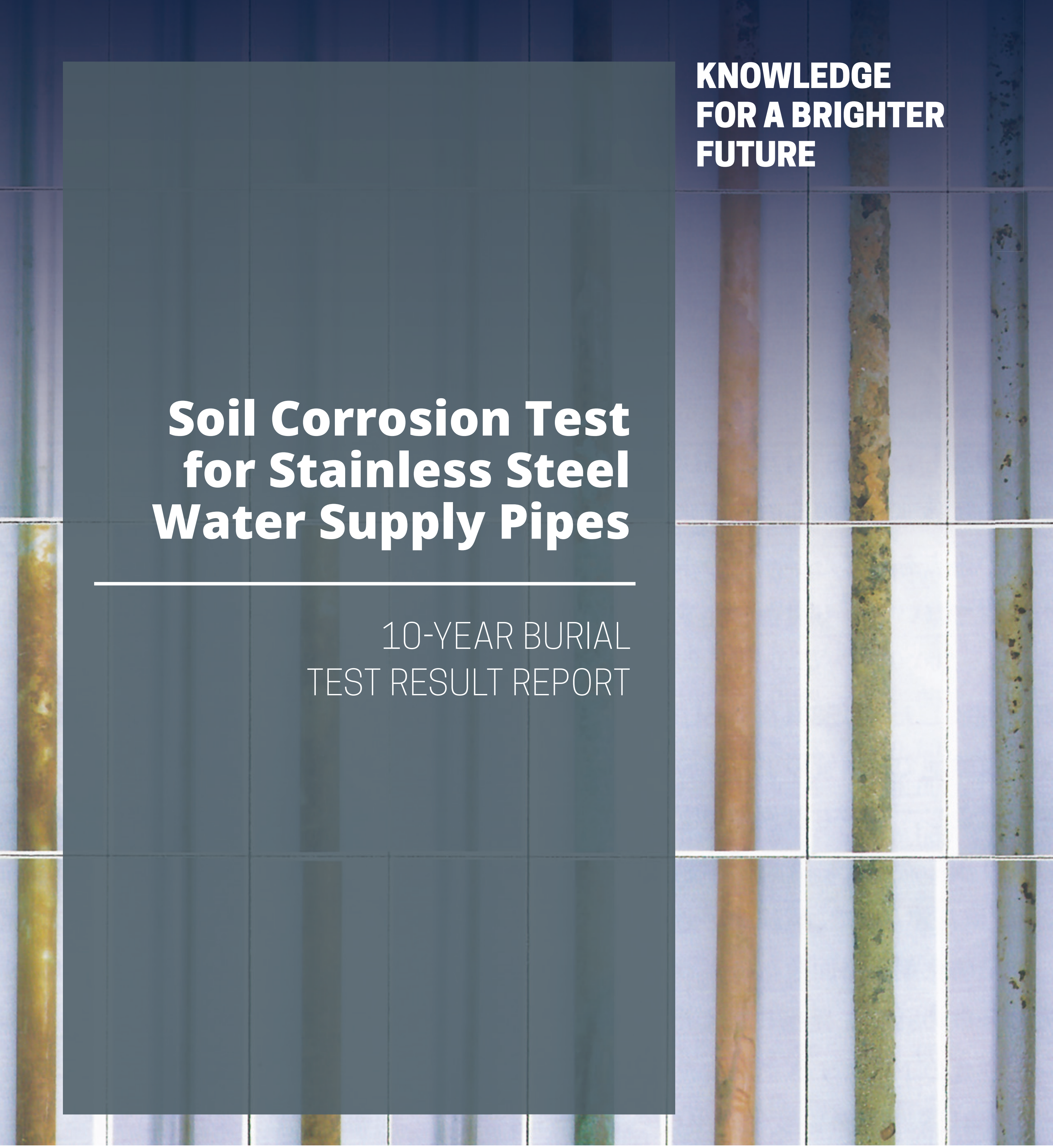

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Soil Corrosion Test for Stainless Steel Water Supply Pipes

10-YEAR BURIAL
TEST RESULT REPORT

Nickel INSTITUTE
knowledge for a brighter future

Soil Corrosion Test for Stainless Steel Water Supply Pipes

VOLUME 3: 10-YEAR BURIAL TEST RESULT REPORT

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5-year test results were published in English in 1988 in 2 volumes under the title *A Report on the Performance of Stainless Steel Pipe for Water Supply in Underground Soil Environments*. Both are available from the Nickel Institute website. Volume 1 contains the extensive data from the report while Volume 2 contains the colour photographs with captions from the 5 year tests. In addition to stainless steels, there is data in all 3 volumes on carbon steel, copper, and lead pipes. As a result of this study, stainless steel Type 316 service water systems are being used extensively in many Japanese cities.

The Nickel Institute decided that the 10-year results should be available in English in order for them to be available to a wider audience.

Soil Corrosion Test for Stainless Steel Water Supply Pipes

10-Year Burial Test Result Report

1. INTRODUCTION

There is a significant amount of corrosion resistance data on carbon steel or cast-iron pipes used as water or gas supply pipes buried in soil. For stainless steel pipes that can replace these pipes, however, the amount of corrosion behaviour/resistance data in soil is very limited, other than a test report[1]) provided by the U.S. National Bureau of Standards (NBS). Furthermore, as the data from NBS was obtained in a U.S.-specific soil environment, it is not adequate for use as a reference for pipe laying in the Japanese soil environment, which has different characteristics from those of the U.S.

In order to evaluate the corrosion resistance of stainless steel water supply pipes in the soils of various regions in Japan, the Japan Stainless Steel Association established the Soil Corrosion Test Committee for Stainless Steel Water Supply Pipes, which carried out soil corrosion testing for five years starting in FY1979 by burying pipes including several types of stainless steel pipes and those connected by several types of couplings, as well as carbon steel pipes, lead pipes, and copper pipes for comparison, at 25 test sites across Japan. The committee then recognised the necessity of additional testing with extended burial time, and carried out long-term burial tests (excluding some test items) for 10 years starting in FY1980 at 12 test sites.

As the test results of 1-year, 3-year, and 5-year burial periods were reported in the previous report [2]), we describe the test results obtained from sample pipes buried at test sites for 10 years in this report.

Table 1 Burial Sites and Burial/Excavation Dates

Symbol	Burial Site	Address	Burial Date	Excavation Date
D	Misono water purification plant, Bureau of Waterworks Tokyo Metropolitan Government	2-10-1 Misono, Itabashi-ku, Tokyo	Dec. 11, 1980	Cancelled
H	Kushiro Waterworks Department	67 Toritoushi, Kushiro-mura, Kushiro-gun, Hokkaido	Sep. 26, 1980	Oct. 3, 1990
I	Aomori Waterworks Department	Harabetsu Water Distribution Station 14 Yadamaemotoizumi, Aomori City, Aomori Pref.	Sep. 24, 1980	Sep. 13, 1990
J	Nihon Stainless Steel, Ltd.	10-29 Kawara-machi, Joetsu City, Niigata Pref.	Dec. 11, 1980	Nov. 2, 1990
K	BENKAN Corporation, Molco Division, Yabuzuka Plant	5 Rokusengoku-Higashiura, Yabuzuka-honmachi, Nitta-gun, Gunma Pref.	Dec. 13, 1980	Nov. 16, 1990
P	Hitachi Metals, Ltd., Kuwana Works	200 Obuke, Asahi-cho, Mie-gun, Mie Pref.	Dec. 20, 1980	Mar. 22, 1991
R	Sumitomo Metal Industries, Ltd., Wakayama Works	1850 Minato, Wakayama City, Wakayama Pref.	Jan. 8, 1981	Feb. 1, 1991

