NIPPON STEEL TECHNICAL REPORT No. 87 JANUARY 2003

UDC 620 . 197 . 6 : 669 . 14 . 018 . 827 : 627 . 2

Development of Metallic Sheathing for Protection of Offshore Steel Structures Using Seawater Resistance Stainless Steel

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Abstract

Offshore steel structures are subjected to severe corrosive environment, thus it is important to apply reliable corrosion protection methods. In recent years, the expected life of structures is extended, therefore the evaluation of the life cycle cost has become a growing interest. A new reliable and economical metallic sheathing for protection of offshore steel structures has been developed. The seawater resistance stainless steel sheets are welded to the structures using an indirect seam welding method. Compared to conventional metallic sheathings, this welding method reduces the material and fabrication costs. The experimental results of the stainless steel sheathing indicate good corrosion resistance in seawater, good impact resistance and good fatigue properties.

1. Introduction

Many offshore structures such as piers and breakwaters compose important social infrastructure and they are required to have a long service life. Offshore steel structures have many advantages such as the use of stable and homogeneous materials, reliable joints by welding, short construction period and high design flexibility. However, the sea forms a severely corrosive environment for steel material and for this reason, corrosion protection measures are indispensable for offshore steel structures. Corrosion occurs most conspicuously at a splash zone and a tidal zone, but it is difficult to apply cathodic protection to these zones. Therefore, the application of reliable corrosion protection measures to the splash and tidal zones is important for sustaining a long service life of offshore steel structures[1,2)].

Covering protection methods whereby steel members are covered with environment insulating material are widely applied as the corrosion protection measures for the splash and tidal zones. Organic materials such as paints, polyethylene resins and fiber-reinforced plastics are widely used as the covering materials. The covering protection using organic materials is an excellent protection method because of relatively low initial costs and ease of application to portions having complex shapes. It is not easy, however, to prevent steel members from contacting corrosive elements, such as water and oxygen, for a long period, because of damage from collision of drifting objects and aging of the protecting materials. Therefore, a considerable amount of maintenance costs is incurred for the repair and renewal of the protecting materials during a long period of use.

For the above reason, corrosion protection by sheathing with corrosion-resistant metal is sometimes applied to offshore steel structures of which an ultra-long service life of 50 to 100 years is expected[3,4)]. The corrosion-resistant metal sheathing is a corrosion protection method wherein steel structural members are completely insulated from corrosive environment by corrosion-resistant metal materials having excellent resistance against corrosion and impact such as titanium and stainless steel. The method realizes low maintenance costs since little repair of the protection materials is neces-

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Photo 1 Example of application of seawater-resistant stainless steel sheathing (jacket type wharf)

sary during the service life of the structures. However, actual application of the method has so far been limited because of higher initial costs including the material costs than heavy-duty coating and the like.

In view of the situation, for reducing the initial costs of the corrosion-resistant metallic sheathing, Nippon Steel Corporation developed a corrosion protection method in which seawater-resistant stainless steel sheathing is employed (see **Photo 1**). This paper reports an outline of the corrosion protection method employing seawater-resistant stainless steel sheathing.

2. Characteristics of Corrosion Protection Method with Seawater-resistant Stainless Steel Sheathing

The developed corrosion protection method consists of insulating structural steel members from corrosive elements by covering them with Nippon Steel's seawater-resistant stainless steel, YUS270[5] (20Cr-18Ni-6Mo-0.2N-LC), and welding the ends of the covering materials[6]. An offshore steel structure covered with YUS270 is protected against corrosion for a long period, thanks to the advantages such as:

- Significantly, lower initial costs compared with conventional metal sheathing methods owing to a newly developed indirect seam welding method.
- Sheathing prefabricated in a fabrication plant ensures stable quality and shortens the time of site work.
- Sealing the structural members with stainless steel sheets completely insulates from penetration of corrosive elements.
- Excellent resistance of the covering material against impact, corrosion and fatigue minimizes the possibility of its being damaged.
- If the covering material is damaged, it can be repaired.

3. Sheathing Work of Seawater-resistant Stainless Steel

3.1 Portions to be covered

As shown in **Fig. 1**, offshore corrosion environment to which offshore steel structures are exposed is classified, vertically, into 5 zones: a normal atmosphere zone above water, a splash zone, a tidal zone, an underwater zone and a seabed zone. It is in the splash and tidal zones that the rate of corrosion is the highest, because there waves and tides easily form a film of water containing much oxygen and salt on the surfaces of the steel members.

