NIPPON STEEL TECHNICAL REPORT No. 85 JANUARY 2002

UDC 669 . 295 : 620 . 197 . 6

Corrosion Prevention by Titanium Cover Petrolatum Lining



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Abstract

Of the conventional corrosion prevention methods for steel pipe piles for use as foundations for piled jetties and wharves, petrolatum lining has a comparative advantage over others as after protection for application in tidal and splash zones. In this conventional petrolatum lining method, after coating the steel pipe with petrolatum, a FRP covering is ordinarily used for additional protection. Problems with FRP, however, include deterioration by ultraviolet rays and susceptibility to cracking on impact with floating matter. In addition to an attempt to extend the life of petrolatum lining by the use of titanium instead of FRP, a new execution method also has been developed so that this titanium cover petrolatum lining method can be competitive with other conventional corrosion protection methods in terms of construction cost. As a result, this method can offer longer life expectancy and adequate cost-competitiveness, as compared to other conventional methods.

1. Introduction

The most serious problem related with ocean structures is corrosion caused by seawater or sea-salt particles. The corrosion (rusting) of steel is the most significant factor in determining the service life of steel ocean structures in particular. Efforts have been made in various industries to prolong the life of steel structures by developing corrosion prevention systems or protection methods for such structures. As for public guidelines designated for the design phase, the "Corrosion Prevention and Repair Manual for Port and Harbor Structures"[1] was compiled by the Coastal Development Institute of Technology, which was revised under the supervision of the Port and Harbor Research Institute of the Ministry of Transport (now reorganized as Port and Airport Research Institute) in 1997; these guidelines abolished the corrosion allowance method by which conventional structures had long been designed and recommended that some means of corrosion prevention be applied to structures. Today, measures are taken as a matter of course to protect steel materials when used in ocean environments.

To prevent the corrosion of steel pipe piles used as foundations for piers and wharves, the piles may be coated with paint or lined with resin before piling, lined with concrete after piling, protected electrically by using a sacrificial electrode and external power source, or by a combination of these methods.

One particularly good conventional method of preventing the corrosion of steel pipe piles for tidal and splash zones is petrolatum lining. In the conventional petrolatum lining method, a steel pipe is coated with petrolatum and then further covered with FRP for pro-

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tection. However, FRP deteriorates due to ultraviolet rays or cracks from the impact of floating matter and its service durability is on the order of 20 years. We have been developing a corrosion prevention system which uses titanium in place of FRP and is more durable, but has a similar construction cost as the conventional method.

We started work on this method in 1985 by conducting application tests of the corrosion prevention system in Hasaki, Nagoya, and offshore of Aga. We have since continuously monitored the conditions of the experimentally treated steel pipe piles, improved the method for reducing costs, and developed optional specifications for enhanced strength. We have thus developed a corrosion prevention method which prolongs the service life compared with conventional methods and is also cost-competitive. This paper introduces the progress and achievements of our studies, together with the current status.

2. Outline and corrosion-prevention mechanism of petrolatum lining

The petrolatum lining method consists of the following procedures. First, the surface of steel pipe piles is prepared. Next, the piles are coated with petrolatum paste, then petrolatum tape (non-woven fabric soaked in petrolatum) is wound around the piles. Petrolatum is a viscous material having minimal mechanical strength. In ocean conditions petrolatum tape is likely to be damaged by the impact from waves or floating matter such as driftwood, so a covering material to protect the petrolatum tape layer is necessary. In the conventional methods, FRP (fiber-reinforced plastic) was used as the covering material. **Fig. 1** shows the flow chart of the FRP-cover type petrolatum lining method.

The corrosion prevention mechanism of this method largely depends on the water-repellent effect of petrolatum which is a type of petroleum wax, as well as the rust-preventive effect of the added inhibitor. When the tape is wound around a steel pipe pile in this method, the tape is tightly pressed so that water will be squeezed off the surface of the pile. However, it is not possible to remove the water completely in this way, and the residual water on the surface will cause rusting of the steel material. An inhibitor such as tannin is therefore added to protect the steel material through the formation of a rust-preventive film of iron tannate or the like[2].

