.3	6.0	47.0	--	<1	0.02	<1	--	9.0	3.5	10.00	1.5
J. Nippon Stainless Steel Co., Ltd.	25.0	6.90	0.4	8.0	15.0	58.0	5.00	0.10	<1	<1	1.0	1.0	10.00	2.0
K. Nippon Benkan Kogyo Co., Molco Division, Yabuzuka Works	27.8	7.40	--	6.0	134.0	--	5.20	0.76	--	<0.2	58.0	3.4	12.40	
L. Riken Corp., Kumagaya Works	21.8	8.00		10.2	46.6	101.8	4.40	1.70	0.1>	0.01>	45.0	21.8	9.60	
M. Nippon Metal Industry Co., Sagamihara Works	143.0	6.50	5.9	16.4	11.4	--	<0.1	0.10	<1	<1	44.0	9.8	5.70	
N. Nippon Yakin Kogyo, Kawasaki Works	24.6	8.50	0.7	5.0	174.0	--	<1	0.88	<1	--	72.0	8.0	14.00	15.0
O. Nippon Bulge Industries, Ltd., Ashikaga Works	20.0	6.79		1.1	6.2	11.0	11.0	0.22		<0.2	13.0	7.0	3.00	
P. Hitachi Metals Ltd., Kuwana Works	40.5	7.10		20.0	--	120.0	10.20	4.00		--	12.0	20.2	25.00	
Q. Kawasaki Steel Corp., Nishinomiya Works	11.8	8.00	--	3.5	20.6	28.4	4.84	1.66	<0.05		70.9	10.8	10.00	10.0
R. Sumitomo Metal Industries, Ltd., Wakayama Works	8.0	8.10	--	9.9	61.5	--	14.30	1.72	--	<0.4	52.4	3.0	8.89	11.0
S. Nippon Kokan K.K., Fukuyama Works	13.1	7.30		8.5	12.8	27.0	0.10	0.62	--		27.0	19.0	11.60	
T. Nippon Steel Corp., Hikari Works	11.1	8.30	--	6.4	7.8	135.5	6.10	2.24	<0.02	<0.02	74.0	22.0	4.80	3.9
U. Nisshin Steel Co., Shunan Works	25.9	6.60	--	8.4	83.1	25.8	0.90	0.20	0.20	0.20	33.4	4.1	10.90	6.5
V. Nippon Steel Corp., Yahata Works, Nakatsu Factory	8.6	8.10	--	3.2	13.2	109.9	3.30	1.52	<0.02	<0.02	72.0	6.0	4.30	1.2
W. Okinawa Prefectural Misato Technical High School	19.4	8.10	--	50.0	420.0	154	8.30		<0.2	<0.2	67.6	44.2	130.00	
X. Okinawa Prefectural Nanbu Technical High School	24.7	8.00	--	16.0	340.0	168.0	43.00	2.90	<0.2	<0.2	109.0	35.3	28.90	
Y. Matsuyama City Public Enterprise Bureau	9.4	7.54	--	6.0	30.0	200.0	3.20	4.00	<0.1	<0.1	52.8	5.0	10.90	1.4

Analyses of seeping water (mg/ℓ)	pH	Cl^-	SO_4^{2-}	HCO_3^-	NO_3^-	M alkalinity (epm)	H_2S	Ca^{2+}	Mg^{2+}	Na^+
Riken Corp., Kumagaya Works (I)	7.90	11.5	27.4	135.0	13.70	112.00	0.1>	54.0	19.3	10.70
Nippon Kokan K.K., Fukuyama Works (S)	7.30	38.0	130.0		0.80	96.00	--	25.0	35.0	276.00
Nisshin Steel Co., Shunan Works (U)	7.80	3.9	23.9	74.7	5.80	1.20	Tr	33.1	3.8	8.60

Table 5 Resistivity and Oxidation-reduction Potential of Soil

Installation	Resistivity (Ω-cm)	Oxidation-reduction potential (mV, NHE)
A. Harumi Pumping Station	5,083	504
B. Toyozumi Pumping Station	5,600	400
C. Kanamachi Purification Plant	6,566	365
D. Misono Purification Plant	6,966	471
E. Suginami Purification Plant	17,333	607
F. Wadabori Pumping Station	25,000	507
G. Kinutashimo Purification Plant	22,333	412
H. Kushiro City Waterworks Bureau	10,733	166
I. Aomori City Waterworks Dept.	4,200	67
J. Nippon Stainless Steel Co., Ltd.	4,733	557
K. Nippon Benkan Kogyo Co., Molco Division, Yabuzuka Works	2,633	144
L. Riken Corp., Kumagaya Works	5,033	450
M. Nippon Metal Industry Co., Sagamihara Works	35,666	454
N. Nippon Yakin Kogyo, Kawasaki Works	4,733	420
O. Nippon Bulge Industries, Ltd., Ashikaga Works	11,633	518
P. Hitachi Metals Ltd., Kuwana Works	3,733	296
Q. Kawasaki Steel Corp., Nishinomiya Works	18,722	717
R. Sumitomo Metal Industries, Ltd.,	45,000	507
S. Nippon Kokan K.K., Fukuyama Works	5,800	316
T. Nippon Steel Corp., Hikari Works	14,933	463
U. Nisshin Steel Co., Shunan Works	19,500	254
V. Nippon Steel Corp., Yahata Works, Nakatsu Factory	32,666	519
W. Okinawa Prefectural Misato Technical High School	1,706	409
X. Okinawa Prefectural Nanbu Technical High School	820	474
Y. Matsuyama City Public Enterprise Bureau	31,000	509

e) Oxidation-Reduction Potential

In the soil whose oxidation-reduction potential is lower than 200 mV, corrosion of iron would be accelerated by the presence of anaerobic sulfate-reducing bacteria.

The oxidation-reduction potential is no more than 100 mV at Kushiro (H), Aomori (I) and southern Okinawa (X). At most test sites it ranges from 200 to 600 mV, showing that the possibility of bacteria- induced corrosion is not high.

4.2 Standard Tests

4.2.1 Corrosion Patterns

A total of 1,275 specimens–including SUS304 and 316 stainless steel pipes; SUS304 stainless steel pipes attached with five different types of fittings; reference pipes of carbon steel, lead, copper; and other metals–were installed underground at 25 test sites throughout the country.

Some of these pipes were recovered one, three and five years after installation and examined in detail for progress of corrosion.

Results of this survey are shown in Table 6.

Light discoloration or brown stains were observed on the SUS304 stainless steel pipes that were installed horizontally at several test sites. No corrosion occurred on any of them. Only at the Okinawa (W) and Misono (D) test sites did pitting corrosion develope–under the vinyl tapes wrapped around the ends of specimens which were recovered five years after they had been installed.

The appearance of the SUS316 stainless steel pipes did not exhibit any changes at all of the test sites, except Wakayama (R) where slight discoloration was noted on the pipe surface. This result indicates that the SUS316 is more resistant to corrosion than SUS304.

As far as stainless steel pipes with various types of fittings are concerned, the soldered section of the solder type fitting was blackened at the majority of test sites. Through-holes resulted from pitting corrosion at Okinawa (W).

Pipes attached with the press type fittings were found free of corrosion in the joint section and on the pipe surface.

The pipes with gun metal casting fittings (compression type and expansion and flexible type fittings A and B), at many test sites, were attacked to a depth of about 0.5 mm under patina in the joint section. It is yet to be determined whether such attacks were caused by galvanic action between copper alloy and stainless steel.

Turning to the vertically installed SUS304 stainless steel pipes, through-holes caused by pitting corrosion were observed in the lower surface areas of specimens that were underground for one year at Kawasaki (N), and for one, three and five years at Fukuyama (S) and Okinawa (W).

It should be noted that the vertically installed pipe is affected by differences in kinds of soil or air-permeability; its lower portion is liable to develop corrosion resulting in a through-hole. This corrosion results from the fact that the vertically installed pipe is in undisturbed soil while the horizontally installed pipe is in the soil disturbed through excavation. No pitting corrosion was noted, however, on the surfaces of vertically installed SUS316 stainless steel pipes at all the test sites except Okinawa (W).

Carbon steel pipes were seriously corroded on their entire surfaces at all test sites, no matter whether they were horizontally or vertically installed. At several sites, even through-holes or breakage was noted.

On the other hand, the vertically installed copper pipes were corroded under patina and the horizontally installed lead pipes developed local corrosion at many test sites.

Table 6 Corrosion Patterns of Specimens

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			A Harumi Pumping Station (Chuo-ku, Tokyo)			B Toyozumi Pumping Station (Koto-ku, Tokyo)		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○ Brown-yellow spot x 2 to 3	○○ Several slightly discolored locations	○○ Earth accumulation in the lower area; slight stain	○○	○○	○○
	SUS304TPD-E		○○ Brown-yellow spot x 2 to 3	○○ Several slightly discolored locations	○○ Earth accumulation in the lower area; slight stain	○○ Brown-yellow spot x 2 to 3	○○	○○
	SUS316TPD-A		○○	○○ Several slightly discolored locations	○○ Earth accumulation in the lower area; slight stain	○○ Brown-yellow spot x 2 to 3	○○	○○
	SGP·black		● Corrosion on the entire surface ; loss in thickness	● Corrosion on the entire surface	● Serious corrosion on the entire surface; maximum corrosion depth, 1.7 mm	● Corrosion on the entire surface ; rust thickness, 0.5 to 0.8 mm	● Corrosion on the entire surface	● Serious corrosion on the entire surface; large loss in weight
	PbTW-2		● Serious, local corrosion maximum corrosion depth, 1.0 mm	● Local corrosion; maximum corrosion depth, 0.3 mm	● Local corrosion; maximum corrosion depth, 1.3 mm	● Pittings scattered on the entire surface ; maximum pitting depth, 1.0 mm	● Numerous pittings; pitting depth, 1 to 2 mm	● Pipe turned blackish gray and local corrosion maximum corrosion depth, 2.0 mm
Pipes with fittings	Solder type	Pipe	○	○ Earth accumulation	○ Earth accumulation	○	○	○
		Fitting	◎ Reinforcement solder peeling	● Corroded solder and peeling	● Corrosion of exposed solder	○	◎ Slight brown-yellow coloring	◎ Discolored solder; whitened outer surface and blackish gray inner surface
	Press type	Pipe	○	○	○	○	○	○
		Fitting	○	○	○	○	○	○
	Compression type	Pipe	○	○ Earth accumulation	○ Earth accumulation	○	○	○
		Fitting	◎ Patina	● Browning; patina; maximum corrosion depth, 0.3 mm	● Patina and local corrosion maximum corrosion depth, 0.9 mm	◎ Patina	● Patina	● Local corrosion; maximum corrosion depth, 0.6 mm
	Expansion and flexible type (A)	Pipe	○	○ Earth accumulation	○ Earth accumulation	○	○	○
		Fitting	● Patina and initial signs of pitting corrosion	● Patina; maximum corrosion depth, 0.5 mm	● Patina and local corrosion maximum corrosion depth, 0.5 mm	◎ Patina	● Browning	● Local corrosion
	Expansion and flexible type (B)	Pipe	○	○ Earth accumulation	○ Earth accumulation	○	○ Earth accumulation	◎ Joints turned red-brown
		Fitting	● Patina and corroded retainer	● Browning; patina; corroded retainer and lock ring	● Patina and local corrosion maximum corrosion depth, 2.0 mm	● Patina and corroded retainer	◎ Rusty retainer and lock ring	● Local corrosion; corroded lock ring
Vertically embedded pipe	SUS304TPD-A		○ Brown-yellow spot x 2 to 3	○	◎ Browning in the lower area	○	◎ Browning in the lower area	○
	SUS316TPD-A		○ Brown-yellow spot x 2 to 3	◎ Slight browning in the lower area	◎ Browning in the lower area	○	◎ Browning in the lower area	○
	C1220T·H		● Patina on the entire surface	● Patina on the entire surface Slight erosion < 0.01 mm	● Patina on the entire surface and slight erosion; maximum corrosion depth, 0.1 mm	● Patina on the entire surface	● Corrosion on the entire surface	● Patina on the surface up to 30 cm from the bottom end
	SGP·black		● Corrosion on the entire surface ; loss in thickness	● Corrosion on the entire surface; corrosion depth, 0.2 to 1.0 mm	● Serious corrosion on the entire surface; maximum corrosion depth, 1.8 mm	● Corrosion on the entire surface; rust thickness, 0.5 to 0.8 mm	● Corrosion on the entire surface; maximum corrosion depth, 0.2 mm	● Serious corrosion on the entire surface