The sheathing of the seawater-resistant stainless steel is applied in the normal atmosphere zone, splash zone, tidal zone and a part of the underwater zone. The cathodic protection method, which is economical and reliable, as well, is applied to the most of the underwater zone and the seabed zone.

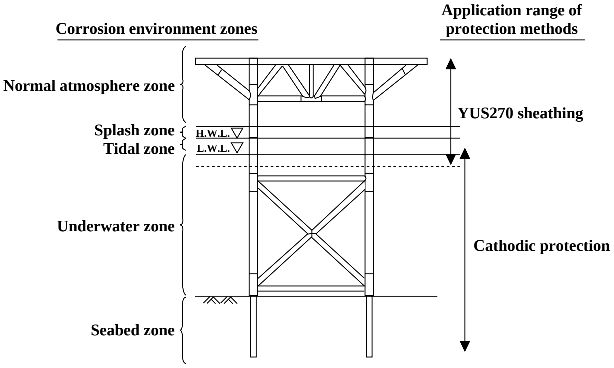


Fig. 1 Corrosion environment zones and application range of YUS270 sheathing of offshore steel structure

3.2 Indirect seam welding method

Owing to good seawater corrosion resistance of YUS270 used for the sheathing, no corrosion allowance has to be provided for in the thickness of the protecting material. An indirect seam welding method was newly developed for stably welding 0.4-mm thick sheets of YUS270, which are widely available as a building roof material. The indirect seam welding method is a welding method for continuously welding sheet materials by passing a welding current intermittently between two disc-shaped electrodes while having the electrodes travel along a weld joint line as shown in **Fig. 2**. When a large current is passed for a short period between two disc electrodes pressed onto the surfaces of the materials to be welded, the materials melt locally by resistance heating between contact surfaces and weld together. The method has the following advantages over the sheathing work by conventional TIG welding:

- Whereas, in TIG welding, a minimum thickness of material of 1.5 mm or so is required for avoiding fusion damage, the developed method can stably weld sheet materials as thin as 0.4 mm or so.
- Welding speed of the indirect seam welding is approximately 1 m/min, higher than that of TIG welding.
- Automatic welding under operator's monitoring and adjustment is possible.
- Since the welding is done by resistance welding, no welding material is necessary.

Thanks to these advantages, the new welding method realizes significant reduction of initial costs compared with TIG welding through lower material costs and higher work efficiency.

3.3 Sheathing thickness of seawater-resistant stainless steel

In simple shape portions such as straight pipe or box members, the material cost is reduced when the indirect seam melding method is applied because thin covering sheets of on order 0.4 to 0.6 mm can

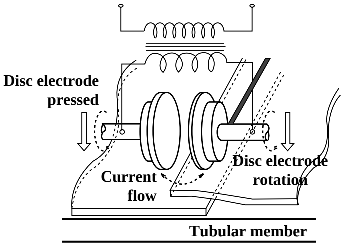


Fig. 2 Schematic illustration of indirect seam welding

Table 1 Thickness of seawater-resistant stainless steel sheet for sheathing

Portion to be sheathed	Thickness of YUS270 sheet
Straight pipes or beams	Approx. 0.4 to 0.6 mm
Complicated shape portion like tubular joints and portions requiring high strength	Approx. 1.5 mm

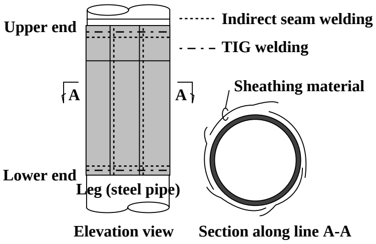


Fig. 3 Sheathing of tubular member with YUS270 sheets

be used. In complicated shape portions like tubular joints, YUS270 covering sheets 1.5 mm or so in thickness are welded by TIG welding. Even in the simple shape portions, use of a covering material about 1.5 mm in thickness may be recommended in the case that ship collision is expected and a greater strength is required (see **Table 1**).

3.4 Work method of simple shape portions

Fig. 3 shows the sheathing of tubular member with YUS270 sheets. The portion to be protected is covered with the YUS270 sheets, and the portions where the covering sheets overlap with each other and their upper and lower ends are welded by the indirect seam welding. For securing water-tightness of the overlapped joints between the YUS270 sheets, the upper and lower ends of the sheathing are sealed, additionally, by TIG welding. After the sheathing work, the welded joints are tested for soundness through a leak test by blowing air from inside the steel pipe into the interface between the pipe and the sheathing.