U	Nisshin Steel Co., Ltd., Shunan Works	4976 Tonda, Shin-nanyou City, Yamaguchi Pref.	Dec. 23, 1980	Feb. 22, 1991
V	Shin-Nippon Steel Corporation, Yahata Works, Nakatsu Plant	332 Higashihama, Nakatsu City, Oita Pref.	Dec. 18, 1980	Apr. 24, 1991
W	Okinawa Pref. Misato Industrial High School	1629 Awase, Okinawa City, Okinawa Pref.	Oct. 6, 1980	Cancelled
X	Okinawa Pref. Nanbu Industrial High School	1240 Tomori, Kochinda-cho, Okinawa Pref.	Oct. 7, 1980	Nov. 21, 1990
Y	Matsuyama City Local Public Enterprise Division	4-7-2 Niban-cho, Matsuyama City, Ehime Pref.	Oct. 2, 1980	Sep. 27, 1990

2. TEST SPECIFICATIONS

2.1 Test sites

Sites where sample pipes were buried are as shown in *Table 1* (12 sites). Of these sites, tests at Misono (D) and Okinawa Misato (W) were cancelled during testing due to reasons specific to the burial sites. At each burial site, an area next to the 5-year burial test area was selected as the test area.

2.2 Sample pipes

304 and 316 stainless steel pipes (length: 500 mm, diameter: 25Su), as well as 304 stainless steel pipes connected by five types of couplings, were used as sample pipes. For comparison, carbon steel pipes and water supply lead pipes with the same dimensions were also tested. Sample pipes were buried at a depth of 1.0 to 1.5 m side by side. Furthermore, 304 and 316 stainless steel pipes, carbon steel pipes for piping, and seamless phosphorus-deoxidised copper pipes (length: 1,800 mm) were buried vertically with one end protruding approx. 300 mm from the ground. For weight measurement, 304 and 316 stainless steel, carbon steel, and lead short pipes were used.

The types and dimensions of these sample pipes are listed in *Table 2*.

Table 2 Sample Pipe Types and Dimensions

(1) Stainless steel pipes

Pipe Types	Standards	Dimensions (mm)
SUS 304 TPD-A	JIS G 3448	25Su (28.58ø x 1.0t) x 500*l*, 1,800*l*
SUS 304 TPD-E	JIS G 3448	25Su (28.58ø x 1.0t) x 500*l*
SUS 316 TPD-A	JIS G 3448	25Su (28.58ø x 1.0t) x 500*l*, 1,800*l*

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

(2) Stainless steel pipes with couplings

		Pipes	
Couplings	**Standards**	**Types**	**Dimensions (mm)**
Solder-type	JWWA G 116	SUS 304 TPD-E	25Su (28.58ø x 1.0t) x 250*l*
Press-type	JWWA G 116	SUS 304 TPD-A	25Su (28.58ø x 1.0t) x 250*l*
Compression-type	JWWA G 116	SUS 304 TPD-E	25Su (28.58ø x 1.0t) x 250*l*
Expansion flexible (A)	JWWA G 116	SUS 304 TPD-E	25Su (28.58ø x 1.0t) x 250*l*
Expansion flexible (B)	—	SUS 304 TPD-A	25Su (28.58ø x 1.0t) x 250*l*

(3) Comparison pipes		
Comparison materials	**Standards**	**Dimensions (mm)**
SGP black (Carbon steel pipes for piping)	JIS G 3452	20A (27.2ø x 2.8t) x 500*l*, 1,800*l*
PbTW-b (Lead pipes for water supply)	JIS H 4312	28.4ø X4 .2tX500*l*
C1220T-H (M) (Seamless phosphorus-deoxidised copper pipes)	JIS H 3300	28. 58ø X 0.89tX 1,800*l*

(4) Weight-measurable pipes	
Pipe types	**Dimensions (mm)**
SUS 304 TPD-A	25Su (28.58ø x 1.0t) x 130*l*
SUS 316 TPD-A	25Su (28.58ø x 1.0t) x 130*l*
SGP black	15A (21.7ø x 2.8l) x 70*l*
PbTW-2	16.2 ø x 3.1l x 60*l*

Table 3 Chemical Analysis Values of Soil Upper side: When buried Lower side: When excavated

Burial Site	Water Content (%)	pH	Organic Matter Content (%)	Water-soluble Compositions (mg/kg) *epm										
				Cl-	SO_4^{2-}	HCO_3^-	NO_3^-	M-alkalinity	H_2S	Sulfides	Ca^{2+}	Mg^{2+}	Na-	K-
Kushiro (H)	875.2 88.8	4.3 4.4	4.0 79.6	58.0 60.7	2240 4130	- -	0.6 9.3	0.53 0.35	<0.1 <0.1	<0.1 <0.1	591 1140	86 267	60 224	- 9.4
Aomori (I)	39.8 28.4	5.2 5.4	1.6 1.9	4.1 4.0	37.7 92.0	- -	<1 <1	0.07 0.02	<0.1 <0.1	- -	6 10	2 5	2 13	-
Naoetsu (J)	24 22	7.1 6.5	0.4 0.4	8 10	36 6	44 47	22 8	0.6 0.2	<1 <1	<1.0 <1.0	8 1	6 1	23 5	3 <1
Yabuzuka (K)	44.8 32.3	5.4 6.5	2.1 -	15.6 18	- 44	- 3.4	115 7.8	0.2 0.17	<0.03 <0.2	<0.03 <0.2	34.4 15.2	5.3 1.2	8.3 10.4	- -
Kuwana (P)	39.8 28.5	6.9 6.3	- -	24 3.1	80 6.3	6.0 3.7	0 1.9	15 14	- <0.1	0 0.6	12 0.2	7.4 3.9	22 11	- -
Wakayama (R)	- 6.8	8.3 8.5	- -	7.2 4.0	28.8 32.6	2.9 28.2	2.1 -	39 38	- -	<0.5 <0.4	62.5 47.0	2.6 5.0	9.0 2.2	7.5 2.2
Shunan (U)	21.7 15.1	6.8 7.2	- -	28.9 4.2	28.0 0.8	1218 30	0.5 88.0	0.1 0.8	0.3 -	0.3 -	13.3 24.0	1.7 4.0	5.6 6.0	4.3 6.0
Nakatsu (V)	5.6 7.8	6.9 7.4	- -	2.4 8.9	4.1 4.3	6.2 22.4	1.4 4.6	11.8 33.0	0 <0.02	0 <0.02	4.9 19.6	1.2 4.1	2.1 1.7	1.3 1.7
Okinawa (X)	52.1 28.6	7.4 8.0	- -	50 44	872 240	- 101	- 1.9	- 8.1	- <0.2	- <0.2	32.5 126	127 24	87 22	- -
Matsuyama (Y)	20.0 9.5	6.9 7.9	- -	36.0 7.8	51.9 0.6	tr 152	529 78	0.4 3.3	0.8 -	0.7 -	11.5 80.0	3.7 6.0	7.0 6.0	1.3 <4.0

2.3 Test methods

The methods of sample pipe creation and burial, the soil environment survey, pipe appearance observation, corrosion amount measurement, and potential measurement are all the same as those described in the previous report[2]).

3. TEST RESULTS

3.1 Soil survey

Chemical analysis was performed on soil samples obtained from 10 test sites. Soil resistivity and oxidation-reduction potential measurements were also performed at each test site.