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			C Kanamachi Purification Plant (Katsushika-ku, Tokyo)			D Misono Purification Plant (Itabashi-ku, Tokyo)		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○	○○	○○	○○	○○	●○ One crevice-corroded location under the tape
	SUS304TPD-E		○○	○○	○○	○○	○○	○○
	SUS316TPD-A		○○	○○	○○	○○	○○	○○
	SGP·black		● Corrosion on the entire surface; surface irregularities	● Corrosion on the entire surface; maximum corrosion depth, 0.5 mm	● Serious corrosion on the entire surface; loss in weight	● Corrosion on the entire surface	● Corrosion on the entire surface; large surface irregularities	● Serious corrosion on the entire surface; large surface irregularities
	PbTW-2		● Numerous pittings; maximum pitting depth, 1.0 mm	● Local corrosion; Numerous pittings	● Local corrosion; numerous pittings	○	● 2 pittings; numerous small pittings	● Local corrosion; one pitting 7 mm in diameter by 1 mm deep
Pipes with fittings	Solder type	Pipe	○	○	○	○	○	○
		Fitting	◎ Discolored solder	◎ Whitened solder	◎ Whitened solder	○	◎ Solder turned blackish gray	● Local corrosion
	Press type	Pipe	○	○	○	○	○	○
		Fitting	○	○	○	○	○	○
	Compression type	Pipe	○	○	○	○	○ Earth accumulation	◎ Discoloration
		Fitting	◎ Patina and white rust	◎ Patinated pipe and browned nut	◎ Patinated pipe and browned nut	◎ Patina	● Patina	◎ Patina
	Expansion and flexible type (A)	Pipe	○	○	○	○	○ Earth accumulation	◎ Discoloration
		Fitting	◎ Patina	◎ Patina on the entire surface	● Local corrosion in the lower area	◎ Patina	● Patina	◎ Patina
	Expansion and flexible type (B)	Pipe	○	○	○	○	○ Earth accumulation	◎ Discoloration
		Fitting	● Patina and corroded retainer	◎ Patina and whitened retainer	◎ Patina and whitened retainer	◎ Patina	● Patina	◎ Patina
Vertically embedded pipe	SUS304TPD-A		○	○	○	○	○	◎ Surface turned light brown at the ground boundary
	SUS316TPD-A		○	○	○	○	○	○
	C1220T·H		◎ Thin patina	● Corrosion on the entire surface	● Patina on the entire surface	◎ Patina	◎ Blackening under the tape	◎ Above the ground: blackish red rust; under the ground: patina
	SGP·black		● Corrosion on the entire surface ; red-brown rust	● Corrosion on the entire surface	● Patina on the entire surface; serious corrosion on the exposed surface	● Corrosion on the entire surface; maximum corrosion depth, 0.55 mm	● Corrosion on the entire surface	● Corrosion on the entire surface; surface irregularities

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			E Suginami Purification Plant (Suginami-ku, Tokyo)			F Wadabori Pumping Station (Setagaya-ku, Tokyo)		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○	○○	○○	○○	○○	○○
	SUS304TPD-E		○○	○○	○○	○○	○○	○○
	SUS316TPD-A		○○	○○	○○	○○	○○	○○
	SGP·black		● Corrosion on the entire surface; maximum corrosion depth, 0.5 mm	● Corrosion on the entire surface; maximum corrosion depth, 0.5 mm	● Corrosion on the entire surface; maximum corrosion depth, 1.7 mm	● Local corrosion; maximum corrosion depth, 0.30 mm	● Corrosion on the entire surface	● Concave corrosion
	PbTW-2		◎ Slight corrosion	● Corrosion on the entire surface	● Corroded surface layer	○	● Pitting	● Local corrosion; small pittings
Pipes with fittings	Solder type	Pipe	○	○	○	○	○	○
		Fitting	○	○	● Slightly corroded solder	◎ Blackened solder	◎ Blackened solder	◎
	Press type	Pipe	○	○	○	○	○	○
		Fitting	○	○	○	○	○	○
	Compression type	Pipe	○	○	○	○	○ Earth accumulation	○
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎
	Expansion and flexible type (A)	Pipe	○	○	○	○	○ Earth accumulation	○
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎
	Expansion and flexible type (B)	Pipe	○	○	○	○	○ Earth accumulation	○
		Fitting	◎ Patina	◎ Patina	● Patina; corroded lock ring	◎ Patina	◎ Patina and rusty lock ring	◎
Vertically embedded pipe	SUS304TPD-A		○	○	○	○	○	○
	SUS316TPD-A		○	○	○	○	○	○
	C1220T·H		◎ Patina	● Patina	● Corrosion on the entire surface; maximum corrosion depth, 0.2 mm	● Patina on the entire surface; maximum corrosion depth, 0.07 mm	◎ Patina under the ground	● Patina; many corroded locations
	SGP·black		● Corrosion on the entire surface; maximum corrosion depth, 0.5 mm	● Corrosion on the entire surface; maximum corrosion depth, 0.7 mm	● Above ground: crevice corrosion under tape; maximum corrosion depth, 0.8 mm. Under the ground: corrosion on entire surface; maximum corrosion depth, 1.7 mm	● Local corrosion; maximum corrosion depth, 0.50 mm	● Corrosion on the entire surface	● Concave corrosion

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			G Kinutashimo Purification Plant (Setagaya-ku, Tokyo)			H Kushiro City Waterworks Bureau		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○	○○	○○	○○	○○	○○
	SUS304TPD-E		○○	○○	○○	○○	○○	○○
	SUS316TPD-A		○○	○○	○○	○○	○○	○○
	SGP-black		● Corrosion on the entire surface; surface irregularities	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface; brownish black rust	● Patina on the entire surface	● Patina on the entire surface
	PbTW-2		◎ White spots	◎ White spots	◎ Scattered white spots	○	◎ Graying	◎ Graying
Pipes with fittings	Solder type	Pipe	○	○	○	○	○	○
		Fitting	◎ Blackened solder	◎ Blackened solder	◎ Blackened solder	◎ Blackened solder	○	◎ Grayed solder
	Press type	Pipe	○	○	○	○	○	○
		Fitting	○	○	○	○	○	○
	Compression type	Pipe	○	○ Sand accumulation	○ Earth accumulation	○	○	○
		Fitting	◎ Patina	◎ Patina	◎ Patina	○	◎ Discoloration to brownish black	◎ Discoloration to dark brown
	Expansion and flexible type (A)	Pipe	○	○ Sand accumulation	○ Earth accumulation	○	○	○
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Patina and blackening	◎ Discoloration to brownish black	◎ Discoloration to dark brown
	Expansion and flexible type (B)	Pipe	○	○ Sand accumulation	○ Earth accumulation	○	○	○
		Fitting	◎ Patina	◎ Patina	◎ Patina	● Blackening and corroded retainer ring	◎ Retainer covered with white powder and turned brownish black	◎ Discoloration to dark brown; browned lock ring and corrosion product
Vertically embedded pipe	SUS304TPD-A		○	○	○ Earth accumulation under the ground	◎ Gray patterns	○	○
	SUS316TPD-A		○	○	○	◎ Light brown patterns	○	○
	C1220T-H		● Patina on the entire surface; surface irregularities	◎ Patina	◎ Patina	●	◎ Patina	◎ Above the ground: limited spread of patina; under the ground: blackening
	SGP-black		● Corrosion on the entire surface; loss in thickness	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface; large surface irregularities	● Patina on the entire surface	● Blackening; serious erosion

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			I Aomori City Waterworks Dept.			J Nippon Stainless Steel Co., Ltd. (Naoezu Works)		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○	○○ Slight local discoloration	○○	○○	○○ Slight local coloring (red-brown)	○○
	SUS304TPD-E		○○	○○ Slight local discoloration	○○	○○	○○ Slight local coloring (red-brown)	○○
	SUS316TPD-A		○○	○○	○○	○○	○○ Slight local coloring (red-brown)	○○
	SGP-black		● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface; maximum corrosion depth, 0.2 mm
	PbTW-2		● Serious local corrosion	● Local corrosion	● Corrosion on the entire surface	◎ Slight corrosion	● Corrosion on the entire surface	● Corroded surface layer
Pipes with fittings	Solder type	Pipe	○	○	○	○	Not collected	○
		Fitting	○	○	○	○	Not collected	○
	Press type	Pipe	○	○	○	○	Not collected	○
		Fitting	○	○	○	○	Not collected	○
	Compression type	Pipe	○	○	○	○	○	○
		Fitting	○	◎ Colored outer surface	◎ Blackening	○	○	◎ Patina
	Expansion and flexible type (A)	Pipe	○	○	● Pierced fitting joint (0.57 mm wide x 6.4 mm long)	○	○	○
		Fitting	◎ Patina and blackening	◎ Colored outer surface	◎ Blackening	○	◎ Patina	◎ Patina
	Expansion and flexible type (B)	Pipe	○	○	○	○	○	○
		Fitting	◎ Rusty retainer and lock ring	● Colored outer surface and corroded lock ring and retainer	◎ Blackening	○	◎ Rusty lock ring	◎ Patina
Vertically embedded pipe	SUS304TPD-A		◎ Browning	◎ Browning on the surface up to 30 cm from the bottom end	◎ Surface turned light brown near the bottom end	○	◎ Browning	○
	SUS316TPD-A		◎ Browning	◎ Browning on the surface up to 40 cm from the bottom end	◎ Surface turned brown	○	◎ Browning	○
	C1220T-H		● Patina on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface	◎ Patina	● Corrosion on the entire surface	● Corrosion on the entire surface; maximum corrosion depth, 0.2 mm
	SGP-black		● Corrosion on the entire surface; large surface irregularities	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface; maximum corrosion depth, 0.5 mm	● Corrosion on the entire surface; maximum corrosion depth, 1.2 mm	● Serious corrosion near the ground surface

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			K Nippon Benkan Kogyo Co., (Yabuzuka Works)			L Riken Corp. (Kumagaya Works)		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○	○○	○○	○○	○○	○○
	SUS304TPD-E		○○	○○	○○	○○	○○	○○
	SUS316TPD-A		○○	○○	○○	○○	○○	○○
	SGP·black		● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface
	PbTW-2		◎ White spots	◎ White spots	◎ Scattered white spots	● Serious local corrosion	● Local corrosion; numerous pittings	● Local corrosion; numerous pittings
Pipes with fittings	Solder type	Pipe	○	○	○	○	○	○
		Fitting	◎ Blackened solder	◎ Blackened solder	◎ Blackened solder	◎ Solder turned light brown	◎ Solder covered with white powder	◎ Whitened solder
	Press type	Pipe	○	○	○	○	○	○
		Fitting	○	○	○	○	○	○
	Compression type	Pipe	○	○ Sand accumulation	○	○	○ Sand accumulation	○ Earth accumulation
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎ Patinated pipe and browned nut	◎ Patina on the pipe and browned nut
	Expansion and flexible type (A)	Pipe	○	○ Sand accumulation	○	○	○ Sand accumulation	○ Earth accumulation
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎ Patina on the entire surface	● Pitting corrosion under the nuts on both sides
	Expansion and flexible type (B)	Pipe	○	○ Sand accumulation	○	○	○ Sand accumulation	○ Earth accumulation
		Fitting	◎ Patina	◎ Patina	◎ Patina	● Patina and corroded retainer	◎ Patinated pipe and discolored nut (dark brown)	◎ Red-brown discoloration under the nuts on both sides
Vertically embedded pipe	SUS304TPD-A		○	○	○	○	○	◎ Discoloration in the upper area 80 to 100 cm wide
	SUS316TPD-A		○	○	○	○	○	○
	C1220T·H		● Patina on the entire surface; slightly concave corrosion	◎ Patina	◎ Patina	◎ Slight patina	● Corrosion on the entire surface	● Patina on the entire surface
	SGP·black		● Corrosion on the entire surface; loss in thickness	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface; brown rust lumps	● Corrosion on the entire surface	● Corrosion on the entire surface