Sheathing of profile members such as H-beams is done, first, by welding cover plates between flanges to form a box section and, then, welding the sheathing sheets from outside by the indirect seam welding.

According to a current specification, the joints welded by the indirect seam welding are finished by TIG welding. TIG welding was not easily applicable to thin stainless steel sheets about 0.4 mm in thickness since the sheets were likely to fuse. By the above procedure, however, the heat of welding is dissipated to the steel structural member through the beads of the welded seams, and thus TIG welding is applicable. The finishing by TIG welding reduces crevices where foreign matters are likely to deposit and which are difficult to inspect visually.

3.5 Work method of complicated shape portions

Since it is difficult to apply the indirect seam welding to complicated shape portions, welding is done by conventional TIG welding and YUS270 sheets 1.5 mm in thickness, instead of 0.4 to 0.6 mm, are used for the sheathing. Corrosion resistance of welded joints is secured by using Inconel 625 as the highly corrosion-resistant welding material. The soundness of welded joints is confirmed by means of a penetrating test.

For reducing total protection costs of a structure, it is desirable that complicated shape portions are arranged, insofar as is possible, in the normal atmosphere zone where maintenance is relatively easy and the underwater zone where the sheathing is not required. Use of organic coatings such as high-build epoxy resin coating in the atmosphere zone may be effective for reducing the total corrosion protection costs, depending on the expected service life of the structure.

4. Corrosion Protection Performance of Seawater-resistant Stainless Steel Sheathing

The protected portion covered with the seawater-resistant stainless steel sheathing is insulated from corrosive elements, and it does not corrode unless the sheathing is broken. The sheathing may be broken when (1) the YUS270 material is corroded, (2) it is physically damaged by a colliding object, or (3) a weld joint is broken by fatigue. In view of the above possibilities, the authors examined corrosion resistance of YUS270 and impact resistance and fatigue properties of the seawater-resistant stainless steel sheathing.

4.1 Mechanical properties of YUS270

The mechanical properties of YUS270 according to its product standard are shown in **Table 2** together with actual values of a sample product. YUS270 is a high-strength stainless steel having a proof stress 1.5 times those of JIS SUS 304 and 316. It is also excellent in impact and abrasion resistance owing to high hardness.

4.2 Corrosion resistance of YUS270

YUS270 is an austenitic seawater-resistant stainless steel having chemical composition designed for realizing excellent corrosion resistance against seawater. Its remarkably high corrosion resistance is realized by adding a sufficient amount of Mo and, then, N and Cu to a high-Cr steel[7], and its typical chemical composition is 20Cr-18Ni-6Mo-0.2N-0.7Cu. It counts many successful applications to seawater desalination plants, heat exchangers for seawater and building roofs in coastal locations.

Table 3 shows pitting corrosion resistance and crevice corrosion resistance of YUS270 as evaluated according to JIS G 0578. The critical crevice corrosion temperature in the table is deemed to correspond substantially to the upper limit temperature not to cause corrosion in normal seawater, and thus, the evaluation result attests to that, YUS270 is suitable for use in normal temperature seawater.

Photo 2 shows test pieces of YUS270 and other stainless steels subjected to a seawater shower test for 4 years and 6 months conducted by the Port and Airport Research Institute, an independent administrative institution. It is clear from the photo that YUS270 keeps its metallic luster after the test period and has better corrosion resistance compared with SUS 304 and 316.

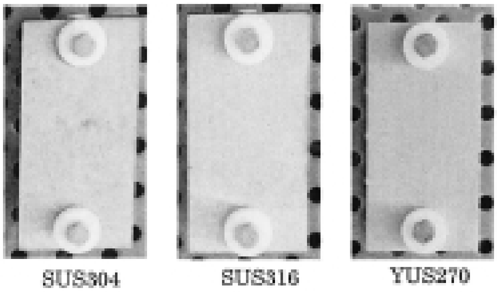
Table 2 Mechanical properties of YUS270

Product standard		Thickness (mm)	0.2% proof stress (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	Hardness V
YUS270	Standard	-	≧ 300	≧ 650	≧ 35	≦ 230
	Example	1.2	461	843	39	192

Table 3 Critical pitting corrosion temperature and critical crevice corrosion temperature