3. Outline of Ti-Cover type petrolatum lining method

3.1 Peculiar characteristics of Ti-cover type petrolatum lining

In the newly developed Ti-cover type petrolatum lining method, FRP cover in the conventional method is replaced by Ti cover; the steps from surface preparation of steel pipe to winding of petrolatum tape are the same as those of the conventional method, and only the cover mounting step as an after-process is different. The functions of the respective substances are the same: the petrolatum layer prevents corrosion of steel pipe and the Ti cover protects the petrolatum layer.

Because Ti is a highly noble metal in terms of thermodynamics, galvanic corrosion or influence on electric protection may occur. However, this is not a problem as the petrolatum between the Ti cover and the steel pipe is an insulating material and anti-corrosion putty is applied to the space between the Ti cover and the fixture to provide complete electrical isolation of the Ti cover sheet.

3.2 Progress of development of Ti cover fixing method

As mentioned above, the development of this method began with application tests of the corrosion prevention system in Hasaki, Nagoya, and offshore of Aga in 1985. **Table 1** lists the works conducted using this method since 1985.

In the early stages, the Ti cover fixing method was the same as that for FRP cover in the conventional method, with a molded flange fastened with bolts and nuts. However, the flange was expensive and time-consuming to mold, and so the method was not economical.

We therefore developed a fixing method based on fitting. We examined various fitting methods and found that the sleeve-pipe method, which employs a sleeve pipe and joint seams prepared on the cover sheet, offered the easiest handling and lowest fabrication cost. This method was named the TP (Titanium cover Petrolatum lining) method.

Three years ago, we also developed a fixing method based on welding for higher reliability and strength, by utilizing a new welder which can perform resistance welding under water. Verification tests have been conducted at some locations and the method is expected