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			M Nippon Metal Industry Co. (Sagamihara Works)			N Nippon Yakin Kogyo (Kawasaki Works)		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○	○○	○○	○○	○○	○○
	SUS304TPD-E		○○	○○	○○	○○	○○	○○
	SUS316TPD-A		○○	○○	○○	○○	○○	○○
	SGP·black		● Corrosion on the entire surface; surface irregularities	● Corrosion on the entire surface	● Corrosion on the entire surface; numerous rust lumps	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface
	PbTW-2		◎ Slight corrosion on the entire surface	◎ Entire surface discolored whitish	◎ Discoloration to dark gray; no gloss	● Serious local corrosion	● Local corrosion	● Local corrosion
Pipes with fittings	Solder type	Pipe	○	○	○	○	○	○
		Fitting	○	◎ Whitened solder	◎ Grayed solder	○	◎ Blackened solder inside the pipe	○
	Press type	Pipe	○	○	○	○	○	○
		Fitting	○	○	○	○	○	○
	Compression type	Pipe	○	○	○	○	○	○
		Fitting	◎ Patina in limited areas	◎ Patina	◎ Patina	○	◎ Discolored outer surface	◎ Blackening
	Expansion and flexible type (A)	Pipe	○	○	○	○	○	○
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Blackening and slight, local patina	◎ Discolored outer surface	◎ Blackening
	Expansion and flexible type (B)	Pipe	○	○	○	○	○	○
		Fitting	◎ Patina	◎ Patina on the pipe and white powder on the retainer	◎ Patina; browning; whitened retainer and brown corrosion product	● Blackening, patina, and corroded retainer	◎ Discolored outer surface and corroded lock ring and retainer	◎ Blackening
Vertically embedded pipe	SUS304TPD-A		○	○	○	● Browning; five pittings in the central area	◎ Earth accumulation and coloring	◎ Browning on the surface up to 50 cm from the bottom end
	SUS316TPD-A		○	○	○	◎ Brown pattern	◎ Coloring	◎ Browning and partial blackening on the surface up to 50 cm from the bottom end
	C1220T·H		● Thick patina in the lower area	◎ Patina	◎ Above the ground: browning; under the ground: patina	● Patina on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface
	SGP·black		● Corrosion on the entire surface; serious corrosion in the central area	● Corrosion on the entire surface	● Above the ground: discoloration to dark brown under the ground: numerous rust lumps	● Corrosion on the entire surface (seriously in the lower area)	● Corrosion on the entire surface	● Corrosion on the entire surface

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen			Installation	O Nippon Bulge Industries, Ltd. (Ashigara Works)			P Hitachi Metals Ltd. (Kuwana Works)		
				1	3	5	1	3	5
Pipe	SUS304TPD-A			○○	○○	○○	○○	○○	○○
	SUS304TPD-E			○○	○○	○○	○○	○○	○○
	SUS316TPD-A			○○	○○	○○	○○	○○	○○
	SGP·black			● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface; 0.3-mm loss in thickness	● Corrosion on the entire surface ; Light brown rust	● Corrosion on the entire surface; Corrosion depth, 0.3 to 0.5 mm	● Serious corrosion on the entire surface; Max. corrosion depth: 1.5 mm
	PbTW-2			◎ Whitened outer surface	● Erosion depth, 0.5 to 1.5 mm	● Whitened outer surface Loss in thickness	● Local pittings; Pitting depth, 0.3 mm	● Local corrosion; Corrosion depth, 0.3 mm	● Many corroded local areas Whitened upper area
Pipes with fittings	Solder type	Pipe		○	○	○	○	○	○
		Fitting		◎ Whitening	◎ Whitened solder	◎ Whitened solder	○	◎ Grayed solder	◎ Solder discolored to grayish black
	Press type	Pipe		○	◎ White spots	○	○	○	○
		Fitting		○	◎ Discoloration to greenish white	○	○	○	○
	Compression type	Pipe		○	○	○	○	○	○
		Fitting		◎ Patina	◎ Patina	◎ Patina	○	◎ Patina	◎ Lower area turned dark brown in color
	Expansion and flexible type (A)	Pipe		○	○	○	○	○	○
		Fitting		◎ Patina	◎ Patina	◎ Patina	◎ Blackening	◎ Browning	● Local corrosion under the nuts; Corrosion depth: 0.5 mm or less
	Expansion and flexible type (B)	Pipe		○	○	○	○	○	◎ Joints discolored to red-brown
		Fitting		◎ Patina	◎ Patina	◎ Patina	● Corroded retainer and lock ring	● Patina and corroded lock ring and retainer	● Corroded lock ring and retainer (brown rust)
Vertically embedded pipe	SUS304TPD-A			○	○	○	◎ Brown patterns in the lower area 50 cm wide	◎ Browning in the lower area	○
	SUS316TPD-A			○	○	○	◎ Brown patterns in the lower area 40 cm wide	◎ Slight browning in the lower area	○
	C1220T·H			◎ Discoloration on the entire surface	◎ Entire surface discolored to greenish white	◎ Patina below the ground surface	● Patina in the entire central area	● Local corrosion	● Under the ground: discoloration to dark brown
	SGP·black			● Corrosion on the entire surface	● Corrosion on the entire surface	● Above the ground: rust Under the ground: numerous rust lumps	● Corrosion on the entire surface; Brown-yellow rust	● Corrosion on the entire surface; Serious corrosion at the boundary	● Above the ground: corrosion on the entire surface; Under the ground: corrosion on the surface; decrease in thickness at the position 30 cm from the bottom end

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			Q Kawasaki Steel Corp. (Nishinomiya Works)			R Sumitomo Metal Industries, Ltd. (Wakayama Works)		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○	○○	○○	○○	○○ Slight browning	◎◎ Browning
	SUS304TPD-E		○○	○○	○○	○○	○○ Patterns of gray spots	◎◎ Patterns of brown spots
	SUS316TPD-A		○○	○○	○○	○○	○○ Patterns of gray spots	◎◎ Patterns of brown spots
	SGP-black		● Corrosion on the entire surface; surface irregularities	● Patina on the entire surface	● Serious corrosion on the entire surface	● Corrosion on the entire surface; surface irregularities	● Corrosion on the entire surface	● Corrosion on the entire surface
	PbTW-2		● Pitting x 1	● Pitting x 4	● Local corrosion	○	○ Sand accumulation	◎ Discoloration to red brown
Pipes with fittings	Solder type	Pipe	○	○	○	○	○ Sand accumulation	○ Earth accumulation on the entire surface
		Fitting	◎ Solder turned light brown in color	◎ Solder turned grayish black	◎ Grayed solder	◎ Solder turned light brown	◎ Solder covered with white rust	◎ Earth accumulation on the entire surface; lime accumulation on the sides
	Press type	Pipe	○	◎	○	○	◎ Browning	◎ Browned boundary
		Fitting	○	○	○	○	○	○
	Compression type	Pipe	○	○	○	○	○ Sand accumulation	○ Earth accumulation on the entire surface
		Fitting	◎ Patina in limited areas	◎ Patina	◎ Patina	◎ Patina and white rust	○	◎ Patina
	Expansion and flexible type (A)	Pipe	○	○	○	○	○ Sand accumulation	○ Earth accumulation on the entire surface
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Patina	○	◎ Patina
	Expansion and flexible type (B)	Pipe	○	○	○	○	○ Sand accumulation	○ Earth accumulation on the entire surface; lime accumulation on the sides
		Fitting	◎ Patina in limited areas	◎ Patina	◎ Patina	◎ Patina and corroded retainer	◎ Patina	◎ Patina
Vertically embedded pipe	SUS304TPD-A		○	◎ Boundary turned light brown	○	○	◎ Browned boundary	◎ Browned boundary
	SUS316TPD-A		○	◎ Boundary turned light brown	○	○	◎ Browned boundary	◎ Browned boundary
	C1220T-H		● Patina on the entire surface	◎ Above the ground: blackening; under the ground: patina	◎ Above the ground: brownish black; under the ground: patina	● Patina on the entire surface ; surface irregularities	● Patina on the entire surface	◎ Red rust on the entire surface and blackening
	SGP-black		● Corrosion on the entire surface; surface irregularities	● Patina on the entire surface	● Above the ground: red-brown; under the ground: corrosion on the entire surface	● Corrosion on the entire surface ; rust and surface irregularities	● Corrosion on the entire surface; serious corrosion at the boundary	● Seriously corroded boundary

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			S Nippon Kokan K.K.			T Nippon Steel Corp. (Hikari Works)		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○ Brown-yellow spots	◎○ Browning	○○	○○	○○	○○
	SUS304TPD-E		○○	○○	○○	○○	○○	○○
	SUS316TPD-A		○○ Brown-yellow spots	◎○ Browning	○○	○○	○○	○○
	SGP·black		● Corrosion on the entire surface; maximum corrosion depth, 0.07 mm	● Corrosion on the entire surface; maximum corrosion depth, 0.7 mm	● Maximum pitting depth, 0.08 mm	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface
	PbTW-2		○	◎	○	○	● Local corrosion	● Local corrosion; corroded area 2 to 3 mm in diam. x 10
Pipes with fittings	Solder type	Pipe	○	○	○	○	○ Earth accumulation	○
		Fitting	○	○	○	◎ Grayed solder	◎ Blackened solder	◎ Grayed solder
	Press type	Pipe	○	○	○	○	○	○
		Fitting	○	○	○	○	○	○
	Compression type	Pipe	○	○	○	○	○ Earth accumulation	○
		Fitting	○	○	◎	◎ Patina in limited areas	◎ Patina	◎ Patina
	Expansion and flexible type (A)	Pipe	○	○	○	○	○ Earth accumulation	○
		Fitting	○	○	○	◎ Patina	◎ Patina	◎ Patina
	Expansion and flexible type (B)	Pipe	○	○	○	○	○ Earth accumulation	○
		Fitting	○	○	○	◎ Rusty lock ring	◎ Patina and rusty lock ring	◎ Patina
Vertically embedded pipe	SUS304TPD-A		● Colored locations, pittings, and through-holes at the position 50 cm from the bottom end	● Crevice corrosion under the bottom tape	● Pitting in earth accumulation under the tape; maximum pitting depth, 0.28 mm	○	○	○
	SUS316TPD-A		◎ Brown patterns in limited areas	◎	◎	○	○	○
	C1220T·H		● Corrosion on the entire surface	● Corrosion on the entire surface; patina	● Corrosion on the entire surface; maximum corrosion depth, 0.49 mm	● Corrosion on the entire surface	◎ Patina under the ground	◎ Patina
	SGP·black		● Corrosion on the entire surface; iron rust	● Corrosion on the entire surface	● Corrosion on the entire surface; maximum corrosion depth, 1.7 mm	● Corrosion on the entire surface; surface irregularities	● Corrosion on the entire surface	● Corrosion on the entire surface