	Seawater-resistant stainless steel YUS270	Pure Ti	SUS 316L
Critical pitting corrosion temperature (°C)	70	> 80	15
Critical crevice corrosion temperature (°C)	50	> 80	0

a) Exposure test at Port and Airport Research Institute



b) Test pieces after 4-year exposure

Photo 2 Corrosion resistance evaluation of stainless steel through seawater shower test

4.3 Measures against galvanic corrosion

In seawater, YUS270 shows a higher electric potential than carbon steel. For this reason, when YUS270 is in contact with carbon steel in seawater, an electric current flows from the carbon steel to YUS270 through the seawater as shown in **Fig. 4**, accelerating corrosion of the carbon steel. When stainless steel and carbon steel are used together in seawater, therefore, attention should be paid to the phenomenon, which is called galvanic corrosion. In the case of the developed sheathing technology, although YUS270 and carbon steel contact each other, since the carbon steel is insulated from corrosive environments by the high-build epoxy resin coating in the atmosphere zone, the galvanic corrosion does not occur under normal conditions. In addition, since cathodic protection with aluminum anodes is applied to the underwater zone, a protective current flows from the aluminum anodes having the lowest potential to the carbon steel portion and the seawater-resistant stainless steel sheathing as seen in Fig. 4 b), the carbon steel is prevented from corroding.

4.4 Impact resistance

The sheathing in the splash and tidal zones may be damaged from the impact of collision of ships and drifting objects. In view of such a possibility, the authors evaluated impact resistance of the seawater-resistant stainless steel sheathing.

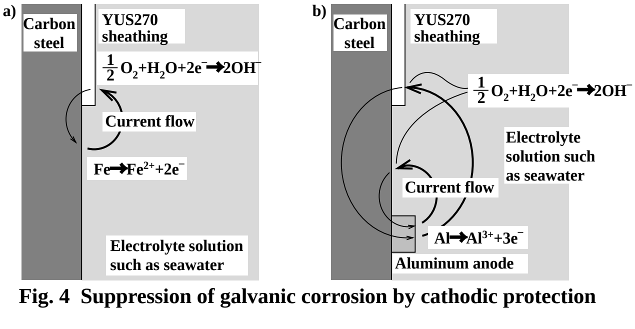


Fig. 4 Suppression of galvanic corrosion by cathodic protection

Impact test was carried out based on ASTM G14, which stipulates the impact resistance evaluation method of protection coating for line pipes; a 25-kg weight was dropped from a height of 4 m as shown in **Fig. 5** to hit a stainless steel sheathing 0.4 mm in thickness at an impact energy of 1,000 N·m. **Photo 3** shows a sectional micrograph of a test piece after the impact test. Although the base metal suffered a deformation, there was no penetrating damage to the sheathing either in flat portions or in welded joints.

The energy of 1 kJ (1,000 N·m) is roughly equivalent to the impact energy of a collision of a 20-gross-ton small ship at a speed of 0.2 m/s[8]. A steel punch having a tip diameter of 16 mm was used in the impact test, but the impact energy will be more widely dispersed in a real collision, since the contact area of the sheathing with the colliding object will be larger. For this reason, the authors consider that the possibility of a penetrating damage to the sheathing is limited even when the impact energy exceeds 1 kJ. **Fig. 6** shows impact test results of other commonly used covering materials for comparison purposes. It is clear from the figure that the seawater-resistant stainless steel sheathing has far higher impact resistance.

4.5 Fatigue properties of welded seam

Welded seams of the sheathing are subject to repetitive external force of wind and waves. For evaluating fatigue properties, the authors carried out a fatigue test of welded joints of sheathing sheets 0.5 mm in thickness.

Test pieces shown in **Fig. 7**(a) were prepared and a partially pulsating stress test (stress ratio: 0.1) was carried out at a frequency of 10 Hz, controlling the stress. As a result, an S-N curve shown in Fig. 7(b) was obtained. The welded seam of the sheathing has fatigue

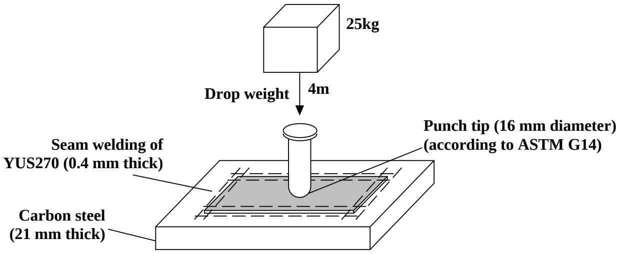


Fig. 5 Drop weight impact test of YUS270 sheathing

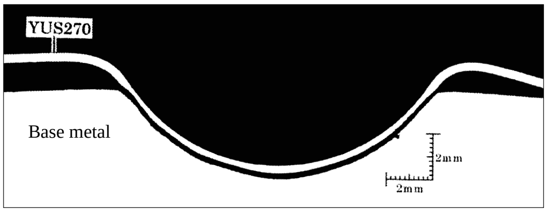


Photo 3 Sectional micrograph of test pieces after impact test (YUS270: 0.4 mm thick)