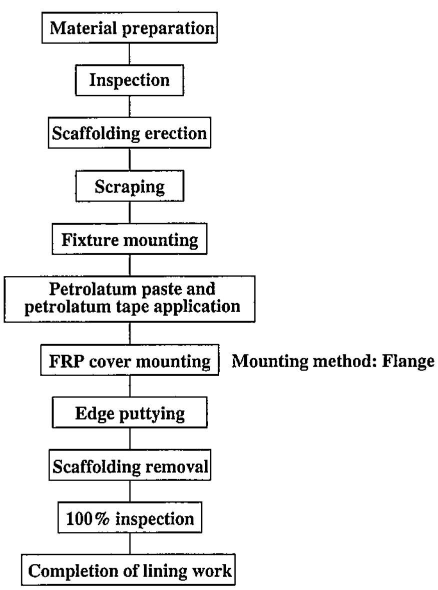


Fig. 1 Flow chart of FRP-cover type petrolatum lining method

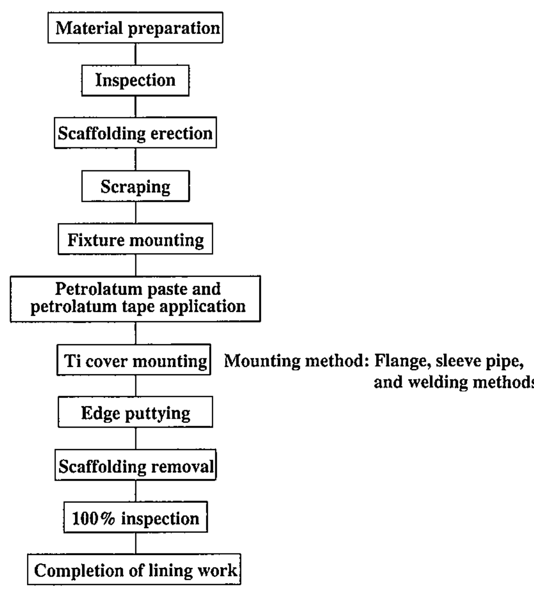


Fig. 2 Flow chart of Ti-cover type petrolatum lining method

Table 1 Records of actual work using Ti-cover type petrolatum lining

No	Year/ month	Site	Client	Facility	General contractor	Working contractor (Execution supervisor)	Working contractor (Working company)	Fixing method	Number of piles	Pile diameter (mm)	Height of corrosion protection work (m)	Area of corrosion protection work (m^2)	Weight of Ti (kg)
1	1985	Hasaki-cho, Ibaraki	Titanium Division (Port and Harbor Research Institute of Ministry of Transport)	Drift sand observation pier	—	Nittetsu Corrosion Prevention Co., Ltd.	—	Flange	1	800	3.88	10	30
2	1985	Tokai-shi, Aichi	Nagoya Works, Nippon Steel Corp.	Raw-material berth	—	Nittetsu Corrosion Prevention Co., Ltd.	—	Flange	2	508	1.90	3	9
3	1985	Niigata	Civil Engineering & Marine Construction Division, Nippon Steel Corp.	Oil rig	—	Nittetsu Corrosion Prevention Co., Ltd.	—	Flange	1	**	**	**	**
4	1990	Kitakyushu-shi, Fukuoka	Fourth Port and Harbor Construction Bureau, Ministry of Transport	Wharf pier	—	Nittetsu Corrosion Prevention Co., Ltd.	—	Flange	17	700	3.20	120	360
5	1995/3	Tokai-shi, Aichi	Nagoya Works, Nippon Steel Corp.	Raw-material berth	—	Nittetsu Corrosion Prevention Co., Ltd.	Company J, Tokyo	TP	1	508	1.90	3	6
6	1995/7	Kimitsu-shi, Chiba	Kimitsu branch, Seitetsu Unyu Co., Ltd.	All-weather berth	Penta-Ocean Construction Co., Ltd.	Nittetsu Corrosion Prevention Co., Ltd.	Company J, Tokyo	TP	2	800	1.70	9	18
7	1996/5	Kimitsu-shi, Chiba	Kimitsu branch, Seitetsu Unyu Co., Ltd.	All-weather berth	Penta-Ocean Construction Co., Ltd.	Nittetsu Corrosion Prevention Co., Ltd.	Company J, Tokyo	TP	1	800	1.22	2	4
8	1996/8	Oita-shi, Oita	Oita Works, Nippon Steel Corp.	Raw-material berth	Penta-Ocean Construction Co., Ltd.	Nakabohtec Corrosion Protecting Co., Ltd. (Nittetsu Corrosion Prevention Co., Ltd.)	Company A, Oita	TP	4	1,500	2.50	48	96
9	1997/3	Susaki-shi, Kochi	Torigatayama Mining Plant, Nittetsu Mining Co., Ltd.	Shipping berth	—	Nittetsu Corrosion Prevention Co., Ltd.	Company N, Matsuyama	TP	17	500-900	3.00	114	228
10	1997/6	Hasaki-cho, Ibaraki	Titanium Division (Port and Harbor Research Institute of Ministry of Transport)	Drift sand observation pier	—	Nittetsu Corrosion Prevention Co., Ltd.	Company J, Tokyo	TP	1	800	3.88	10	20
11	1997/9	Susaki-shi, Kochi	Torigatayama Mining Plant, Nittetsu Mining Co., Ltd.	Shipping berth	—	Nittetsu Corrosion Prevention Co., Ltd.	Company N, Matsuyama	TP	25	500-800	3.00	145	290
12	1997/10	Susaki-shi, Kochi	Torigatayama Mining Plant, Nittetsu Mining Co., Ltd.	Shipping berth	—	Nittetsu Corrosion Prevention Co., Ltd.	Company N, Matsuyama	TP	124	1,200	1.50	701	1,402
13	1998/4	Sodegaura-shi, Chiba	Sodegaura branch, Nittetsu Mining Co., Ltd.	Unloading berth	Toyo Construction Co., Ltd.	Nittetsu Corrosion Prevention Co., Ltd.	Company J, Tokyo	TP	4	1,000	3.00	38	76
14	1998/8	Oita-shi, Oita	Oita Liquefied Gas Kyodo Bichiku Co., Ltd.	Dolphin	—	Nittetsu Corrosion Prevention Co., Ltd.	Company P, Kitakyushu	TP	1	1,200	1.60	4	8
15	1998/9	Susaki-shi, Kochi	Torigatayama Mining Plant, Nittetsu Mining Co., Ltd.	Shipping berth	—	Nittetsu Corrosion Prevention Co., Ltd.	Company N, Matsuyama	TP	20	1,200	4.50	339	678
16	1998/9	Susaki-shi, Kochi	Torigatayama Mining Plant, Nittetsu Mining Co., Ltd.	Shipping berth	—	Nittetsu Corrosion Prevention Co., Ltd.	Company N, Matsuyama	TP	10	600-900	3.00	78	156
17	1999/3	Yokohama-shi, Kanagawa	Yokohama city	Wharf pier	Shimizu Corp.	Nittetsu Corrosion Prevention Co., Ltd.	Company B, Yokohama	TP	30	600	3.00	170	340
18	1999/11	Kitakyushu-shi, Fukuoka	Yawata Works, Nippon Steel Corp.	Raw-material berth	—	Nittetsu Corrosion Prevention Co., Ltd.	Company N, Matsuyama	TP and welding	30	358	1.00	34	102
19	2000/3	Kimitsu-shi, Chiba	Kimitsu Works, Nippon Steel Corp.	Raw-material berth	—	Nittetsu Corrosion Prevention Co., Ltd.	Company H, Chiba	TP	*1	*1,000	*20.0	63	189
20	2000/9	Susaki-shi, Kochi	Torigatayama Mining Plant, Nittetsu Mining Co., Ltd.	Shipping berth	—	Nittetsu Corrosion Prevention Co., Ltd.	Company N, Matsuyama	welding	10	800	3.00	77	231
			Total						301			1,968	4,243