3.1.1 Chemical analysis values of soil

Table 3 shows the chemical analysis values of soil obtained when sample pipes were buried and excavated from the ground after 10 years.

Although the water content changed slightly over time, it became no more than 20% in Wakayama (R), Shunan (U), Nakatsu (V), and Matsuyama (Y). On the other hand, in the moor in Kushiro (H), it was very high.

At most test sites, pH values were 6 to 8 (almost neutral), other than those in Aomori (I) and Kushiro (H), which were less than 6 and indicate mild acidity.

Of water-soluble compositions, concentrations of Cl- and SO_4^{2-}, which have a significant correlation with corrosiveness, were high in Kushiro (H) and Okinawa (X). At other sites, concentrations of Cl- and SO_4^{2-} were less than 25 mg/kg and 100 mg/kg, respectively. Sulfides were hardly detected at any site.

3.1.2 Soil resistivity and oxidation-reduction potentials

The soil resistivity and oxidation-reduction potentials measured when sample pipes were buried and excavated from the ground are shown in *Table 4*.

Soil resistivity is used as a scale to determine soil corrosiveness to steel. Soils in Aomori (I), Naoetsu (J), Kuwana (P) and Okinawa (X) indicated 5,000 Ω•cm or less of resistivity. In particular, it was very low in Okinawa, which means that soil has strong corrosiveness.

The soil oxidation-reduction potentials measured at most test sites were 100 mVNHE or more, which indicates that the soil environment at these test sites is aerobic.

3.2 Corrosion status of sample pipes

Ten years after the burial of 168 pipes in total including 304 and 316 stainless steel pipes, 304 stainless steel pipes connected by five types of couplings, as well as carbon steel, lead, and copper pipes for comparison, they were excavated and their corrosion status was investigated.

Table 4 Soil Oxidation-reduction Potential and Resistivity

Test Sites	Measurement Points	Oxidation-reduction Potential (mV, NHE)		Resistivity (Ω•m)	
		When buried	When excavated	When buried	When excavated
Kushiro (H)	a	73	299	19,500	8,500
	b	55	294	15,500	6,300
	c	66	294	18,000	8,000
Aomori (I)	a	69	211	3,100	4,000
	b	39	66	2,800	4,400
	c	79	106	3,000	4,000
Naoetsu (J)	a	335	507	1,600	4,000
	b	335	527	1,600	4,600
	c	335	417	1,400	7,000
Yabuzuka (K)	a	463	135	7,000	23,500
	b	441	143	7,000	34,000
	c	510	151	6,900	30,000
Kuwana (P)	a	127	235	2,550	4,800
	b	168	275	2,400	3,300
	c	262	310	2,500	2,900
Wakayama (R)	a	355	448	44,000	73,000
	b	375	458	32,000	55,000
	c	345	454	33,000	48,000
Shunan (U)	a	395	389	14,000	18,000
	b	344	334	16,000	16,000
	c	356	331	14,000	12,000
Nakatsu (V)	a	230	280	340,000	170,000
	b	230	220	240,000	91,000
	c	180	160	180,000	180,000
Okinawa (X)	a	65	170	5,700	950
	b	80	228	6,300	900
	c	70	245	6,900	900
Matsuyama (Y)	a	550	557	4,400	5,100
	b	544	589	8,400	5,200
	c	495	594	4,200	7,600

Table 5 Corrosion Status of Sample Pipes

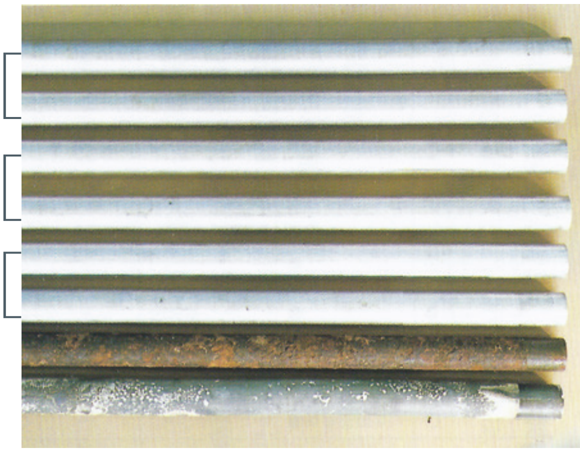
Evaluation:
□: Not corroded
⊡: Staining, discoloration, rusting
■: Corroded (eroded)

Sample pipes			Burial Sites									
			Kushiro H	Aomori I	Naoetsu J	Yabuzuka K	Kuwana P	Wakayama R	Shunan U	Nakatsu V	Okinawa X	Matsuyama Y
Horizontally buried pipes	304 A		□ □	□ Partially □ brown	⊡ Brownish-red ⊡ (lower part)	□ □	□ Partially □ brown	⊡ Brownish-red ⊡ spots	□ □	□ □	⊡ Partially ⊡ brown	□ □
	304 E		□ □	□ Partially □ brown	⊡ Brownish-red ⊡ (lower part)	□ Rusting ⊡ under tape	□ Partially □ brown	⊡ Brownish-red ⊡ spots	□ □	□ □	⊡ Partially ⊡ brown	□ □
	316-A		□ □	□ Partially □ brown	⊡ Brownish-red ⊡ (lower part)	□ □	□ Partially □ brown	⊡ Brownish-red ⊡ spots	□ □	□ □	⊡ Partially ⊡ brown	□ □
	Carbon steel		■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion Max. 1 mm	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion Max. 1.5 mm
	Lead		■ Gray, Slight pitting	■ Gray, White spots	⊡ Gray, White spots	⊡ White	■ White	⊡ Brownish-red	■ White, Black spots	⊡ ¹Slight pitting	■ Gray, Pitting	■ Gray, Some pitting
Pipes (P) with couplings (C)	Solder-type	P	□	□	⊡ Brown	□	□	□	□	■	⊡ Under tape	□
		C	⊡ Gray (solder part)	⊡	■ Minor corrosion	⊡ Rusting (solder part)	⊡ Gray (solder part)	⊡ Gray (solder part)	⊡ Black discoloration on solder part	■ Pitting on solder part	□	■ Solder part corrosion
	Press-type	P	□	□	⊡ Brownish-red	□	□	□	□	□	⊡	□
		C	□	□	⊡ Brownish-red	□	□	□	□	□	□	□
	Compres-sion-type	P	□	□	⊡ Brownish-red	□	□	□	□	□	⊡	□
		C	⊡ Blackish brown	⊡ Blackish brown	⊡ Brownish-red, patina	■ Local corrosion	⊡ Brown	⊡ Patina	⊡ Nut discolouration	⊡ Patina	■ Insertion part corrosion	■ Patina, pitting
	Flexible (A)	P	□	□	⊡ Brownish-red	□	□	□	□	□	■ Connected part corrosion	□
		C	⊡ Blackish brown	⊡ Blackish brown	⊡ Brownish-red, patina	■ Local corrosion	⊡ Brown	⊡ Patina	⊡ Nut discolouration	⊡ Patina	⊡	■ Patina, pitting
	Flexible (B)	P	□	□	⊡ Brownish-red	■ Connected part corrosion	⊡ Brown (connected part)	□	□	□	■ Connected part corrosion	□
		C	■ Overall surface corrosion	⊡ Blackish brown	⊡ Brownish-red, patina	■ Local corrosion	⊡ Local corrosion	⊡ Patina	⊡ Nut discolouration	⊡ Patina	■	■ Patina, pitting
Vertically buried pipes	304 A		□ Partially brown	⊡ Brownish-red (lower part)	■ Brownish-red (lower part), Pitting (surface layer)	□	⊡ Brownish-red (lower part)	⊡ Partially brownish-red	⊡ Brownish-red (lower part)	□	■ Brown (lower part), Corrosion under tape	⊡ Staining (center part)
	316-A		□	⊡ Slightly brownish-red (lower part)	■ Brownish-red (lower part), Pitting (surface layer)	□	Could not be obtained	⊡ Partially brownish-red	⊡ Brownish-red (lower part)	□	Could not be obtained	⊡ Staining (center, lower part)
	Copper		■ Minor corrosion	■ Overall surface corrosion	■ Minor corrosion	⊡ Patina	■ Overall surface corrosion	⊡ Blackish brown, Patina (partial surface)	■ Patina	⊡ Patina	■ Patina (overall surface)	■ Patina (overall surface)
	Carbon steel		■ Overall surface corrosion, 3 through-holes	■ Overall surface corrosion	■ Overall surface corrosion Max. 2 mm	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion	■ Overall surface corrosion