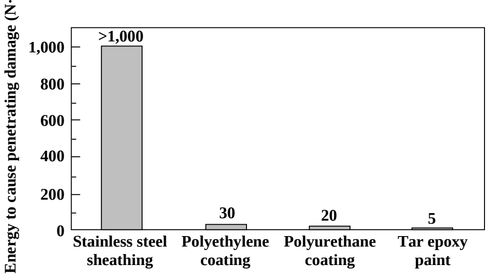
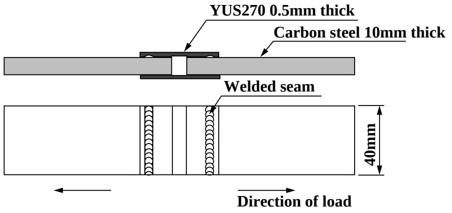
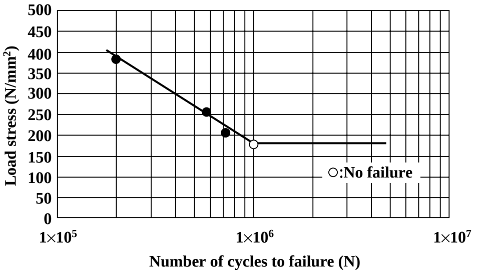


Fig. 6 Impact resistance of coating materials (punch diameter: 16 mm)



(a) Test piece for fatigue test



(b) S-N curve obtained through fatigue test

Fig. 7 Fatigue test of welded joints by indirect seam welding

Photo 4 Marine exposure test of steel pipes with YUS270 sheathing

properties nearly equivalent to the fatigue design curve of Category A (for shear stress joints) of the Fatigue Design Guideline[9]. The properties of the fatigue design curve of Category A is the same as that of a mechanically finished steel strip (with mechanically finished surfaces and edges) and thus, the above result confirms very good fatigue properties of the welded seam of the sheathing.

4.6 Marine exposure test

Steel pipes covered with the seawater-resistant stainless steel sheathing were exposed to a marine environment at the quay of Nippon Steel's Wakamatsu Fabrication Center in Wakamatsu-ku, Kita-kyushu City (see **Photo 4**). After 3 years of exposure, no corrosion was observed in any part of the sheathing including welded joints and crevices where marine life has attached. It was also confirmed through the test that galvanic corrosion in the underwater zone could be prevented by use of cathodic protection together with the sheathing.

5. Maintenance of Seawater-resistant Stainless Steel Sheathing

5.1 Design of cathodic protection

Since YUS270 does not corrode in normal seawater, no cathodic protection is required for the sheathed portions. However, it should be noted that the sheathing is electrically connected to the carbon steel portions in the underwater zone, which are subject to the cathodic protection, and the protective current from aluminum alloy anodes flows to the YUS270 sheathing, too. It was confirmed through tests that the amount of current flowing to the seawater-resistant stainless steel sheathing below the waterline was nearly equal to that flowing to the carbon steel portions in the underwater zone[10]. Based on this finding, Nippon Steel recommends that, in the design of cathodic protection, the seawater-resistant stainless steel sheathing below the mean seawater level be covered by the cathodic protection as shown in **Table 4**.

Table 4 Example of cathodic protection design for steel structure with stainless steel sheathing

Portions covered by cathodic protection	Protective current density
Carbon steel portions	100 mA/m²
Seawater-resistant stainless steel sheathing (from underwater zone to mean seawater line)	100 mA/m²

5.2 Repair of damaged portions

In the event that damage is inflicted on the sheathing, if the position is in the splash zone or in the upper part of the tidal zone, the damage can be repaired on the spot by patching the damaged portion with a YUS270 sheet 1.5 mm in thickness using TIG welding. It has been confirmed that if the damage is in the underwater zone and even if the carbon steel is exposed to seawater, the carbon steel is protected by the cathodic protection. Such damage can be repaired by the patching method by setting up a dry chamber around the damaged part. Further, any of the petrolatum and protective cover system, which are established technologies for site repair work, can be applied[11].