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			U Nisshin Steel Co. (Shunan Works)			V Nippon Steel Corp. (Yahata and Nakatsu Works)		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		○○	○○	○○	○○	○○	○○
	SUS304TPD-E		○○	○○	○○	○○	○○	○○
	SUS316TPD-A		○○	○○	○○	○○	○○	○○
	SGP·black		● Corrosion on the entire surface	● Corrosion on the entire surface; maximum corrosion depth, 0.3 mm	● Corrosion on the entire surface; maximum erosion depth, 0.5 mm	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface
	PbTW-2		○	● Corrosion on the entire surface	◎ Yellowish white deposits; blackening	○	● Local corrosion	● Local corrosion
Pipes with fittings	Solder type	Pipe	○	○	○	○	○	○
		Fitting	○	○	◎ Blackened solder	◎ Blackened solder	◎ Blackened solder	◎ Corrosion on the entire surface
	Press type	Pipe	○	○	○	○	○	○
		Fitting	○	○	○	○	○	○
	Compression type	Pipe	○	○	○	○	○	○
		Fitting	○	○	◎ Slightly discolored cap nut	◎ Patina	◎ Patina	◎ Patina
	Expansion and flexible type (A)	Pipe	○	○	○	○	○	○
		Fitting	◎ Local blackening	◎ Slight amount of patina and blackening	◎ Slightly discolored cap nut	◎ Patina	◎ Patina	◎ Patina
	Expansion and flexible type (B)	Pipe	○	○	○	○	○	○
		Fitting	● Corroded retainer and lock ring	◎ Rusty retainer	◎ Slightly discolored cap nut; rusty retainer	● Corroded retainer	◎ Patina and rusty lock ring	◎ Patina
Vertically embedded pipe	SUS304TPD-A		◎ Brown patterns in the lower half	◎ Earth accumulation in the upper area; browning in the lower area	◎ Earth accumulation in the upper area; browning in the lower area	○	○	○
	SUS316TPD-A		◎ Brown patterns in limited areas	◎ Earth accumulation in the upper area; browning in the lower area	◎ Earth accumulation in the upper area; browning in the lower area	○	○	○
	C1220T·H		● Patina in the central area maximum corrosion depth, 0.10 mm	● Patina on the entire surface maximum corrosion depth, 0.1 mm	● Patina at the boundary; browning in the lower area	◎ Patina in the central area	◎ Patina under the ground	◎ Patina
	SGP·black		● Corrosion on the entire surface ; Browning	● Corrosion on the entire surface; maximum corrosion depth, 0.1 to 0.7 mm	● Corrosion on the entire surface; maximum erosion depth, 0.6 mm	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation ○ No corrosion ◎ Coloring, discoloration, or rusting ● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			W Okinawa Prefectural Misato Technical High School			X Okinawa Prefectural Nanbu Technical High School		
			1	3	5	1	3	5
Pipe	SUS304TPD-A		◎◎ Browning	○● One pitting 3.5 (long diameter)x 3.2 (short diameter) x 0.2 (depth) mm 180 mm from the extreme right	○● One pitting 2.5 (long diameter) x 2 (short diameter) x 0.5 (depth) mm	◎● Browning / one pitting at the position 15 cm from the extreme right	◎◎ Browned areas	○○
	SUS304TPD-E		◎◎ Browning (in the area 37.5 to 38.0 cm wide from the upper extreme right)	●○ One pitting 0.8 mm deep under the tape at the extreme right	○○	◎◎ Browning	◎◎ Browned areas	◠◠
	SUS316TPD-A		◎◎ Browning	○○	○○	●◎ One pitting at the position 18 cm from the lower extreme right and browning	◎◎ Browned areas	○○
	SGP-black		● Corrosion on the entire surface	● Corrosion on the entire surface ; through-hole 300 mm from the lower extreme right	● Corrosion on the entire surface ; numerous through-holes	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface ; numerous through-holes
	PbTW-2		● Many corroded locations	● Extensive local corrosion	● Corrosion on the entire surface and numerous pittings 0.5 to 1.5 mm deep	● Many corroded local locations	● Extensive local corrosion	● Corrosion on the entire surface and numerous pittings 0.5 to 1.2 mm deep
Pipe with fitting	Solder type	Pipe	● Pierced right-hand solder	● Pitting corrosion in the solder	● Pitting corrosion in the solder	◎ Browning	○	◎ Blackened solder
		Fitting	● Pierced right- hand fitting	● Pitting corrosion in the solder	● Numerous through-holes	◎ Blackening	○	○
	Press type	Pipe	● Two pittings in the lower area	○	○	◎ Browning	○	○
		Fitting	● Corroded groove end	○	○	◎ Blackening	○	○
	Compression type	Pipe	○	○ White deposits	○ Earth accumulation	● One pitting in the upper area	○ White deposits	○ Earth accumulation
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎ Patina
	Expansion and flexible type (A)	Pipe	○ Sand accumulation	○ White deposits	○ Earth accumulation	◎ Browning	○ White deposits	○ Earth accumulation
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎ Patina	● Patina and pitting corrosion
	Expansion and flexible type (B)	Pipe	○ Sand accumulation	○ White deposits	○ Earth accumulation	◎ Sand accumulation	○ White deposits	○ Earth accumulation
		Fitting	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎ Patina	◎ Patina
Vertically embedded pipe	SUS304TPD-A		● Pitting corrosion 129 cm from the bottom end ; browning 4 cm from the bottom end	◎ Local browning	● Browning / pitting corrosion under the tape	◎ Dark-brown discoloration up to 45 cm from the bottom end	◎ Local browning	◎ Under the ground: browned surface up to 400 mm from the bottom end
	SUS316TPD-A		● Browning ; Pitting corrosion 90 cm from the bottom end	◎ Local browning	● Coloration to light brown and pitting corrosion under the tape	◎ Dark-brown discoloration up to 70 cm from the bottom end	◎ Local browning	◎Under the ground: browned surface up to 400 mm from the bottom end
	C1220T-H		● Patina under the ground	◎ Patina under the ground	● Patina on the entire surface	◎ Patina below the ground surface	◎ Patina under the ground	● Patina on the entire surface
	SGP-black		● Corrosion on the entire surface	● Corrosion on the entire surface ; limited corrosion at the boundary	● Corrosion on the entire surface ; section 90 cm wide missing from the bottom end	● Corrosion on the entire surface	● Corrosion on the entire surface	● Corrosion on the entire surface; through-holes

Table 6 Corrosion Patterns of Specimens (cont'd)

Evaluation

○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
E: Electric resistance welded pipe

Specimen \ Installation			Y Matsuyama City Public Enterprise Bureau		
			1	3	5
Pipe	SUS304TPD-A		○○ Slightly stained location x 1 to 2	○○	○○
	SUS304TPD-E		○○ Slightly stained location x 1 to 2	○○ Slight staining	○○
	SUS316TPD-A		○○ Slightly stained location x 1 to 2	○○ Slight staining	○○
	SGP-black		● Corrosion on the entire surface; 0.2-mm decrease in pipe diam.	● Corrosion on the entire surface; maximum erosion depth, 1.7 mm	● Serious corrosion on the entire surface; through-hole in the central area
	PbTW-2		● Scattered erosion; corrosion depth 0.3 mm; maximum hole size, 6 (long diameter) x 3 (short diameter) mm	● Scattered eroded locations; maximum erosion depth, 0.4 mm	● Local corrosion; maximum corrosion depth, 0.7 mm
Pipe with fitting	Solder type	Pipe	○ Earth accumulation	○ Slight earth accumulation	○ Slight earth accumulation
		Fitting	◎ Blackened solder	◎ Blackened solder and yellowish white corrosion product	◎ Blackened solder; white deposits
	Press type	Pipe	○ Slight staining	○ Slight staining	○
		Fitting	○	○	○
	Compression type	Pipe	○ Earth accumulation	○ Much accumulation of earth	○ Earth accumulation
		Fitting	◎ Thin patina on the pipe	◎ Patinated pipe and browned nut	◎ Patina; browned nut
	Expansion and flexible type (A)	Pipe	○ Earth accumulation	○ Much accumulation of earth	○ Earth accumulation
		Fitting	◎ Patina in local areas	◎ Patina on the entire surface	◎ Patina on the entire surface
	Expansion and flexible type (B)	Pipe	○ Earth accumulation	○ Much accumulation of earth	○ Earth accumulation
		Fitting	◎ Discoloration to reddish black and rusty retainer	● Patinated pipe, browned nut, and corroded lock ring	● Patinated pipe, browned nut, and corroded retainer and lock ring
Vertically embedded pipe	SUS304TPD-A		◎ Staining	◎ Scattered stains	◎ Under the ground: staining and earth accumulation
	SUS316TPD-A		◎ Staining	◎ Scattered stains	◎ Under the ground: staining and earth accumulation
	C1220T-H		● Patina on the entire surface; pitting in the lower area x 1 to 2; maximum pitting depth, 0.1 mm	● Patina on the entire surface; small pittings, less than 0.1 mm deep	● Patina on the entire surface 0.05-mm erosion near the bottom end and at the boundary
	SGP-black		● Corrosion on the entire surface; 0.1-0.25-mm decrease in pipe diameter	● Corrosion on the entire surface; erosion depth, 0.5 to 1.5 mm	● Corrosion on the entire surface; maximum corrosion depth, 1.8 mm

4.2.2. Corrosion Rate

Easy to weigh small pipe specimens were used for determining their corrosion rates.

Small specimens of SUS304 and SUS316 stainless steel, carbon steel, and lead pipes were installed at 25 test sites all over the country. Their corrosion weight losses were measured one, three and five years after installation and their corrosion rates (in mdd or mm/y) were calculated. The corrosion rates of carbon steel and lead pipes are shown in Table 7.

It should be noted that neither SUS304 nor SUS316 stainless steel pipes had corrosion weight loss at any test site, even five years after installation.

The corrosion rate of carbon steel pipes was particularly noticeable five years after installation at the Okinawa (W) and southern Okinawa (X) test sites situated in an oceanic climate. Relatively higher corrosion rates were noted at Kuwana (P), Toyozumi (B), Yabuzuka (K), Sagamihara (M) and Matsuyama (Y) than in other sites.

The order of decreasing corrosion rate of lead pipes five years after installation is Toyozumi (B), Kumagaya (L), southern Okinawa (X), Kuwana (P) and Harumi (A).

Table 8 shows the average corrosion rate of all small carbon steel and lead pipes by period underground. As is clear from this table, their average rate decreased in the first one to three years, but later the corrosion rate of lead pipe remained unchanged while that of carbon steel pipe slightly decreased. The maximum corrosion rates of the pipes of both materials were five to six times as high as the average.

Table 7 Corrosion Rate (mm/y)

Site	Carbon steel			Lead		
	1 yr	3 yr	5 yr	1 yr	3 yr	5 yr
A	0.0272	0.0514	0.0138	0.0012	0.0040	0.0037
B	0.0194	0.0159	0.0229	0.0064	0.0035	0.0091
C	0.0126	0.0123	0.0085	0.0021	0.0016	0.0014
Ⓓ	–	–	–	–	–	–
E	0.0404	0.0218	0.0161	0.0012	0.0017	0.0013
F	0.0265	0.0012	0.0171	0.0003	0.0002	0.0002
G	0.0164	0.0208	0.0088	0.0020	0.0022	0.0006
Ⓗ	0.0034	0.0062	0.0115	0.0011	0.0003	0.0006
Ⓘ	0.0035	0.0053	0.0177	0.0011	0.0017	0.0017
Ⓙ	0.0064	0.0034	0.0056	0.0003	0.0009	0.0010
Ⓚ	0.0202	0.0193	0.0218	0.0023	0.0012	0.0006
L	0.0152	0.0155	0.0096	0.0215	0.0091	0.0084
M	0.0337	0.0238	0.0221	0.0003	0.0002	0.0004
N	0.0023	0..091	0.0067	0.0004	0.0004	0.0003
O	0.0061	0.0056	0.0038	0.0028	0.0003	0.0003
Ⓟ	0.0148	0.0244	0.0285	0.0026	0.0074	0.0048
Q	0.0207	0.0100	0.0154	0.0029	0.0002	0.0006
Ⓡ	0.0266	0.0182	0.0130	0.0009	0.0006	0.0006
S	0.0036	0.0094	0.0034	0.0006	0.0007	0.0003
T	0.0085	0.0045	0.0049	0.0020	0.0002	0.0001
Ⓤ	0.0261	0.0106	0.0075	0.0016	0.0029	0.0010
Ⓥ	0.0428	0.0201	0.0097	0.0008	0.0003	0.0001
Ⓦ	0.2193	0.1236	0.0624	0.0211	0.0022	0.0019
Ⓧ	0.1594	0.1352	0.0936	0.0194	0.0060	0.0075
Y	0.0471	0.0028	0.0216	0.0015	0.0009	0.0002

Table 8 Average Corrosion Rate of Carbon Steel and Lead (mm/y)

Metal		After 1 year	After 3 years	After 5 years
Carbon steel	Average	0.033	0.024	0.019
	Maximum	0.240	0.140	0.094
	Minimum	0.002	0.001	0.003
Lead	Average	0.004	0.002	0.002
	Maximum	0.022	0.009	0.009
	Minimum	0.000	0.000	0.000

4.2.3 Natural Potential

To examine the corrosion behavior of the materials in soil, 13 different materials specimens–including stainless steel pipes, carbon steel pipes, lead pipes, and stainless steel pipes with fittings–before installation had lead wires attached for potential measurement purposes. Figures 8.1 through 8.8 show changes with time in natural potential of the specimens installed at 11 selected test sites.

a) Stainless Steel Pipes

On the whole, the potential of SUS304 and SUS316 pipes at all test sites changed immediately after installation and such changes continued for several months. Afterward, the potential tended to become steady. Large changes in potential were observed, however, at Aomori (I) and Wakayama (R) more than three years after installation.