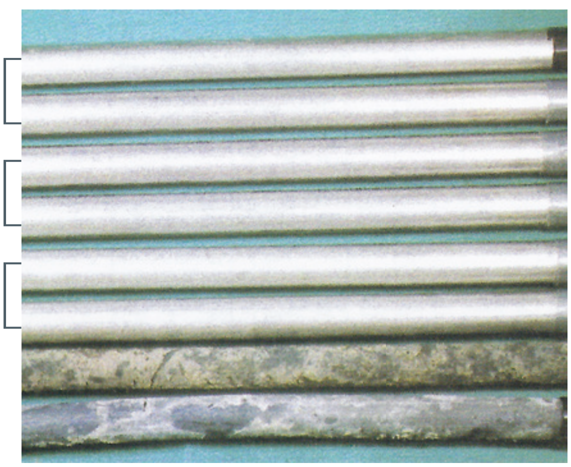
Photo 1 Appearance of Horizontally Buried Pipes

Kushiro (H) test site (after pickling)

Aomori (I) test site (after water washing)



Kuwana (P) test site (after pickling)



Okinawa (X) test site (after water washing)

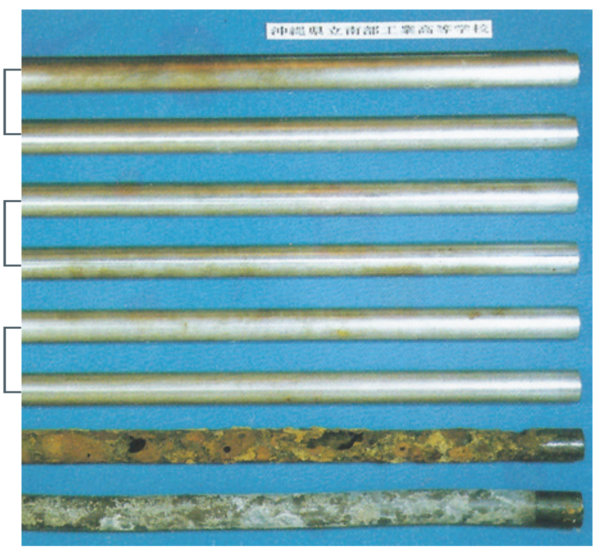
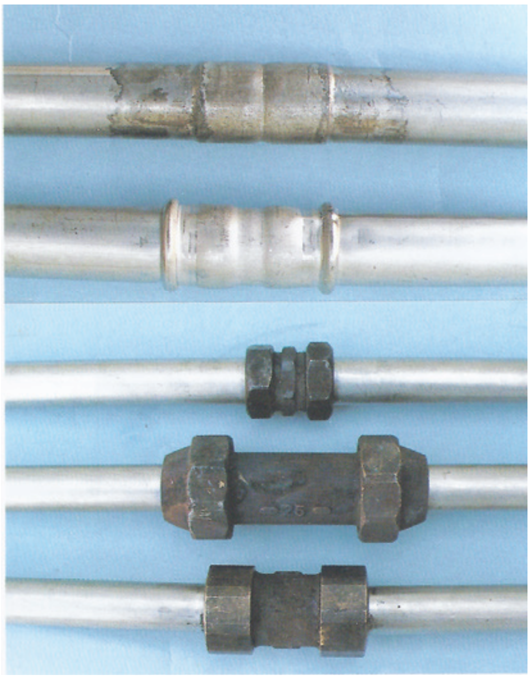
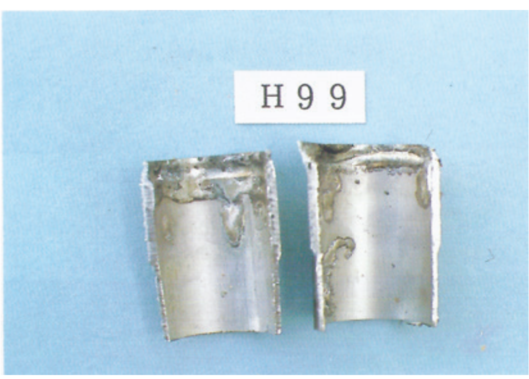


Photo 2 Appearance of Pipes with Couplings (Kushiro (H) Test Site)

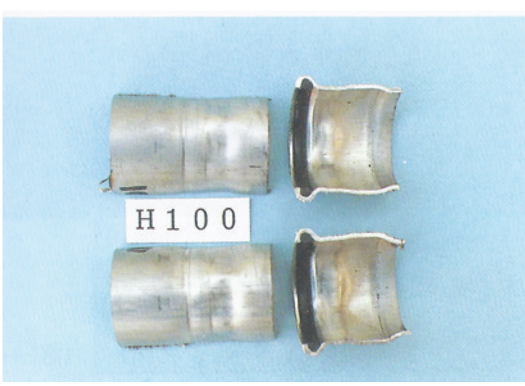
(1) Appearance (after pickling)



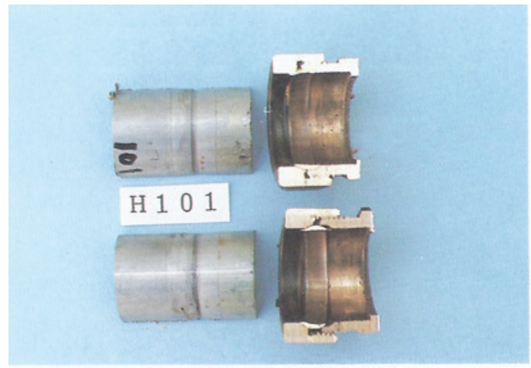
(2) Solder-type coupling (after pickling)



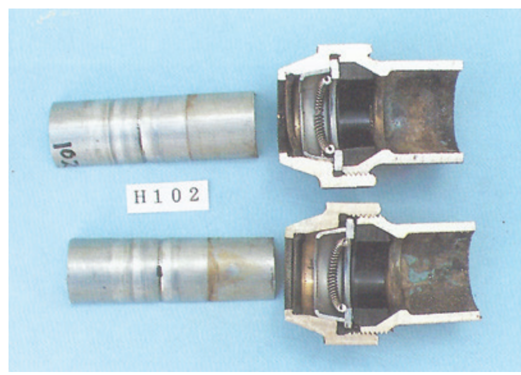
(3) Press-type coupling (after pickling)



(4) Compression-type coupling (after pickling)



(5) Flexible (A) coupling (after pickling)



(6) Flexible (B) coupling (after pickling)