*: cross-beam, **: unknown

to be put into practical use in the near future.

3.3 Outline of the three fixing methods

Fig. 2 shows the flow chart for the fixing Ti cover and flange method, sleeve-pipe method (TP method), and welding method. **Photos 1 to 3** show examples of using the method. **Figs. 3 and 4** show rough illustrations of the flange method and sleeve-pipe method (TP method).

3.3.1 Outline of flange method

In the flange method, a Ti cover with bending and drilling done on both edges is prepared. The flange should be a thick Ti sheet, or a Ti cover welded with a flat bar or angle element, or a Ti cover itself with the edge bent. The flange should be reinforced by FRP flat bars or angle elements.

The size of the Ti sheet depends on the diameter of the steel pipe pile and the height of the corrosion prevention zone. However, since

Photo 1 Example of flange method application (oil rig offshore of Aga)

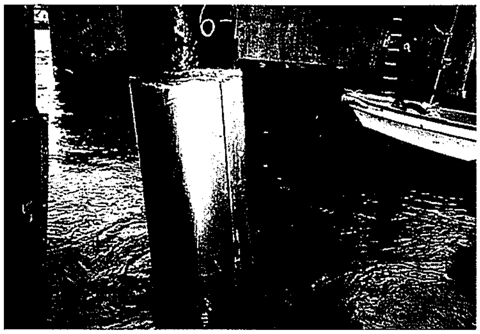


Photo 2 Example of TP method application (Torigatayama Mining Plant, Nittetsu Mining Co., Ltd.)

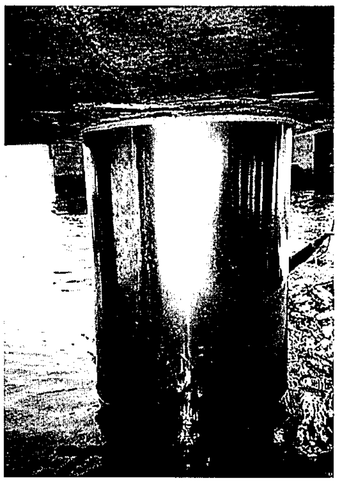


Photo 3 Example of welding method application (Torigatayama Mining Plant, Nittetsu Mining Co., Ltd.)