The examination of the potential in steady state five years after installation reveals that it was as high as + 0.40 to + 0.50 V at Yabuzuka (K), Wakayama (R), Nakatsu (V) and Matsuyama (Y), but as low as -0.30 to -0.45 V at Kushiro (H), Naoetsu (U) and Shunan (V).

On the other hand, the potential continued to changing with time, even three years after installation, over the range from 500 to 900 mV at Aomori (I), Okinawa (W), southern Okinawa (X) and Matsuyama (Y). At those test sites, the ground water level was so high that its fluctuations caused changes in soil water content or air-permeability. Such changes, in turn, are considered to have exerted a large influence on the potential behavior of stainless steel.

b) Carbon Steel Pipes

The potential of carbon steel pipes became almost steady soon after installation, indicating -0.60 to -0.70 V at many test sites. A potential of about – 0.30, V measured at the Wakayama (R) and Nakatsu (V) test sites of sandy soil, was higher than the levels measured at other test sites.

c) Stainless Steel Pipes with Fittings

Some stainless steel pipes with solder type fittings had the potential the level near that of lead pipes, as was observed at Kushiro (H) and Kuwana (P). At other test sites, their potential was close to that of stainless steel pipes without fittings.

At all test sites, pipes with press type fittings exhibited changes in potential in a pattern similar to that for stainless steel pipes without fittings.

As far as pipes with compression type and expansion and flexible type copper alloy fittings (A) and (B) are concerned, they all showed a potential that was almost the same as that of ordinary stainless steel pipes without fittings.

Higher potential than that exhibited by stainless steel pipes without fittings was noted at several test sites, in including Okinawa (W).

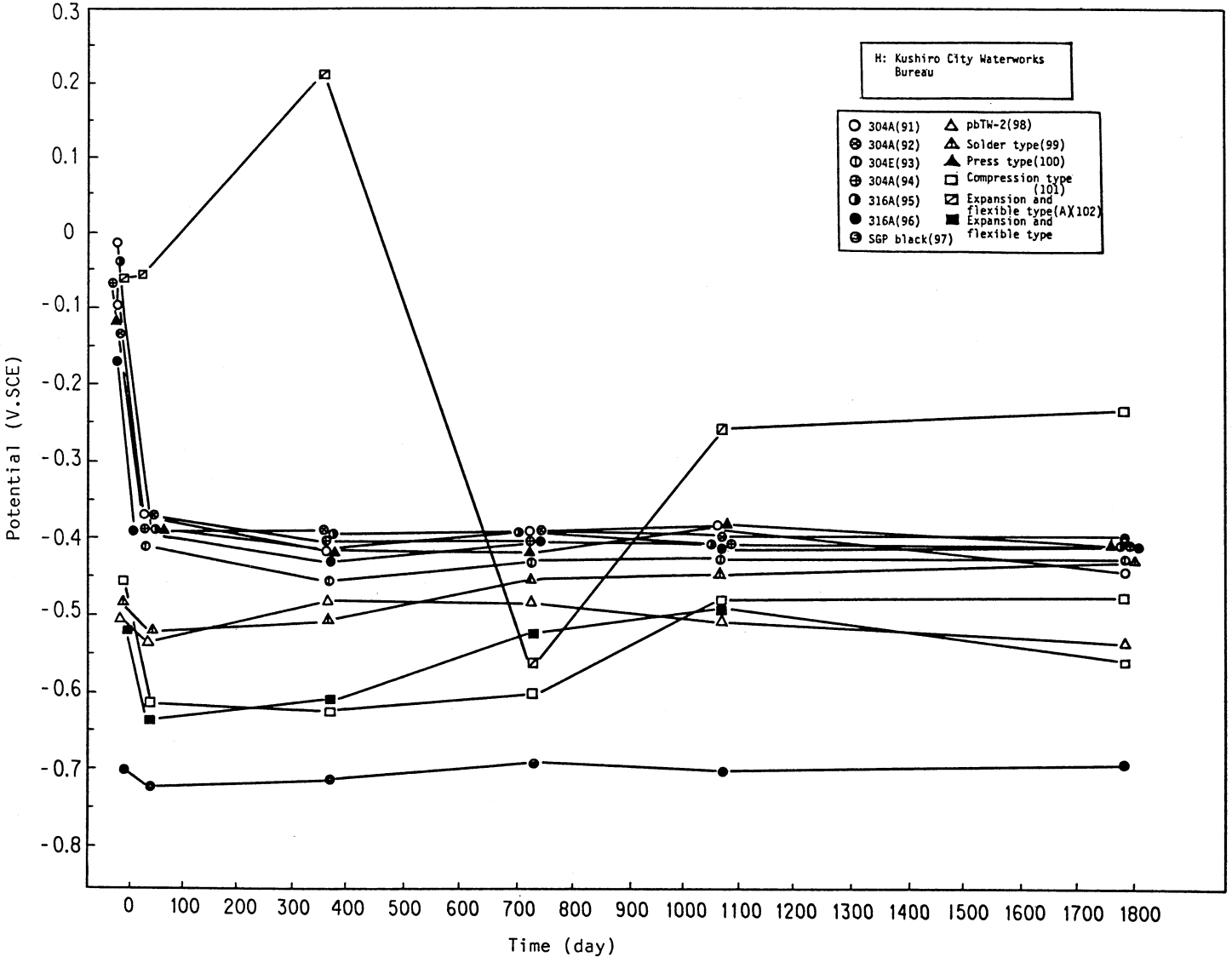


Figure 8.1 Changes in Natural Potential with Time in Kushiro (H)

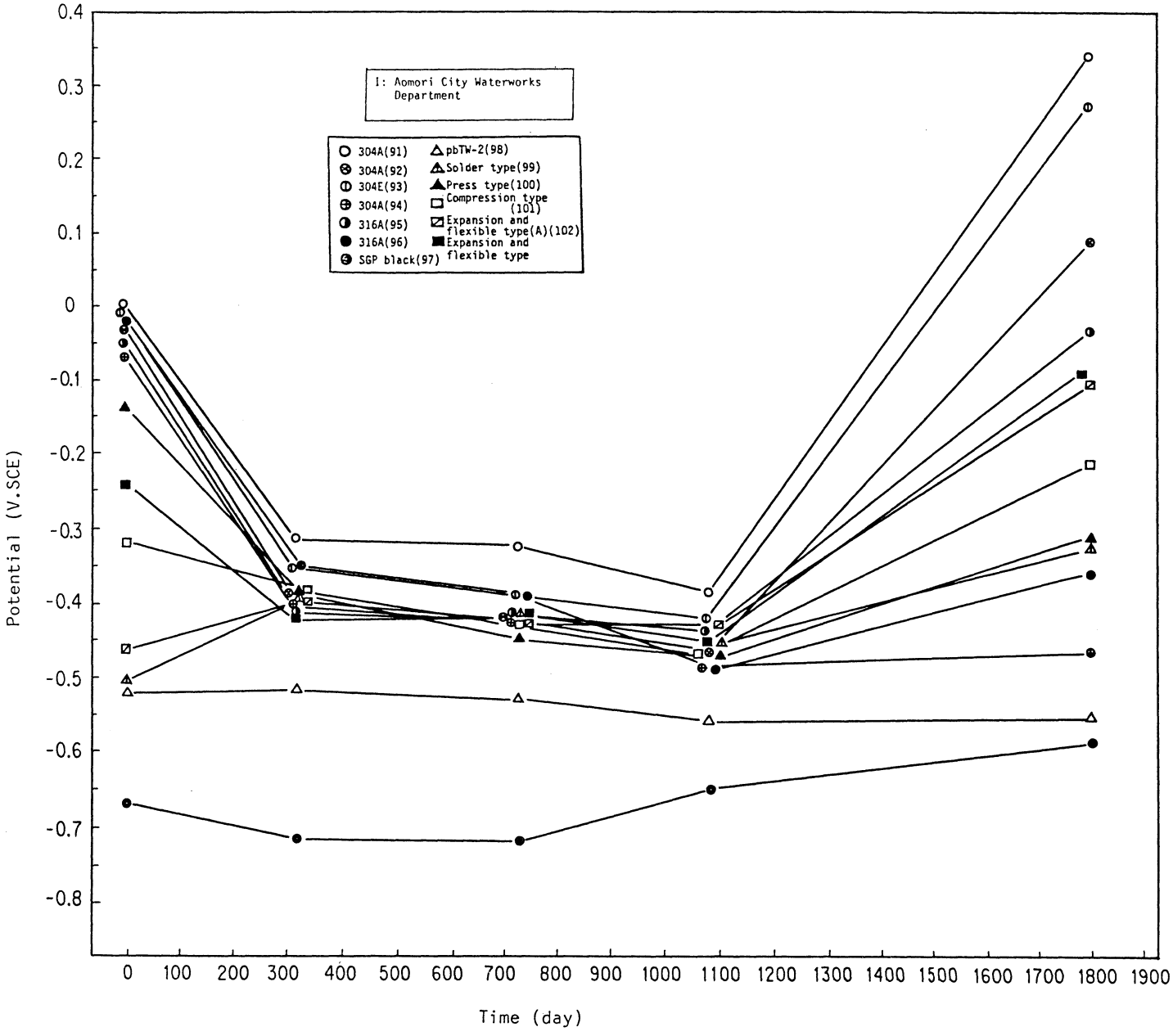


Figure 8.2 Changes in Natural Potential with Time in Aomori (1)

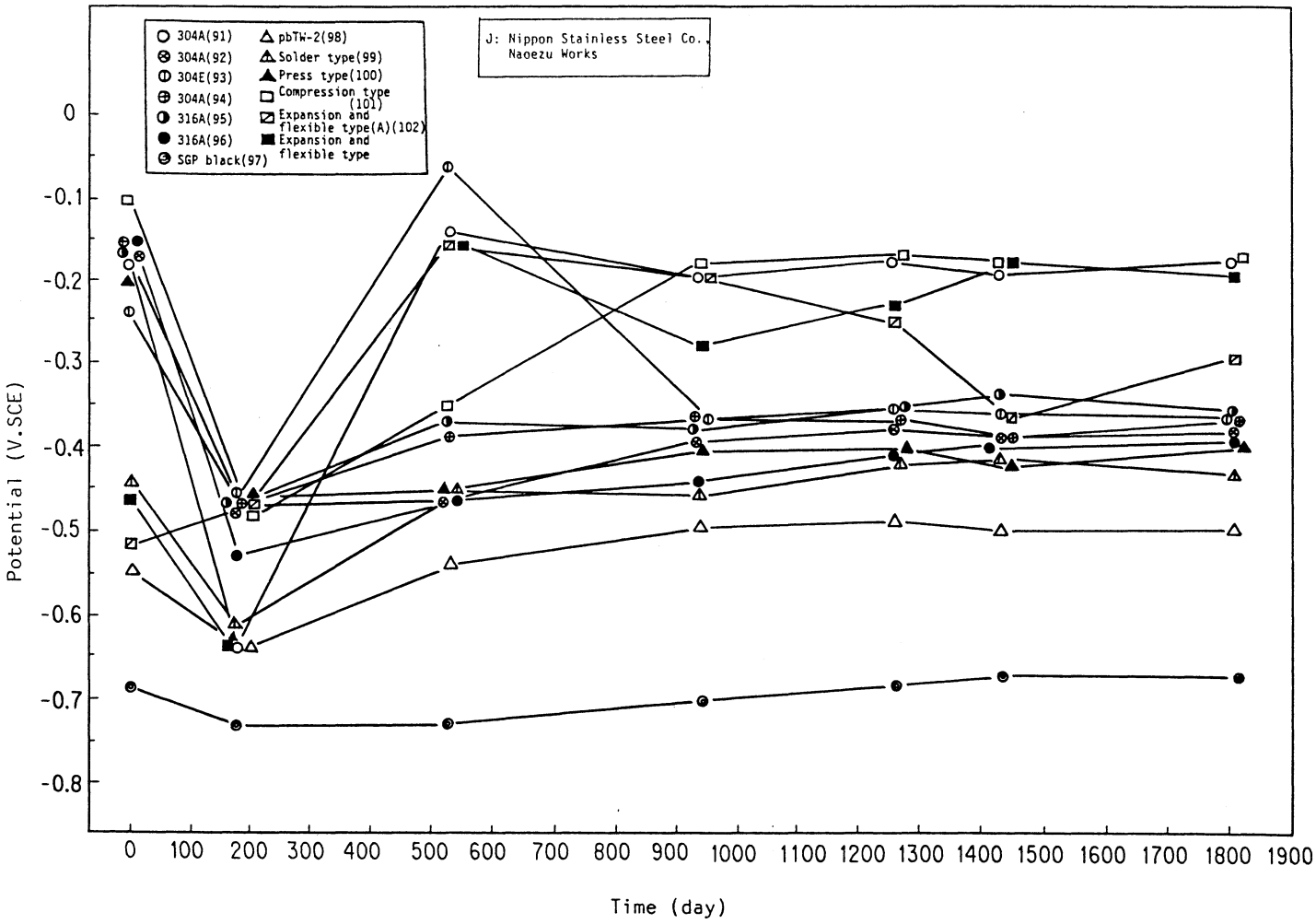


Figure 8.3 Changes in Natural Potential with Time in Naoezu (J)