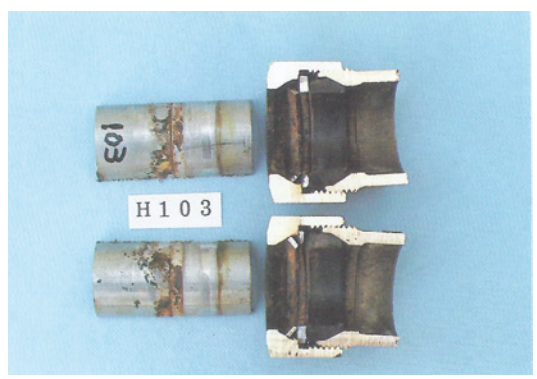
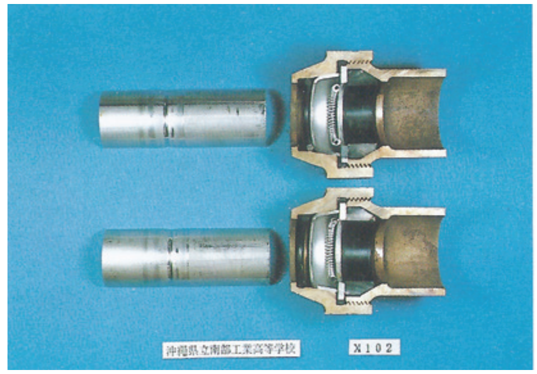


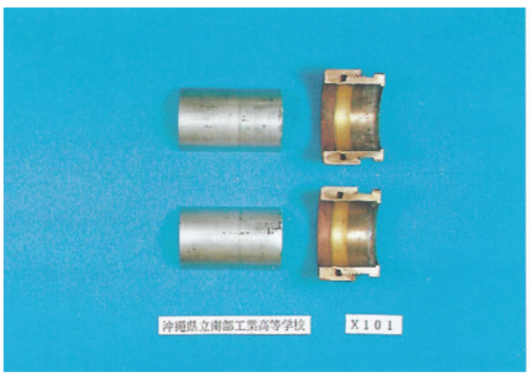
Photo 3 Appearance of Pipes with Couplings (Okinawa (X) Test Site)

(1) Appearance (after water washing)

(4) Compression-type coupling (after pickling)



(2) Solder-type coupling (after pickling)



(5) Flexible (A) coupling (after pickling)

(3) Press-type coupling (after pickling)

(6) Flexible (B) coupling (after pickling)

Photo 4 Appearance of Vertically Buried Pipes (Shunan (U) Test Site)

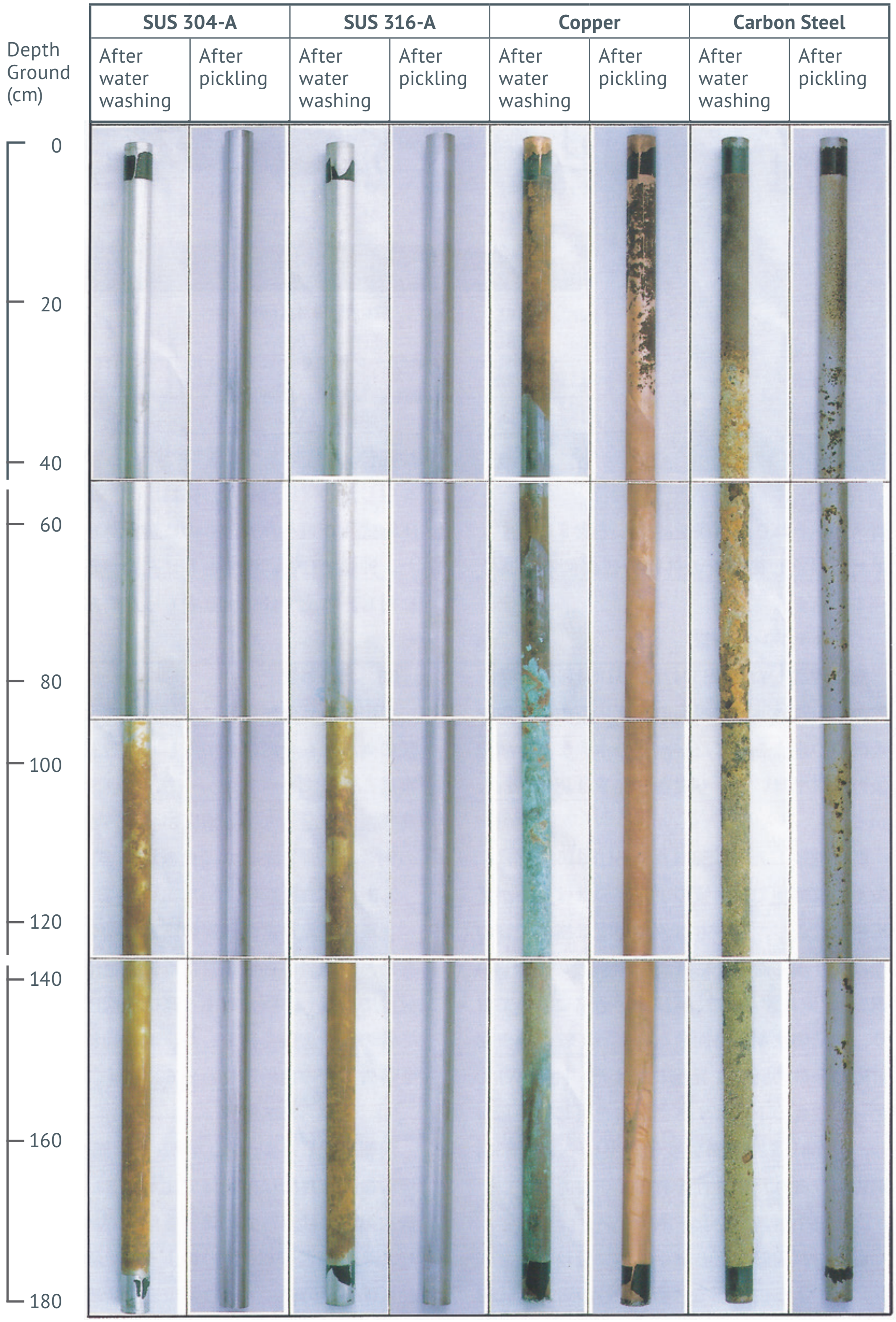
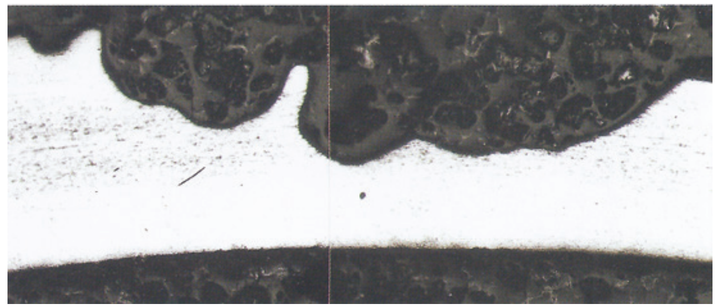


Photo 5 Crevice Corrosion that Occurred under the Vinyl Tape Covering (Okinawa (X) Test Site, Vertically Buried Pipe)

(1) Appearance



(2) Cross-section (x50)

The results are collectively shown in *Table 5*. Photos 1 to 5 show typical pipe appearance after excavation.

(1) Stainless steel

304 and 316 stainless steel pipes buried horizontally: At some test sites, brown staining or brownish-red spots occurred on some parts of the pipe surfaces. However, corrosion was not found during observation after water washing or pickling.