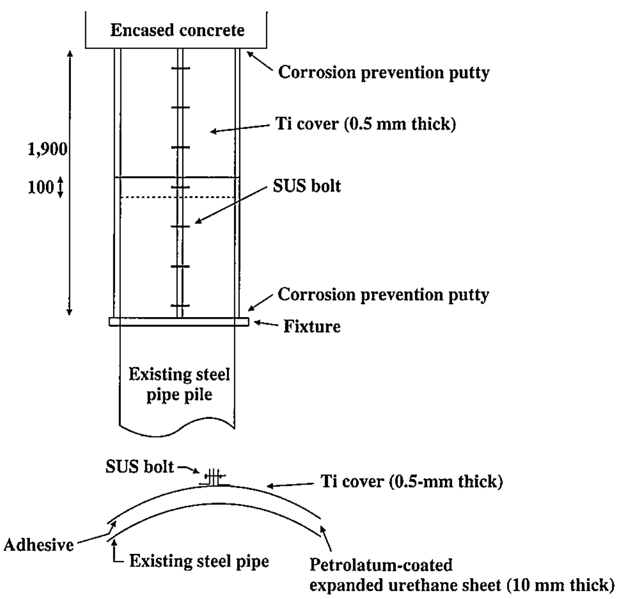


Fig. 3 Rough illustration of flange method

it is equally divided in the direction of the height, the width should be in a range of 1,000 to 1,200 mm with an allowance of 100 mm for overlapping. The thickness of the sheet in the test was 0.7 to 0.5 mm

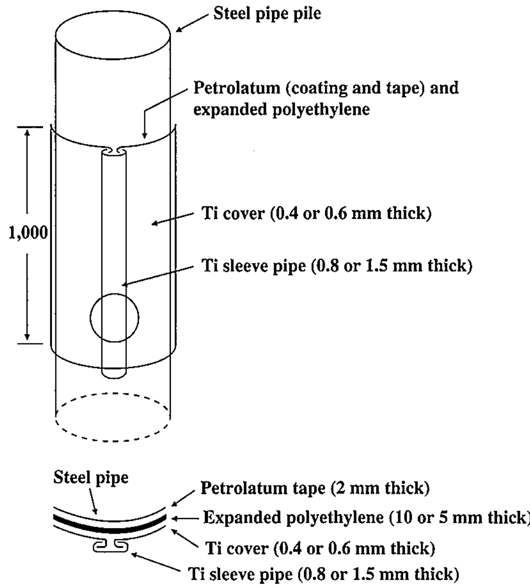


Fig. 4 Rough illustration of TP method

in consideration of the workability and availability of the material.

In the actual work, petrolatum tape was wound around the piles and then Ti cover sheets were applied. The Ti cover sheets were fastened with bolts and nuts on the mated flange surfaces. The most typical bolts and nuts used for this process are SUS304 or SUS316. This process is done from the top or bottom in sequence to enclose the steel pipe with an allowance of 100 mm for overlap. Then, the fixture is mounted at the bottom and finally corrosion prevention putty is applied to both the top and bottom ends.

3.3.2 Outline of TP method

In the TP method, a Ti cover sheet whose two ends are machined for joint seams and a Ti sleeve pipe which is bent like a C-shaped channel are prepared first. The size of the sheet is determined on the same basis as for the flange method.

The sheet thicknesses employed in the test were 0.4 mm for the cover and 0.8 mm for the sleeve pipe at first. We calculated the thickness on the basis of the wave conditions in Osaka Bay and the shape and tensile strength of the sheet so as to provide sufficient retention capacity of the sheet[2]. However, as the method might be used in ocean conditions, the thickness seemed to be insufficient against much tougher wave conditions, so we currently mainly use such thicknesses as 0.6 mm for the cover sheet and 1.5 mm for the sleeve pipe to increase the strength and raise the safety factor.

In the actual work, petrolatum tape is wound around the steel pipe and the steel pipe is covered with Ti cover sheet. Then the sleeve pipe is inserted over the joint seams on both ends of the Ti cover sheet from the top or from the bottom. The subsequent steps are the same as in the flange method.