5.3 Maintenance of stainless steel sheathing

It is important to keep a structure designed for a long service life under good maintenance of protective materials. Nippon Steel recommends, for example, an offshore structure provided with the seawater-resistant stainless steel sheathing in the tidal zone and above and anodic protection in the underwater zone be inspected as follows: visual inspection of the sheathing and potential measurement for confirming the condition of the cathodic protection once a year; and detail visual inspection of the sheathing and inspection of the sheathing and anodes in the underwater zone by a diver once in every 5 years. An ultra-long service life of 100 years or more can be realized without requiring large-scale maintenance work, if the above periodical inspections are abided by and in the event of an accident, an extra inspection is carried out and appropriate repairing measures are taken. Further rationalization and man-power saving of maintenance activities will be realized through remote 24-hour monitoring of the protective materials and similar measures, which will probably be made viable before long.

6. Application Records

Typical structures to which the seawater-resistant stainless steel sheathing has been applied so far are listed in **Table 5**.

7. Closing Remarks

The importance of life cycle cost evaluation is increasing lately in the design of structures. In the corrosion-protection design of offshore steel structures intended for a long service life, conventionally, there were only two alternatives: "low initial costs and high maintenance costs" or "high initial costs and low maintenance costs". The seawater-resistant stainless steel sheathing described herein is a corrosion protection method for minimizing life cycle costs of long service life structures whereby “low initial costs and low maintenance costs” are realized.

While the developed sheathing method is accumulating actual application references, studies for more efficient joint work and exposure tests are continuing aiming at further reduction of initial costs and enhancement of reliability. The authors intend to further refine the corrosion protection system by improving both the economical efficiency and reliability through the studies and feedback of the actual performance of the sheathing already applied.

Table 5 Typical structures to which the seawater-resistant stainless steel sheathing is applied

Name of facility	Location	Type of structure	Year
Unloading bridge of Etomo fishing harbor	Muroran, Hokkaido	Pier	1997
Breakwater of Haedomari fishing harbor	Takashima, Nagasaki	Jacket type breakwater	1998, 1999
Breakwater of Ohtsushima (Umashima) fishing harbor	Tokuyama, Yamaguchi	Jacket type breakwater	1999, 2000
Pier of Sakai fishing harbor	Sakaiminato, Tottori	Jacket type pier	1999, 2002
No. 2 LNG berth of Futtsu Thermal Power Plant	Futtsu, Chiba	Jacket type wharf	1999
Breakwater of Saganoseki fishing harbor	Saganoseki, Oita	Jacket type breakwater	2001
New berth No. 5, Oi Container Terminal	Shinagawa-ku, Tokyo	Jacket type wharf	2002
Vertical shaft of Yumesu Tunnel, Osaka port	Osaka, Osaka	Vertical shaft of immersed tube tunnel	2002
Futajima berth, Kita-kyushu port	Kita-kyushu, Fukuoka	Jacket type wharf	2002
Kawashiro berth, Kita-kyushu port	Kita-kyushu, Fukuoka	Jacket type wharf	2002

Reference

1) Kanai, H., Ishida, M.: Bosei Kanri (Rust Prev. Control). 43(5), 167-185 (1999)
2) Tamada, A.: Zairyo-to-Kankyo. 45(4), 244-255 (1996)
3) Yamamoto, A., Hase, T., Takahashi, Y.: Titanium. 47(3), 218-226 (1999)
4) Jones, B. L., Sansum, A. J.: Corrosion Management. 1996, p.9-14
5) Yoshida, T.: Bosei Kanri (Rust Prev. Control). 42(9), 330-334 (1998)
6) Sato, H., Kawai, Y., Iwami, H., Ishida, M., Kanai, H., Moritaka, H.: Proceeding of Civil Engineering in the Ocean. 16, 405-410 (2000)
7) Uki, T.: Zairyo-to-Kankyo. 41, 329-340 (1992)
8) Watabe, Y.: Harbour Engineering. Corona Publishing, 1979
9) Japanese Society of Steel Construction: Fatigue Design Guideline of Steel Structures. 1993
10) Sasaki, N., Sato, H., Ishida, M., Abe, M.: Bosei Kanri (Rust Prev. Control). 46(3), 6-11 (2002)
11) Abe, M.: Corrosion and Corrosion Protection of Offshore Steel Structures. Japan Association of Corrosion Control, 2002