304 and 316 stainless steel pipes buried vertically: At many test sites, almost all surfaces of the sample pipe lower (buried) parts were subject to brownish-red staining. The extent of staining was more remarkable than the pipes buried horizontally. Furthermore, in Naoetsu (K) where the test area was next to the road, the surfaces of 304 stainless steel pipes near the ground underwent considerable pitting corrosion due to anti-icing agent scattered on the road. In Okinawa (X), crevice corrosion occurred under the tape wrapped around the pipes. However, 316 stainless steel pipes exhibited little change in appearance, and had superior corrosion resistance to 304 stainless steel pipes.

(2) Stainless steel pipes with couplings

After the samples were divided into pipes and coupling bodies, it was found that, as shown in *Table 5*, only 304 stainless steel pipes connected by flexible couplings (B) in Yabuzuka (K) became corroded, and in Okinawa (X), the pipes connected by flexible couplings became corroded. On the other hand, when looking at coupling bodies, corrosion was found on a significant number of solder-type, compression-type (manufactured by BC) and flexible couplings. A great deal of pitting corrosion was found on both pipes and couplings in Okinawa, while widely spread local corrosion was found on the main islands.

(3) Pipes for comparison

At all test sites, all surfaces of both horizontally and vertically buried carbon steel pipes were subject to severe corrosion, and at some sites, through-holes or loss was found. Meanwhile, the horizontally buried pipes exhibited local corrosion at many sites and the vertically buried ones became corroded due to patina formation.

3.3 Self-potential

To order to observe the corrosion behavior of sample pipes in soil, the pipes to which potential-measuring wires were attached were buried horizontally, and reference electrodes and a high-resistance voltmeter were used to measure their self-potentials. *Table 6* shows the self-potential of each sample pipe 10 years after burial.

(1) Stainless steel pipes

As described in the previous report, although the potential of stainless steel significantly changed as a whole for several months after the burial of the pipes, it then had a tendency to reach an almost steady-state value. Meanwhile, at certain sites including Aomori (I) and Matsuyama (Y), a large potential change occurred over time along with the change in the soil environment.

Table 6 Self-potentials of Sample Pipes Unit: mV (SCE)

Sample Pipes		Test Sites									
		Kushiro (H)	Aomori (I)	Naoetsu (J)	Yabuzuka (K)	Kuwana (P)	Wakayama (R)	Shunan (U)	Nakatsu (V)	Okinawa (X)	Matsuyama (Y)
304A		−349 −363	263 −425	−338 − 16	450 446	−138 −110	530 520	−627 −397	379 300	−371 −127	284 280
304E		−390 −360	−214 −499	−411 194	456 453	−201 −113	530 485	−417 −341	− 40 398	−393 −124	− 23 409
316A		−369 −377	−440 −399	389 −293	442 457	−181 −165	498 505	−391 −402	−164 382	−376 −330	−105 378
Carbon steel		−434	−562	−531	−332	−299	−215	−525	−254	−486	−422
Lead		−402	−552	−484	−388	−228	−415	−529	−458	−393	−390
Pipes with couplings	Solder-type	−364	−459	−336	461	−107	435	−503	413	−186	− 63
	Press-type	−369	−445	179	477	−161	495	−402	441	−198	441
	Compression-type	−369	−272	−146	35	−137	65	−409	261	−134	0
	Flexible (A)	−241	−235	− 78	65	− 59	8	−413	90	− 37	78
	Flexible (B)	−376	−207	−146	108	−190	75	−450	158	−390	49

Table 7 Corrosion Rates

Test Sites	304 steel	316 steel	Carbon steel		Lead	
	mdd	mdd	mdd	mm/y	mdd	mm/y
Kushiro (H)	0.000 0.000	0.000 0.000	11.00 9.40	0.051 0.044	0.40 0.70	0.001 0.002
Aomori (I)	0.000 0.000	0.000 0.000	1.86 2.06	0.009 0.010	0.75 0.89	0.002 0.003
Naoetsu (J)	0.000 0.000	0.000 0.000	2.29 2.31	0.011 0.011	0.33 0.58	0.001 0.002
Yabuzuka (K)	0.000 0.000	0.000 0.000	2.15 1.82	0.010 0.008	0.05 0.05	0.000 0.000
Kuwana (P)	0.000 0.000	0.000 0.000	1.83 1.55	0.008 0.007	0.76 1.11	0.002 0.004
Wakayama (R)	0.002 0.003	0.002 0.003	2.80 2.76	0.013 0.013	0.21 0.20	0.001 0.001
Shunan (U)	0.000 0.000	0.000 0.000	1.00 1.01	0.005 0.005	0.10 0.23	0.000 0.001
Nakatsu (V)	0.001 0.001	0.001 0.001	3.03 3.03	0.014 0.014	0.07 0.06	0.000 0.000
Okinawa (X)	Could not be obtained	Could not be obtained	Could not be obtained	Could not be obtained	Could not be obtained	Could not be obtained
Matsuyama (Y)	0.000 0.000	0.000 0.000	2.95 3.54	0.014 0.016	0.22 0.25	0.001 0.001

As can be seen from the measured values that almost reached steady-state values after 10 years, + 400 to 500 mV (SCE) of high (electropositive) potential was obtained in Yabuzuka (K), Wakayama (R), and Nakatsu (V), indicating that the passivation of stainless steel remains stable. In Kushiro (H), Aomori (I), Shunan (U), and Okinawa (X), -300 to -420 mV (SCE) of low (electronegative) potential was obtained, indicating the tendency that the passivation of stainless steel became slightly unstable.

(2) Carbon steel and lead pipes

Although the potentials of carbon steel and lead pipes were -400 to -550 mV (SCE) and remained little changed over time, potentials which were more electropositive than those values were confirmed at some sites. Furthermore, the potentials of the lead pipes were generally 30 to 100 mV more electropositive than those of carbon steel pipes.

(3) Stainless steel pipes with couplings

Pipes with solder-type or press-type couplings: Potentials obtained at all test sites were nearly equal to those of stainless steel pipes.

Pipes with compression-type, flexible (A) or (B) couplings: Potentials obtained at some test sites were almost the same as those of stainless steel pipes. Potentials obtained at other sites, however, were intermediate values between those of stainless steel pipes and those of carbon steel pipes, indicating that potentials were affected by the combination of the copper alloy couplings and stainless steel pipes.

3.4 Corrosion rate

Weight-measurable test pipes were used to measure the corrosion amount of sample pipes. Weight-measurable test pipes of two types of stainless steel, carbon steel, and lead were buried at each site. They were excavated 10 years after burial, and their weight loss due to corrosion was measured to calculate corrosion rates (mdd and mm/y). These results are shown in *Table 7*.

Both 304 and 316 stainless steel had no weight loss even 10 years after burial at all test sites.

4. SUMMARY OF ALL TEST RESULTS

The 1-year, 3-year, and 5-year burial test results at 25 test sites (previous report) and 10-year burial test results at 10 test sites (this report) are summarised below.