3.3.3 Outline of welding method

In the welding method, a Ti cover sheet without any machining such as bending or forming of joint seams is prepared. The size of the sheet is determined on the same basis as for the flange method. The cover sheet thickness employed in the test from the beginning was 0.6 mm for the locations requiring strength. In the actual work, petrolatum tape is wound around the steel pipe and the steel pipe is covered with Ti cover sheet. Then the overlapped part of the Ti cover sheet is spot welded. The subsequent steps are the same as in the flange method.

Note that the welder used in the test has a limited distance between the transformer and the torch and so can only be used on the site where the transformer can be arranged nearby.

3.4 Corrosion preventive performance of Ti-cover type petrolatum lining method

3.4.1 Results of dismantling and examination of the corrosion-protected part of the steel pipe pile installed at Nagoya Works, Nippon Steel Corp.

In 1995 we dismantled and examined the corrosion-protected part of the steel pipe installed by the flange method at the raw-material berth at Nagoya Works in 1985[2]. The following results were obtained.

(1) Appearance of the corrosion-protected part: See **Photos 4 through 6.**

1) No damage or abnormal state was observed in the general section, flange section, or welded section in the Ti cover in the protection layer.

2) Though layers of barnacles and sea squirts had adhered to the surface of the Ti cover, they could be removed easily by hand. Marks of white calcareous adhesive matter which seemed to be adhesive protein from barnacles were also removed by a scraper. Further wiping of the surface with soft paper revealed the metallic luster of titanium.

3) The elasticity of the expanded urethane sheet of the buffer layer coated with petrolatum was reduced a little, but the condition as a whole remained almost intact. There was no rusty extraneous matter on the surface which had been in contact with the steel pipe.

4) The petrolatum paste remained almost as it had been set originally without any deterioration in quality such as solidification, discoloration or loss of volume.

5) The putty for sealing at both top and bottom sections was found to be in a normal condition.

(2) Cross-sectional views of Ti sheet: See **Photos 7 and 8.**

1) Observation of the cross-section of the Ti protection cover sheet revealed no abnormal condition such as corrosion.

(3) Appearance check and thickness examination of the surface of steel pipe pile:

1) The surface of the steel pipe after removing the petrolatum paste looked black, which suggested the presence of iron tannate. However, there was no sign of red rust that would indicate the development of corrosion.

2) The thickness examination did not reveal any corrosion.

3.4.2 Results of appearance check of corrosion-protected part installed at Hasaki

In 1999 we conducted an appearance check of the corrosion-protected part of the steel pipe installed by the flange method in the Hasaki Oceanographical Research Station of the Ministry of Transport in 1985[3]. The examination, which was conducted 14 years after applying the corrosion-prevention measures, showed that the steel

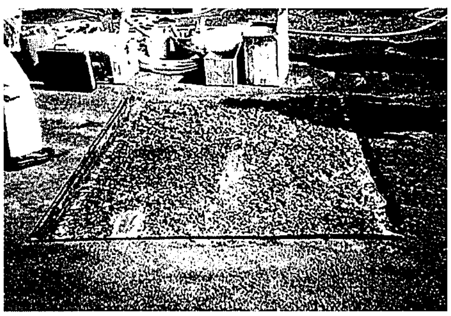


Photo 4 Entire outer surface of Ti cover

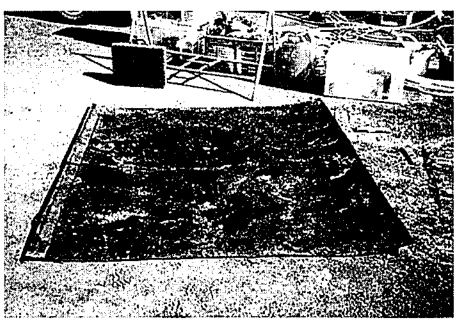


Photo 5 Entire inner surface of Ti cover

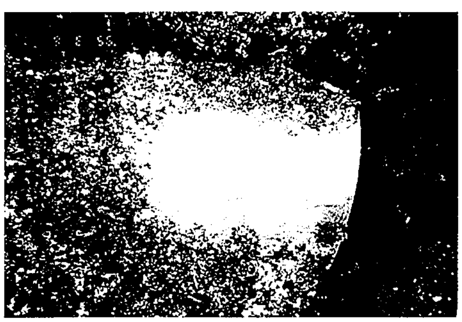


Photo 6 Appearance of outer surface of Ti cover (with marine organisms removed by a scraper)