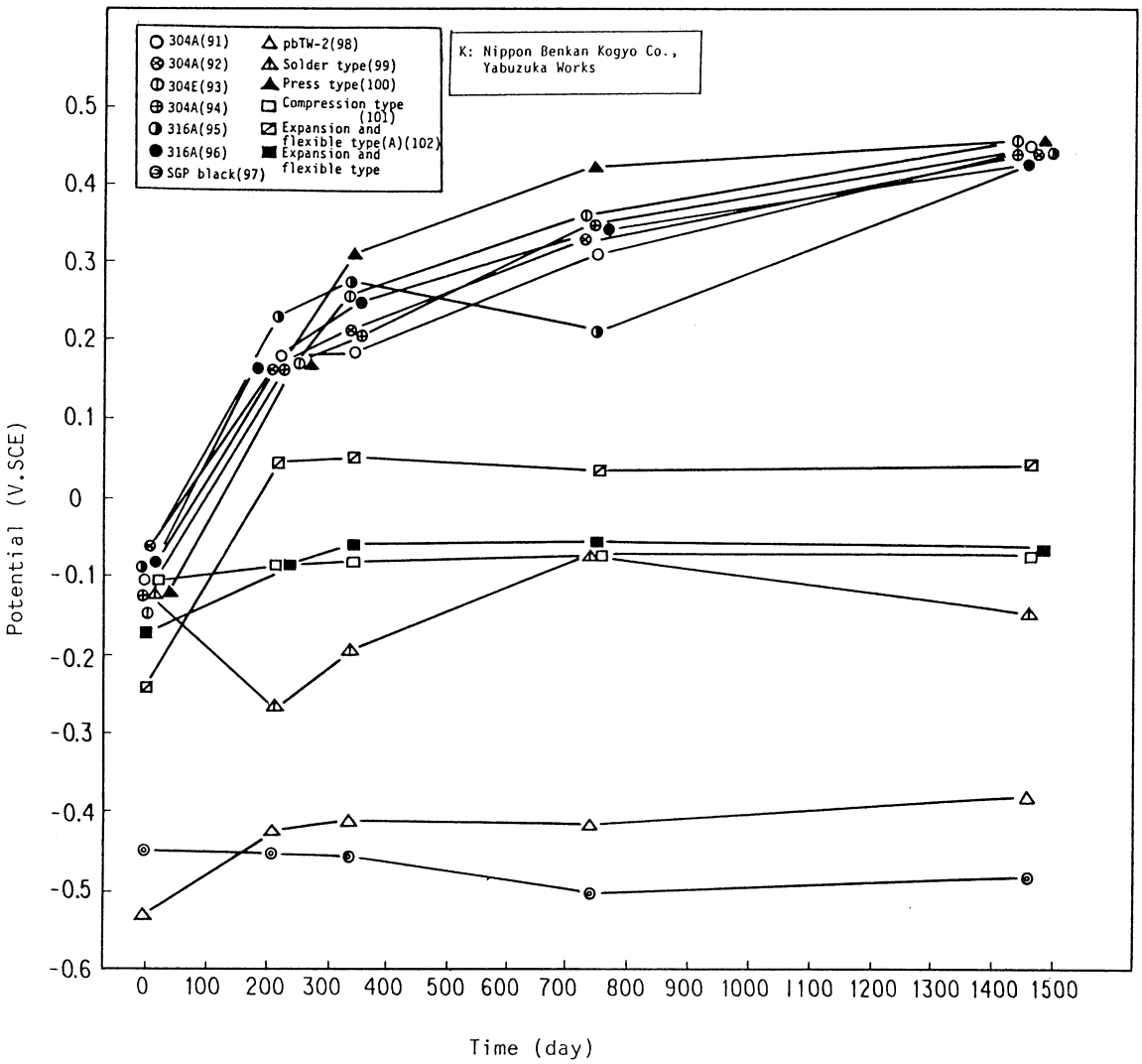


Figure 8.4 Changes in Natural Potential in Yabuzuka (K)

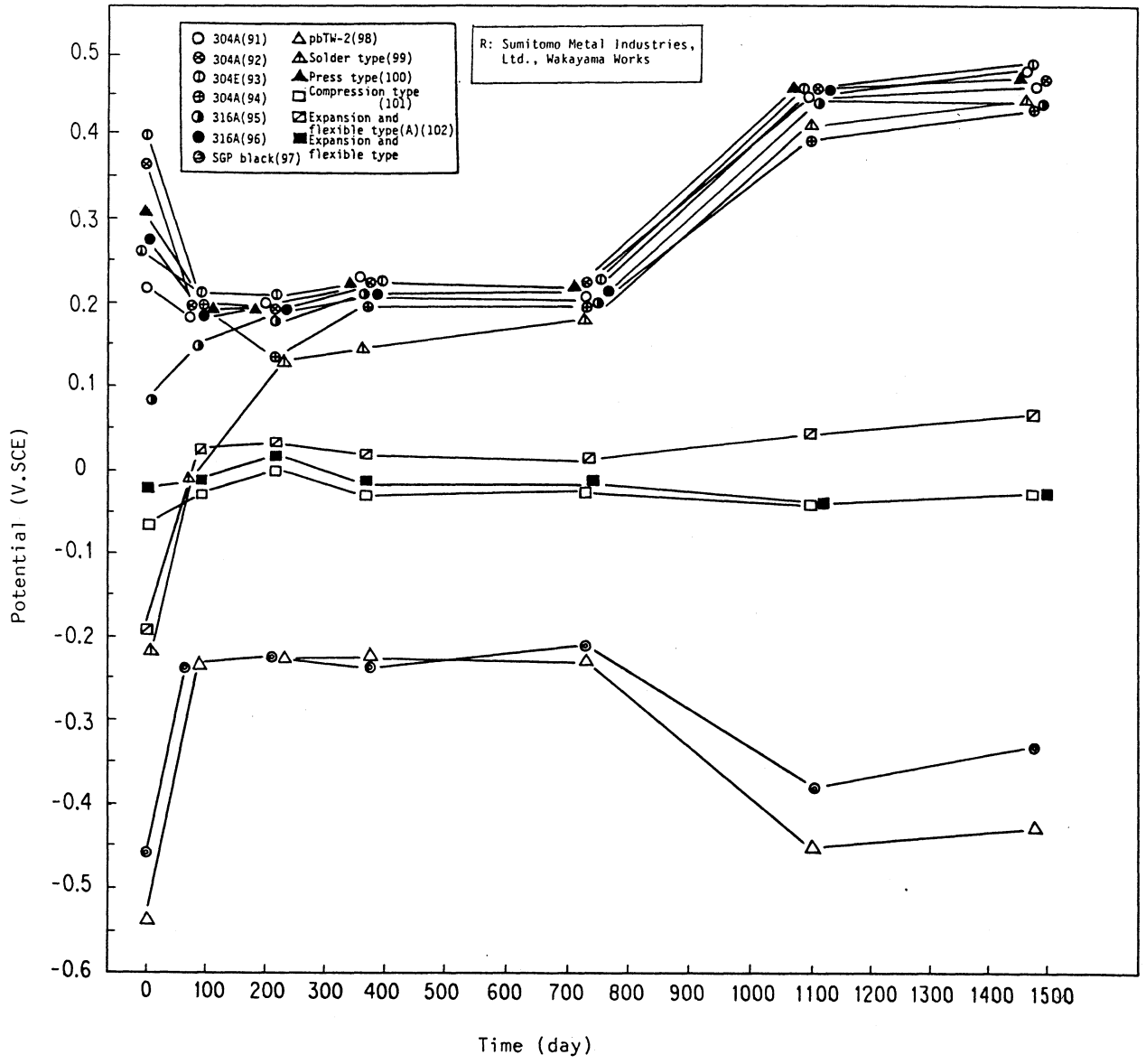


Figure 8.5 Changes in Natural Potential with Time in Wakayama (R)

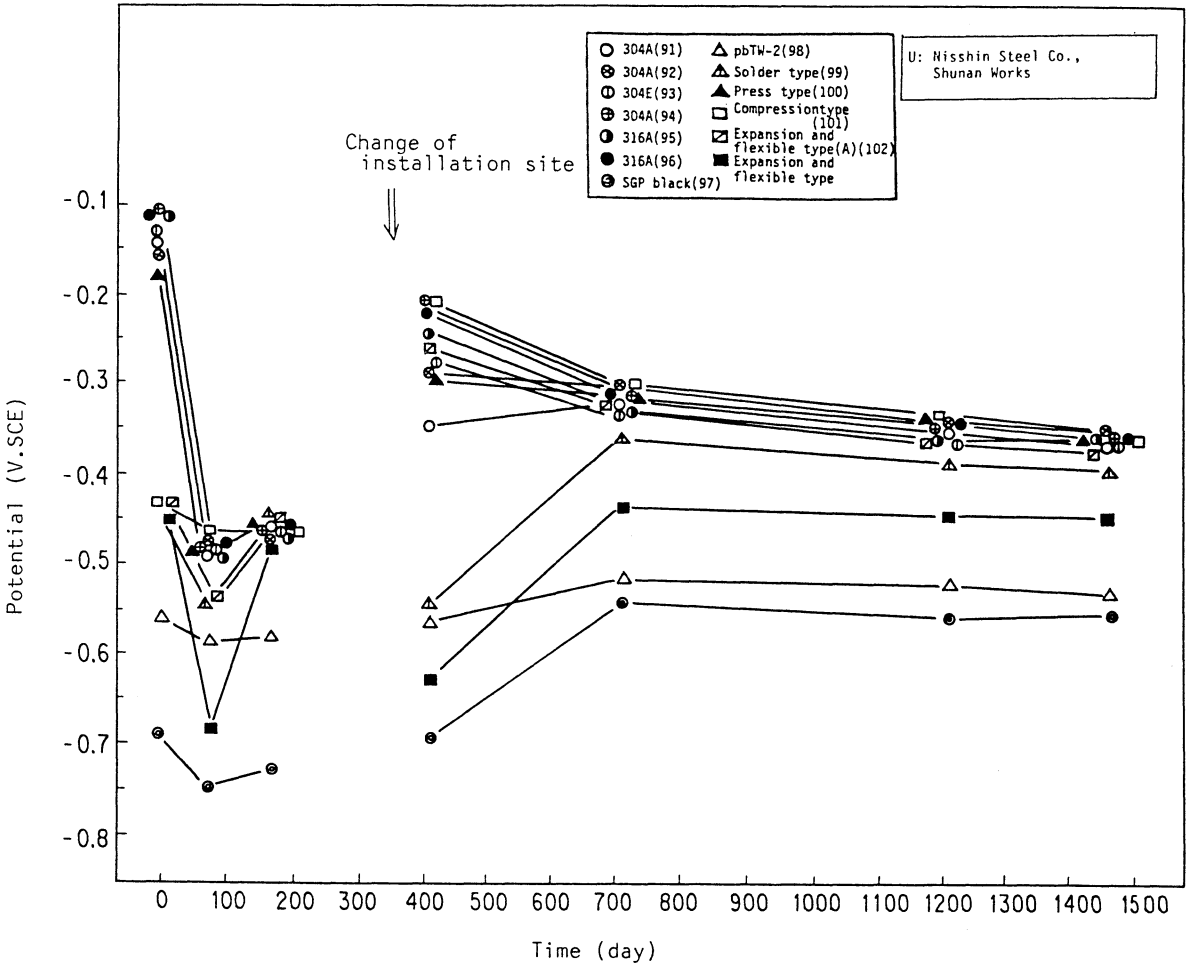


Figure 8.6 Changes in Natural Potential with Time in Shunan (U)