4.1 Surface statuses of sample pipes

The occurrence statuses of pitting corrosion, crevice corrosion, and other local corrosion on the surfaces of 975

Table 8 Surface Statuses of Stainless Steels

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
Horizontally buried pipes	304A				C																			P	P	
	304E				C																			C		
	316A																								P	
Vertically buried pipes	304A														P					C				P	P	
	316A																							C		
Remarks: C: Crevice corrosion P: Pitting corrosion		Tokyo							Hokkaido	Aomori Pref.	Niigata Pref.	Gunma Pref.	Saitama Pref.	Kanagawa Pref.			Mie Pref.	Hyogo Pref.	Wakayama Pref.	Hiroshima Pref.	Yamaguchi Pref.		Oita Pref.	Okinawa Pref.		Ehime Pref.
		Harumi	Toyosumi	Kanamachi	Misono	Suginami	Wadabori	Kinutashimo	Kushiro	Aomori	Naoetsu	Yabuzuka	Kumagaya	Sagamihara	Kawasaki	Ashigara	Kuwana	Nishinomiya	Wakayama	Fukuyama	Hikari	Shunan	Nakatsu	Misato	Nanbu	Matsuyama
(Note) Summary of one, three, five, and 10 years																										

stainless steel pipes excavated from the ground one, three, five, and 10 years after burial are shown by site in *Table 8*.

Although 304 and 316 stainless steel pipes exhibited slight staining, they exhibited largely good corrosion resistance and were not corroded. However, 304 stainless steel pipes buried horizontally in Misono (D) and Okinawa (W and X) became corroded, and 316 stainless steel pipes buried horizontally in Okinawa (X) also became corroded. As for 304 stainless steel pipes buried vertically, those in Kawasaki (N), Fukuyama (S), and Okinawa (W and X) became corroded, and 316 stainless steel pipes buried vertically in Okinawa (W) also became corroded.

Next, the surface statuses of 304 stainless steel pipes (130 pipes) excavated from the ground are shown by section (pipe and coupling) in *Table 9*.

Although stainless steel pipes exhibited good corrosion resistance at most test sites, pitting corrosion and crevice corrosion were found only on the pipes connected by flexible couplings in Aomori (I) and Yabuzuka (K). Furthermore in Okinawa, local corrosion occurred on the surfaces of all pipes connected by couplings. On the other hand, looking at coupling bodies, there was a great deal of patina found on solder-type, compression-type (manufactured by BC), and flexible couplings.

4.2 Corrosion types and occurrence parts

Corrosion types and occurrence parts on single stainless steel pipes and those connected by couplings are shown in *Table 10*.

Corrosion types observed at the test sites on the main islands (excluding Okinawa) were pitting corrosion that occurred on the lower (buried) parts of 304 stainless steel pipes buried vertically, and crevice corrosion that occurred under the vinyl tape. Furthermore, the number of corroded pipes among the vertically buried pipes was larger than that of the horizontally buried pipes, and the ratio of the two was 4:1.

Table 9 Surface Statuses of Sample Pipes with Coupling

	Coupling Types	Coupling Types	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
Pipes	SUS 304	Solder-type																						P	P		
		Press-type																							P		
	BC-6	Compression-type																								P	
		Expansion flexible (A)									C															P	
		Expansion flexible (B)											P													P	
Couplings	SUS304	Solder-type	L			L	L					L												P	P		L
		Press-type																							P		
	BC-6	Compression-type	L	L		L				L			L													P	L
		Expansion flexible (A)	L	L	L	L				L			L	L				L								P	L
		Expansion flexible (B)	L	L	L	L	L			L	L		L	L		L		L					L	L		P	L
Remarks: C: Crevice corrosion P: Pitting corrosion L: Local corrosion			Tokyo							Hokkaido	Aomori Pref.	Niigata Pref.	Gunma Pref.	Saitama Pref.	Kanagawa Pref.			Mie Pref.	Hyogo Pref.	Wakayama Pref.	Hiroshima Pref.	Yamaguchi Pref.		Oita Pref.	Okinawa Pref.		Ehime Pref.
			Harumi	Toyosumi	Kanamachi	Misono	Suginami	Wadabori	Kinutashimo	Kushiro	Aomori	Naoetsu	Yabuzuka	Kumagaya	Sagamihara	Kawasaki	Ashigara	Kuwana	Nishinomiya	Wakayama	Fukuyama	Hikari	Shunan	Nakatsu	Misato	Nanbu	Matsuyama

(Note) Summary of one, three, five, and ten years

Table 10 Corrosion Statuses of Stainless Steel Pipes				
Test Sites	**Steel Types**	**Burial Period (Years)**	**Corrosion Types**	**Corrosion Occurrence Parts**
D Misono	304	5	C. C	Horizontal pipe, under the tape
I Aomori	304	5	C. C	Pipes connected by a flexible A coupling, though-holes on the connection part
K Yabuzuka	304	10	P. C	Pipes connected by a flexible B couplings, connection part
N Kawasaki	304	1	P. C	Vertical pipe, center
S Fukuyama	304	1	P. C	Vertical pipe, through-holes at the point 500 mm away from the lower end
S Fukuyama	304	3	C. C	Vertical pipe, under the tape
S Fukuyama	304	5	C. C	Vertical pipe, under the tape, max. depth: 0.3 mm
V Nakatsu	304	10	P. C	Pipes connected by a solder-type coupling, straight pipe section
W Okinawa, Misato	304	3	P. C	Horizontal pipe, max. depth: 0.2 mm
W Okinawa, Misato	304	3	C. C	Horizontal pipe, under the tape
W Okinawa, Misato	304	5	P. C	Horizontal pipe, max. depth: 0.5 mm
W Okinawa, Misato	304	1, 3, 5	P. C	Pipes connected by a solder-type coupling, through-holes on straight pipe section
W Okinawa, Misato	304	1	P. C	Pipes connected by a press-type coupling, straight pipe section
W Okinawa, Misato	304	1	P. C	Vertical pipe, 1200 mm away from the lower end
W Okinawa, Misato	304	5	P. C	Vertical pipe, under the tape
W Okinawa, Misato	316	1	P. C	Vertical pipe, 900 mm away from the lower end
W Okinawa, Misato	316	5	C. C	Vertical pipe, under the tape
X Okinawa, Nanbu	304	1	P. C	Horizontal pipe, centre
X Okinawa, Nanbu	316	1	P. C	Horizontal pipe, centre
X Okinawa, Nanbu	304	1	P. C	Pipes connected by a compression-type coupling, straight pipe section
X Okinawa, Nanbu	304	10	P. C	Pipes connected by a flexible A coupling, straight pipe section
X Okinawa, Nanbu	304	10	P. C	Pipes connected by a flexible B coupling, straight pipe section
X Okinawa, Nanbu	304	10	P. C	Vertical pipe, occurrence part unknown
(Note) C: Crevice corrosion P: Pitting corrosion				

The vertically buried pipes were covered with both the upper soil layer that was stirred during excavation and backfill, as well as the lower soil layer that was not stirred during pipe driving. Therefore, the pipes were subject to differential aeration between the upper and lower layers. It is thought that, due to this, macrocells were formed on steel surfaces and they facilitated staining and corrosion on the lower parts of the pipes in combination with corrosive factors in the soil.

According to the results of the differential aeration macrocell corrosion test[3]) done by Mori et al. using divided pipes, due to differential aeration caused by the difference in soil wettability, a large potential difference (several hundred mV) occurred on the surfaces of 304 stainless steel pipes buried vertically. They also confirmed that the lower parts of the pipes that came into contact with the wet soil with a low oxygen concentration became anodes and corrosion current flowed out, thereby causing corrosion.

Most of the stainless steel pipes that were corroded were those buried in Okinawa, which is in a marine environment. The characteristic points at this site in terms of the corrosion types is that the proportion of pitting corrosion was about 4.5 times that of the crevice corrosion, while the number of horizontally buried pipes that were corroded was the same as that of the vertically buried pipes that were corroded. There characteristics are thought to be due to the high concentrations of Cl- and SO_4^{2-} in the soil of Okinawa as shown in *Table 3*.