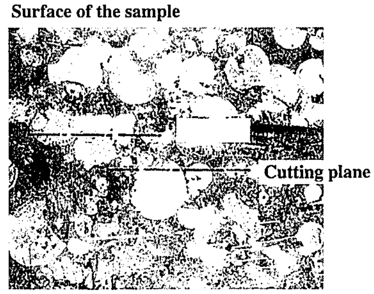


Photo 7 Outer surface of Ti cover

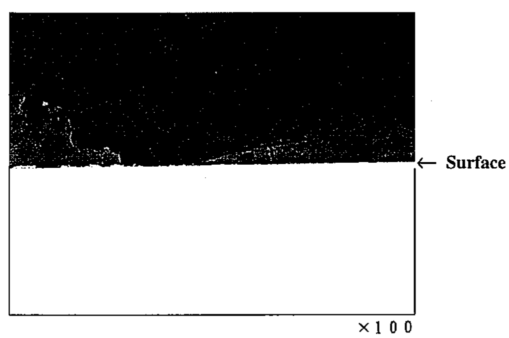


Photo 8 Cross-sectional view of Ti cover

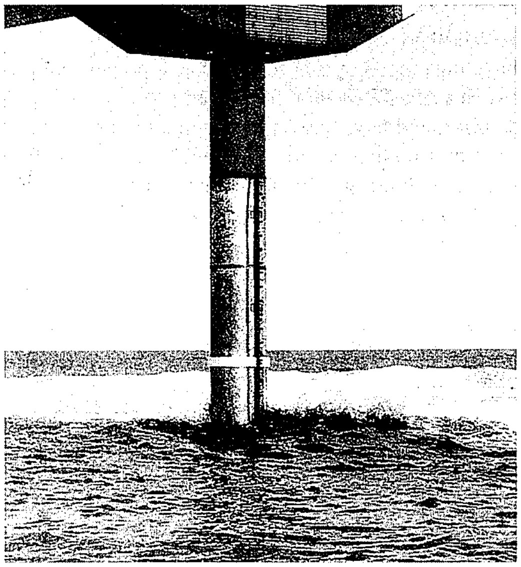


Photo 9 Research pier for field measurement in the nearshore at Hasaki (1985)

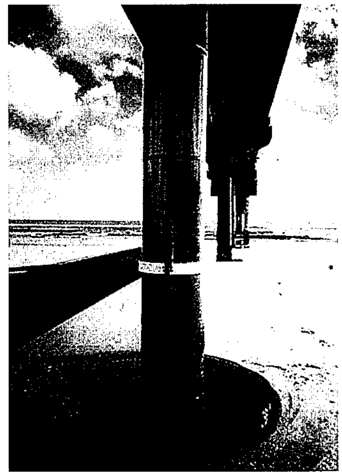


Photo 10 Research pier for field measurement in the nearshore Hasaki (1999)

pipe was in very good condition without any corrosion or damage. (See **Photos 9 and 10**.)

3.4.3 Summary of observation

The dismantling and examination of the steel pipe 10 years after installation showed no corrosion of the steel pipe or deterioration of petrolatum, the appearance check of the steel pipe 14 years after installation showed no corrosion or damage. Therefore, the method is estimated to have a durability of longer than 30 years.

3.5 Ti-cover type petrolatum lining cost

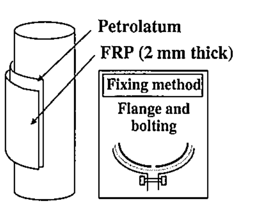
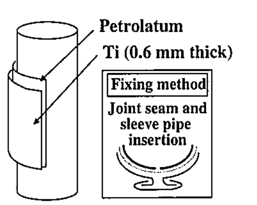
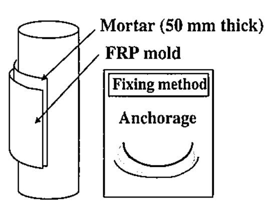
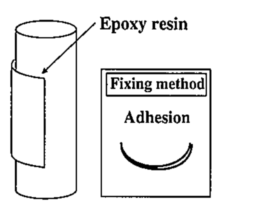
Ti has a high corrosion resistance against sea water and is not vulnerable to corrosion under natural conditions. In addition, the material is not likely to crack from the impact of floating matter due to its high ductility, though some deformation may develop under certain conditions. These advantageous properties enable thinner cover sheet to be used than with FRP, thus reducing the material cost. The total cost of the method is almost the same as that of the conventional FRP method.