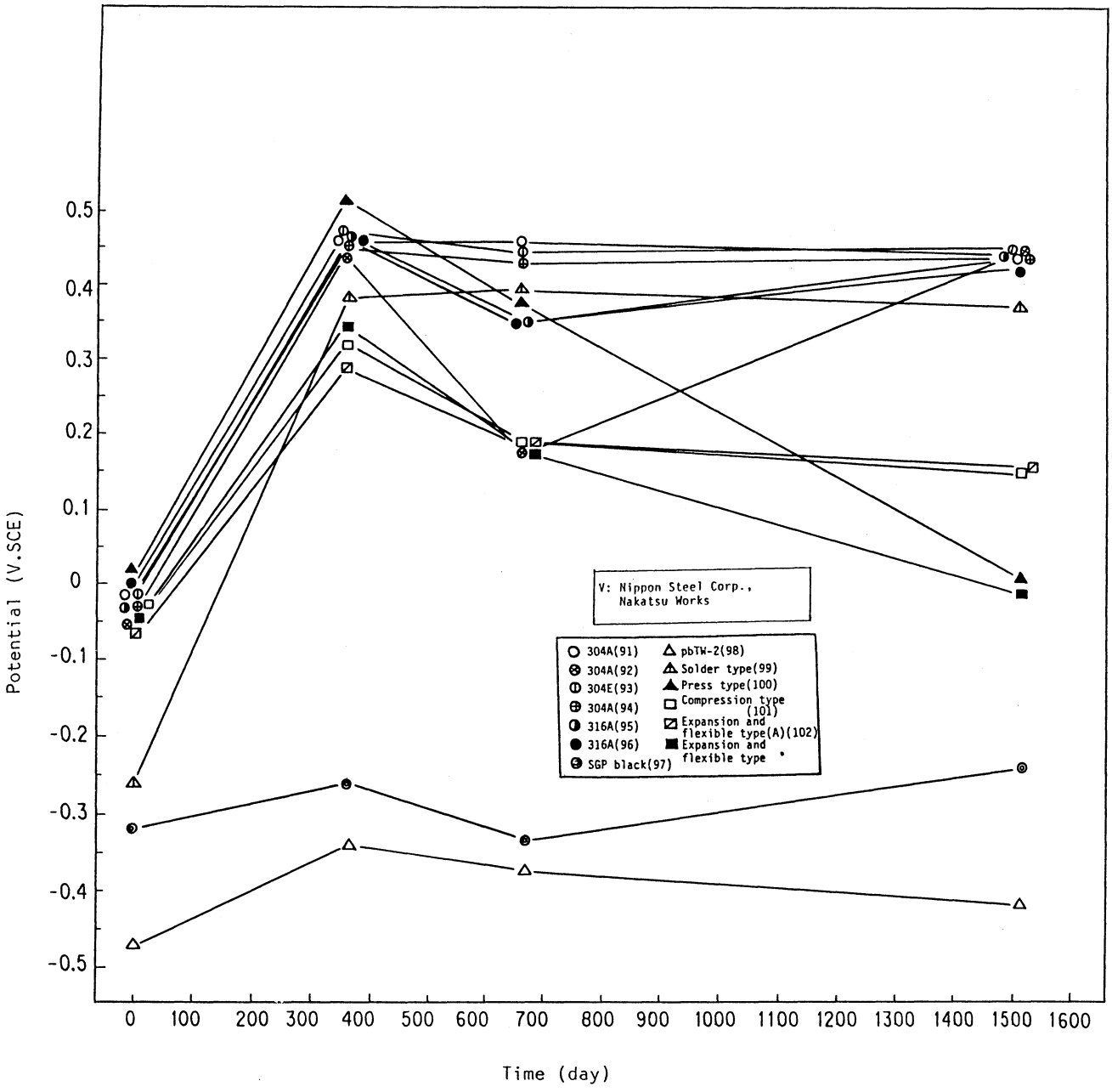


Figure 8.7 Changes in Natural Potential with Time in Nakatsu (V)

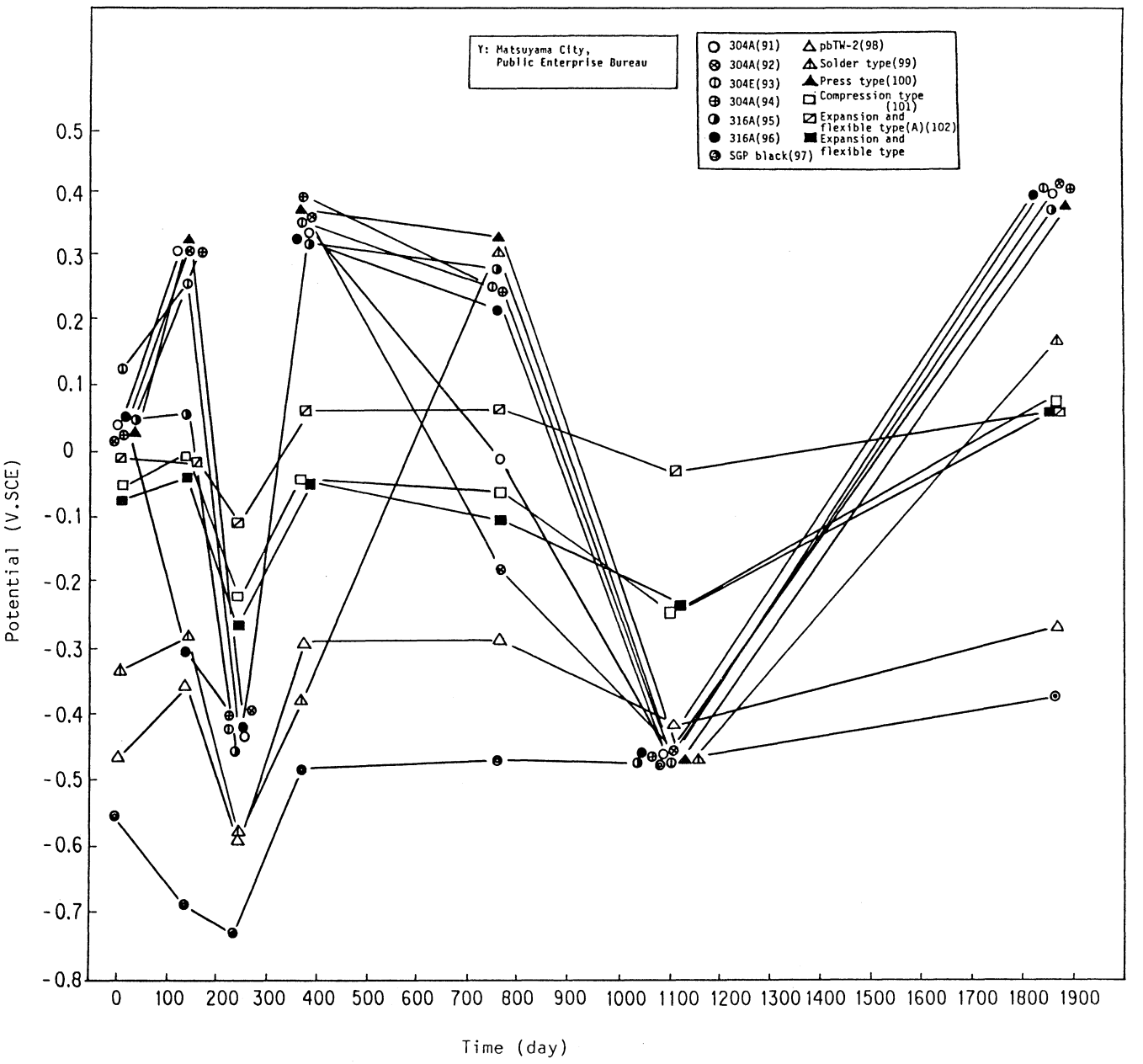


Figure 8.8 Changes in Natural Potential with Time in Matsuyama (Y)

4.3 Special Tests

Pipes of various special construction shown in Table 3, and 430 modified stainless steel pipes, were installed at the Harumi (A) test site. Those pipes were recovered one, three and five years after installation and checked for corrosion. Results of the tests are shown in Table 9, and Table 10 shows the corrosion rate of each special test specimen.

a) Pipes Coupled with Device of Same Metal

Copper pipes developed corrosion products of patina on their entire surfaces irrespective of the time of recovery, and their soldered section was found discolored.

Threads of carbon steel pipes were seriously rusted. No corrosion was observed on welded stainless steel pipes and cast steel fittings.

b) Pipes Coupled with Device of Different Metal

Patina developed on the entire surface of the bronze casting hydrant and the pipe bottom had turned red-brown. The hydrant connected to stainless steel pipe had an attacked area 0.1 to 0.5 mm deep. Lead pipes corroded heavily, developing an attacked area 1 mm or more deep whether or not they were connected to stainless steel pipes.

The carbon steel and ductile cast steel specimens developed serious corrosion on their entire surfaces.

Slight corrosion was observed on the bronze casting hydrant which was connected to stainless steel pipes. Corrosion was not quantitatively determined on the pipes of other metals, however. Surfaces of all stainless steel pipes, connected to the devices or pipes of other metals, were covered with a large amount of soil. Since a similar amount of soil was not observed on the stainless steel pipes which were individually installed, those pipes are considered to have acted as a cathode relative to the specimens of other metals, promoting corrosion on the latter as an anode.

c) Macrocell Pipe Specimens Half-Covered with Concrete

Turning to the macrocell pipe specimens, half of which were covered with concrete, the findings are as follows. In the case of stainless steel pipes, their surfaces were free of corrosion irrespective of concrete covering. On the other hand, bare surfaces of carbon steel pipes developed corrosion extensively while their surfaces covered with concrete were free of any abnormalities.

d) 430 Modified Welded Pipes

No corrosion was noted on the base metal surfaces or welded sections of the pipes of any steel.

Table 9-1 Corrosion Patterns of Special Test Specimens

(After one year)

Installation site: Harumi, Tokyo (A)
Evaluation ○ No corrosion ◎ Coloring, discoloration, or rusting ● Corrosion (erosion)

A: Automatic arc welded pipe
B: Automatic welded pipe

Patina
Corrosion

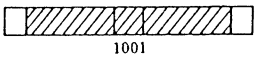
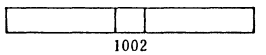
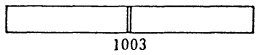
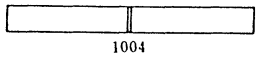
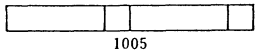
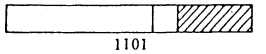
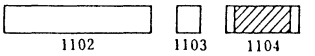
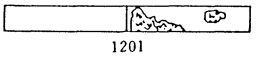
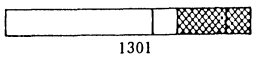
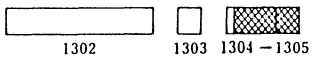
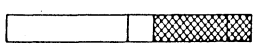
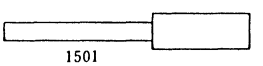
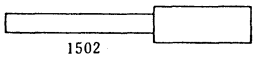
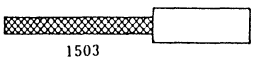
	Specimen	1 year	
Reference	C1220T - H + solder type fitting	 1001	◎ Fitting, ◎ Pipe: Patina on the entire surface; Discolored solder
Reference	SGPW + screw type fitting	 1002	○ Fitting, ○ Pipe: No corrosion; Rusty pipe threads
Reference	304TPD - A + welding	 1003	○ Weld, ○ Pipe: No corrosion
Reference	304TPD - A + welding	 1004	○ Weld, ○ Pipe: No corrosion
Reference	304TPD - A + stainless cast iron fitting	 1005	○ Weld, ○ Pipe: No corrosion
Corrosion resulting from contact with different type of metal	304TPD - A + 304 press type female adapter + BC quick close stop	 1101	○ Pipe: No corrosion despite much accumulation of earth ○ Adapter: No corrosion despite much accumulation of earth ◎ Quick close stop: Patina on the entire surface; lower area turned red-brown
		 1102 1103 1104	○ Pipe: No corrosion ○ Adapter: No corrosion ◎ Quick close stop: lower area turned red-brown
	304TPD-E + PB TW-2	 1201	○ SUS pipe: No corrosion despite much accumulation of earth ● Pb pipe: Serious corrosion (maximum erosion depth, 0.7 mm; maximum pitting size, 80 x 58 mm)
		 1202 1203	○ SUS pipe: No corrosion ● Pb pipe: Serious corrosion (maximum erosion depth, 1.5 mm; maximum pitting size, 21 x 8 mm)
	304TPD-A + 304 press type male adapter + ductile cast iron socket + ductile cast iron plug	 1301	○ SUS pipe: No corrosion despite much accumulation of earth ○ SUS adapter: No corrosion despite much accumulation of earth ●● Cast iron socket and plug: Corrosion on the entire surface
		 1302 1303 1304 – 1305	○ SUS pipe: No corrosion ○ SUS adapter: No corrosion ●● Cast iron socket and plug: Corrosion on the entire surface
	304TPD - A + 304 press type female adapter + SGP black + malleable cap	 1401	○ SUS pipe: No corrosion despite much accumulation of earth ○ SUS adapter: No corrosion despite much accumulation of earth ●● SGP black and cap black: Corrosion on the entire surface
		 1402 1403 1404 1405	○ SUS pipe: No corrosion ○ SUS adapter: No corrosion ●● SGP black cap: Corrosion on the entire surface
Concrete macrocell corrosion test	304TPD - A + concrete	 1501	○ Surface under soil: No corrosion ○ Surface under concrete: Slight coloring at the boundary with soil
Concrete macrocell corrosion test	316TPD - A + concrete	 1502	○ Surface under soil: No corrosion ○ Surface under concrete: Slight coloring at the boundary with soil
Concrete macrocell corrosion test	SGP black + concrete	 1503	● Surface under soil: Corrosion on the entire surface ○ Surface under concrete: No corrosion