Figure 1 shows the relationship between the pitting corrosion on stainless steel and Cl- concentration/resistivity of the soil based on the soil corrosion test results from NBS. As shown in this figure, the occurrence tendency of pitting corrosion on stainless steel has a higher correlation with the Cl- concentration than with the soil resistivity. Furthermore, 304 stainless steel is likely to suffer pitting corrosion when the Cl- concentration is 300 mg/kg or more, while 316 stainless steel is unlikely to suffer it even when the Cl-concentration is remarkably high. On the other hand, excluding Okinawa, the soils at test sites where this test was performed have 100 mg/kg or less of Cl- concentration, indicating that their corrosiveness to stainless steel is low.

4.3 Corrosion rate

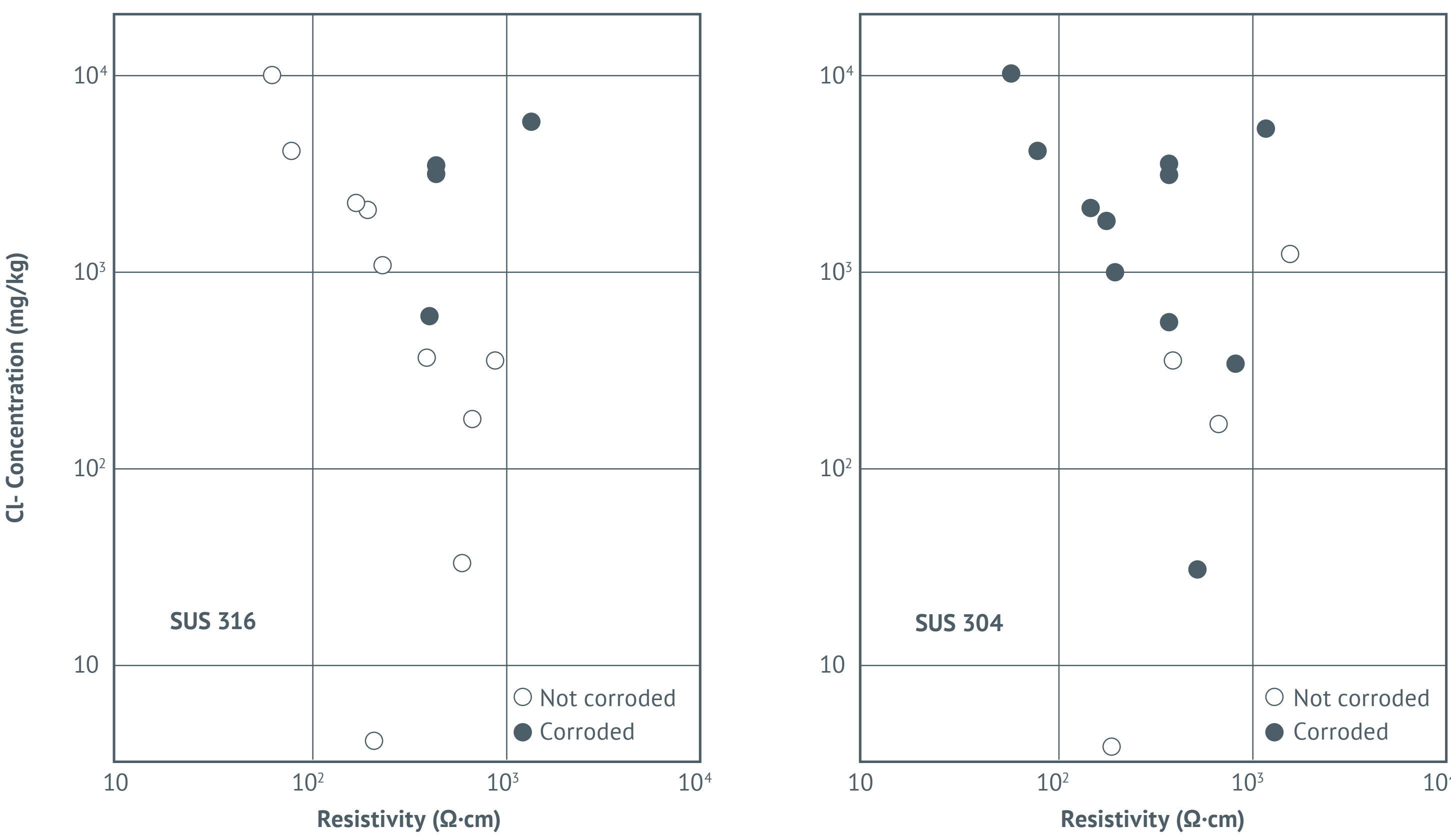
The average corrosion rates of the weight-measurable test pipes made of stainless steel, carbon steel, and lead are shown by burial periods in *Table 11*.

Both corrosion rates of 304 and 316 stainless steel were zero. The average corrosion rates of carbon steel and lead reduced over time, and the rates 10 years after burial were 0.013 mm/y and 0.001 mm/y, respectively. The maximum corrosion rates for both materials are five to six times the average corrosion rates.

Table 11 Average Corrosion Rates of Weight-measurable Pipes (mm/y)

Metals		1 year	3 year	5 year	10 year
SUS304	Max.	0.000	0.000	0.000	0.000
	Min.	0.000	0.000	0.000	0.000
	Ave.	0.000	0.000	0.000	0.000
SUS316	Max.	0.000	0.000	0.000	0.000
	Min.	0.000	0.000	0.000	0.000
	Ave.	0.000	0.000	0.000	0.000
Carbon steel	Max.	0.240	0.140	0.094	0.047
	Min.	0.002	0.001	0.003	0.004
	Ave.	0.033	0.024	0.019	0.013
Lead	Max.	0.022	0.009	0.009	0.003
	Min.	0.000	0.000	0.000	0.000
	Ave.	0.004	0.002	0.002	0.001

Figure 1 Relationship between the Pitting Corrosion on Stainless Steel and Cl- Concentration/Resistivity of the Soil



5. CONCLUSION

The conclusions drawn from the above long-term burial test results are described below.

1) Although 304 stainless steel pipes buried horizontally exhibited slight staining, they exhibited good corrosion resistance and were not subject to pitting or other types of corrosion at many test sites. At the test site which was in a marine environment, however, crevice corrosion occurred under the vinyl tape covering.

2) 316 stainless steel pipes buried horizontally exhibited almost no staining or corrosion at all test sites other than one site in Okinawa, and provided superior corrosion resistance to 304 stainless steel pipes.

3) The self-potentials of the aforementioned stainless steel pipes in soil ranged widely from +500 to -450 mV (SCE), and they changed significantly depending on soil environment conditions.

4) At some test sites, pitting or crevice corrosion occurred on the lower parts of 304 stainless steel pipes buried vertically. On the vertically buried pipes, macrocells may be formed due to differential aeration between the upper and lower soil layers, causing corrosion in combination with corrosive factors in the soil. Furthermore, stainless steel pipes are highly likely to become corroded if they are buried in soil that is not stirred rather than when buried in stirred soil.

5) Corrosion often occurred on bronze or solder-type couplings. Press-type stainless steel couplings exhibited good corrosion resistance.

6) The average corrosion rates of carbon steel and lead are 0.013 mm/y and 0.001 mm/y, respectively. The maximum corrosion rates for both materials are approximately five times the average corrosion rates, while the corrosion rates of both 304 and 316 stainless steel are zero.

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