We also optimized the installation procedure of the TP method and successfully reduced the time and manpower required to the same level as that of the conventional method, thus reducing the operating cost as well as material cost to those of the conventional level.

In addition to the properties mentioned above, the Ti cover is impenetrable to UV and protects the inner petrolatum against deterioration. As a result, the corrosion prevention tape layer, which directly affects the durability of the corrosion prevention work itself, is extremely durable.

From the above, it is clear that the Ti-cover type petrolatum lining method is practical, offering almost the same work cost yet longer service life than the conventional FRP-cover type petrolatum lining

Table 2 Comparison of corrosion prevention methods for existing steel pipe piles

Name	Petrolatum lining method		FRP mortar lining method	Underwater coating
	FRP-cover type	Ti-cover type		
Typical drawing				
Estimated price (work within Japan)	60,000 yen/m^2 Material Petrolatum 8,000 yen/m^2 FRP-cover 20,000 yen/m^2 Work 32,000 yen/m^2	60,000 yen/m^2 Material Petrolatum 8,000 yen/m^2 Ti-cover 20,000 yen/m^2 Work 32,000 yen/m^2	62,000 yen/m^2 Material Mortar, FRP mold 34,000 yen/m^2 Work 28,000 yen/m^2	50,000 yen/m^2 Material Epoxy resin 20,000 yen/m^2 Work 30,000 yen/m^2
Durability	15 to 20 years	30 to 40 years	15 to 20 years	5 to 10 years
Drawbacks	(1)Cracks due to UV-induced FRP deterioration (2)Cracks due to the impact of driftwood, etc.	Nothing in particular	(1)Cracks due to mortar deterioration (2)Cracks due to the impact of driftwood, etc. (3)Excessive weight	(1)Peeling due to UV-induced coat deterioration (2)Peeling due to the impact of driftwood, etc.
Total evaluation	○ (3,000 yen/m^2/year)	◎ (1,500 yen/m^2/year)	△ (3,100 yen/m^2/year)	▲ (5,000 yen/m^2/year)

method.

Table 2 compares the costs and expected service life of the four major existing post-application methods of corrosion prevention for steel pipe piles: the FRP-cover type petrolatum lining method, TP method, concrete encasing method, and underwater coating method. The table clearly shows that the Ti-cover type petrolatum lining method is the best of these.

3.6 Selection of Ti-cover fixing method

There are three versions of the Ti-cover type petrolatum lining method developed for cover sheet fixing, and a guideline to selecting a particular method is presented below.

(1) The most economical TP method should be used at a site where wave conditions are comparatively moderate.

(2) The welding method should be used at a site where it appears to be difficult to use the TP method due to wave conditions, when a welder can be used on the site.

(3) The flange method should be used in any case other than cases (1) and (2), or when wave conditions are not known for an application abroad.

The detailed conditions required for method selection are now under study and will be compiled in the form of a manual.

4. Conclusions

We have developed optimum Ti-cover type petrolatum lining methods such as the TP method for preventing corrosion in existing steel pipe piles, and have shown that the method costs almost the same as the conventional method, but with better cost-performance.

In September 2000, the recommendations proposed almost simultaneously by the Ministry of Construction and the Ministry of Transport "New Action Plan for the Reduction of Public Work Costs " clearly stipulated the "reduction of life-cycle cost" together with the "reduction of working cost" as measures to reduce the total cost. It is becoming increasingly important to reduce life-cycle cost by reducing maintenance costs and prolonging the service life of all structures.

We believe that the method described in this paper meets today's need to minimize the life-cycle cost. We will promote utilization of this method through various media from now on.

References

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