Table 9-2 Corrosion Patterns of Special Test Specimens

(After three years)

Installation site: Harumi, Tokyo (A)
○ No corrosion
Evaluation ◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
B: Automatic welded pipe
Patina
Corrosion

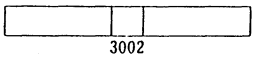
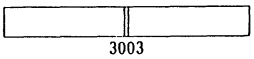
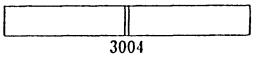
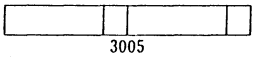
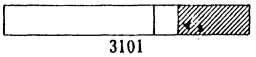
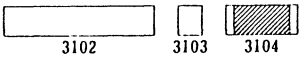
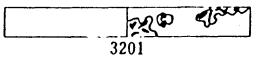
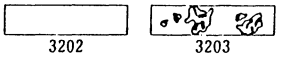
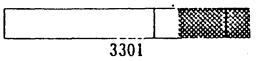
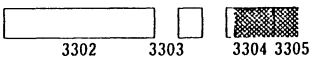
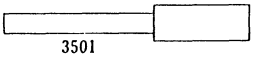
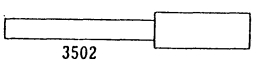
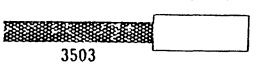
	Specimen	3 years	
Reference	C1220T - H + solder type fitting	 3001	◎ Fitting ◎ Pipe } Patina on the entire surface Discolored solder
	SGPW + screw type fitting	 3002	○ Fitting ◎ Pipe } Light browning on the surface Rusty threads
	304TPD - A + welding	 3003	○ Weld ○ Pipe } No corrosion
	304TPD - A + welding	 3004	○ Weld ○ Pipe } No corrosion
	304TPD - A + stainless cast iron fitting	 3005	○ Fitting ○ Pipe } No corrosion
Corrosion resulting from contact with different type of metal	304TPD - A + 304 press type female adapter + BC quick close stop	 3101	○ Pipe ○ Adapter } No corrosion despite much accumulation of earth ● Quick close stop: Patina on the entire surface; slight corrosion (0.1 mm)
		 3102 3103 3104	○ Pipe ○ Adapter } No corrosion ● Quick close stop: Patina on the entire surface; lower area turned red-brown
	304TPD-E + PB TW-2	 3201	○ SUS pipe: No corrosion despite much accumulation of earth ● Pb pipe: Serious corrosion (0.5 mm)
		 3202 3203	○ SUS pipe: No corrosion ● Pb pipe: Serious corrosion (0.9 mm)
	304TPD-A + 304 press type male adapter + ductile cast iron socket + ductile cast iron plug	 3301	○ SUS pipe ○ SUS adapter } No corrosion despite much accumulation of earth ● Cast iron socket and plug: Serious corrosion on the entire surface
		 3302 3303 3304 3305	○ SUS pipe: Corrosion on the mating surface between pipe inner surface and rubber stopper ○ SUS adapter: No corrosion ●● Cast iron socket and plug: Serious corrosion on the entire surface
	304TPD - A + 304 press type female adapter + SGP black + malleable cap	 3401	○ SUS pipe ○ SUS adapter } No corrosion despite much accumulation of earth ●● SGP black and cap black: Serious corrosion on the entire surface
		 3402 3403 3404 3405	○ SUS pipe ○ SUS adapter } No corrosion ●● SGP black and cap black: Serious corrosion on the entire surface
Concrete macrocell corrosion test	304TPD - A + concrete	 3501	○ Surface under soil: No corrosion ◎ Surface under concrete: Slight coloring at the boundary with soil
	316TPD - A + concrete	 3502	○ Surface under soil: No corrosion ◎ Surface under concrete: Slight coloring at the boundary with soil
	SGP black + concrete	 3503	● Surface under soil: Corrosion on the entire surface ○ Surface under concrete: No corrosion

Table 9-3 Corrosion Patterns of Special Test Specimens

(After five years)

Installation site: Harumi, Tokyo (A)

Evaluation ○ No corrosion
◎ Coloring, discoloration, or rusting
● Corrosion (erosion)

A: Automatic arc welded pipe
B: Automatic welded pipe

Patina
Corrosion

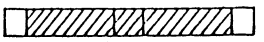
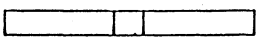
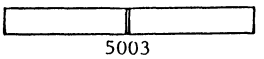
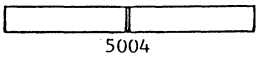
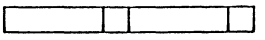
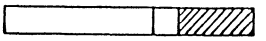
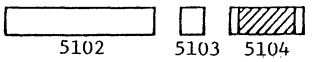
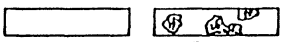
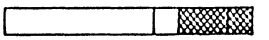
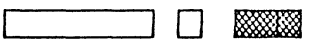
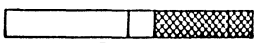
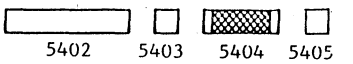
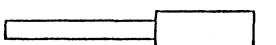
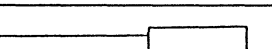
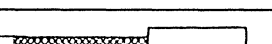
	Specimen	5 years	
Reference	C1220T - H + solder type fitting	 5001	● Fitting: Corroded or peeled solder ◎ Pipe: Patina on the entire surface
	SGPW + screw type fitting	 5002	○ Fitting: ◎ Pipe: Rusty threads
	304TPD - A + welding	 5003	○ Weld ○ Pipe } No corrosion
	304TPD - A + welding	 5004	○ Weld ○ Pipe } No corrosion
	304TPD - A + stainless cast iron fitting	 5005	○ Fitting ○ Pipe } No corrosion
Corrosion resulting from contact with different type of metal	304TPD - A + 304 press type female adapter + BC quick close stop	 5101	○ Pipe ○ Adapter } No corrosion despite much accumulation of earth ● Quick close stop: Patina on the entire surface and pittings (maximum erosion depth, 0.5 mm)
		 5102 5103 5104	○ Pipe ○ Adapter } No corrosion ◎ Quick close stop: Patina on the entire surface
	304TPD-E + PB TW-2	 5201	○ SUS pipe: No corrosion despite much accumulation of earth ● Pb pipe: Serious local corrosion (max. erosion depth, 1.3 mm)
		 5202 5203	○ SUS pipe: No corrosion ● Pb pipe: Serious local corrosion (max. erosion depth, 1.3 mm)
	304TPD-A + 304 press type male adapter + ductile cast iron socket + ductile cast iron plug	 5301	○ SUS pipe ○ SUS adapter } No corrosion despite much accumulation of earth ● Cast iron socket and plug: Serious corrosion on the entire surface
		 5302 5303 5304 5305	○ SUS pipe ○ SUS adapter } No corrosion ● Cast iron socket and plug: Serious corrosion on the entire surface
	304TPD - A + 304 press type female adapter + SGP black + malleable cap	 5401	○ SUS pipe ○ SUS adapter } No corrosion ●● Cast iron socket and plug: Serious corrosion on the entire surface
		 5402 5403 5404 5405	○ SUS pipe ○ SUS adapter } No corrosion ● SPG black: Serious corrosion on the entire surface
Concrete macrocell corrosion test	304TPD - A + concrete	 5501	○ Surface under soil: No corrosion ◎ Surface under concrete: Slight coloring at the boundary with soil
	316TPD - A + concrete	 5502	○ Surface under soil: No corrosion ◎ Surface under concrete: Slight coloring at the boundary with soil
	SGP black + concrete	 5503	● Surface under soil: Serious corrosion ○ Surface under concrete: No corrosion

Table 10 Corrosion Rate of Special Specimens

Installation site : Harumi, Tokyo (A)
Evaluation : ○ No corrosion
● Corrosion

Type of steel	1 year		3 years		5 years	
	Corrosion rate (mdd)	Presence or absence of corrosion	Corrosion rate (mdd)	Presence or absence of corrosion	Corrosion rate (mdd)	Presence or absence of corrosion
18 Cr-0.5 Mo	0.00	○	0.00	○	0.00	No corrosion ○
18 Cr-0.5 Mo	0.00	○	0.00	○	0.00	○
	0.00	○	0.00	○	0.00	○
18 Cr-2 Mo	0.00	○	0.00	○	0.00	○
	0.00	○	0.00	○	0.00	○
	0.00	○	0.00	○	0.00	Slight erosion (1 mm in diam.; 0.02 mm deep) in the soldered section ●
	0.00	○	0.00	○	0.00	No corrosion ○
	0.00	○	0.00	○	0.00	○
18 Cr-Ti or Nb	0.00	○	0.00	○	0.00	Slight erosion (2 x 5 mm; 0.02 mm deep) in the area of weld scale ●
	0.00	○	0.00	○	0.00	No corrosion ○
	0.00	○	0.00	○	0.00	○
	0.00	○	0:00	○	0.00	○
	0.00	○	0.00	○	0.00	○
SUS 304	0.00	○	0.00	○	0.00	○
SUS 316	0.00	○	0.00	○	0.00	○

5. Conclusion

Stainless steel and other pipes used for city water supply were subjected to the five-year underground installation test at 25 sites throughout the country. The results obtained are summarized below.

1) SUS304 stainless steel pipes which were horizontally installed did not develop pitting corrosion or any other degradation at many test sites. Generally speaking, they exhibited excellent corrosion resistance although their surfaces were slightly discolored. Crevice corrosion was noted, however, underneath the vinyl tape wrapper at the test sites in an oceanic climate.
2) Horizontally installed SUS316 stainless steel pipes were almost free of discoloration or corrosion at all sites except one in Okinawa, showing its superiority to SUS304 pipes.
3) Potential of the above stainless steel pipes ranged widely, from +0.50 to -0.45 V (SCE), depending on soil conditions and other environmental factors.
4) Pitting corrosion was noted on the lower part of vertically installed SUS304 stainless steel pipe at several test sites. The incidence of corrosion was higher for the pipes installed in undisturbed soil than for those in disturbed soil.
5) Copper alloy casting fittings or solder type fittings frequently corrode. In contrast, stainless steel press type fittings have excellent corrosion resistance.
6) The average corrosion rates of carbon steel and lead are 0.019 and 0.002 mm/y, respectively. Their maximum corrosion rates are five to six times as high as their average rates. On the other hand, the corrosion rate is nil for SUS304 and SUS316 stainless steels.
7) SUS430 modified ferritic stainless steel has corrosion resistance comparable with that of SUS304 and SUS316 stainless steels.

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