Development of Anti-Biofouling Methods for Gate Facilities

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In the maintenance and management of gate facilities, a large sum of money and labor are required to remove and clean organisms that attach themselves to the facilities. That is why we developed two anti-biofouling systems, one that uses a weak electric current and another that uses ultrasonic waves. We carried out basic examinations and actual environment examinations to verify the effects of these methods. As a result, it has been confirmed that these methods effectively anti-foul the parts they are applied to, and that they can be used on gate facilities. In the future, we will evaluate their adaptability to aqueducts, such as those used in thermal and nuclear power plants, and marine structures, such as floating breakwaters, in addition to gate facilities.

1. Introduction

In the maintenance of dams, water gates, weir, sluice and other gate facilities constructed at locations close to river mouths, a large amount of money and labor are required to remove and dispose of marine organisms that attach themselves to the facilities. A particular concern is that marine organisms such as barnacles not only spoil the appearance of the facilities, but also cause crevice corrosion at the point of contact between the marine organisms and steel materials. When marine organisms attach themselves to gate guide at a gate facility, there is a risk of the rubber seal becoming damaged during the facility's operation, thereby significantly impairing its functionality.

There are three main types of measures that can be implemented to prevent the attachment of marine organisms: chemical, physical and mechanical. Chemical measures include the injection of a hydrogen peroxide solution and the application of anti-biofouling paint, physical measures include ultraviolet light irradiation and hot water treatment, while mechanical measures include dust filters for marine organisms and high-pressure washing machines.[(1), (2)] However, all of these measures are problematic in terms of the sustainability of their effects, workability, costs and environmental impact.

In light of these factors, we have developed a revolutionary anti-biofouling system that prevents the attachment of marine organisms without affecting the environment. This system enables two types of systems to be flexibly applied to facilities in accordance with their structure and shape, as shown in **Fig. 1**. One of these systems is the weak-current, anti-biofouling system which utilizes an oxygen consumption reaction initiated by energizing seawater or brackish water and is effective for side gate guide (particularly those made of stainless steel) with narrow and intricately shaped sections. The other is the ultrasonic anti-biofouling system, which utilizes ultrasonic cavitation and is effective for skin plate with a large surface area. These measures are environmentally safe and provide long-lasting anti-biofouling effects.

This paper outlines the anti-biofouling system that we have developed and details the results of the basic verification test and the one-year verification test that we conducted under an actual environment using test pieces.

2. Weak-current anti-biofouling system[(3)]

2.1 Principles and system configuration

The weak-current anti-biofouling system involves the use of insoluble electrodes and a DC constant current power supply. This system prevents marine organisms from attaching themselves to a protected area in a manner that reduces the diffusion layer of the cathode (Nernst diffusion layer) to a hypoxic atmosphere through an oxygen consumption reaction. The reaction is initiated by applying an electric current from an insoluble electrode installed near the protected area as an anode to the protected area as a cathode (**Fig. 2**).

2.2 Effects

Figure 3 shows the results of the test that we conducted to confirm the anti-biofouling effect of the weak-current anti-biofouling system under an actual environment with test pieces immersed in seawater for about 3 months during the breeding season for marine organisms. Barnacles and other marine organisms attached themselves across the entire surface of test piece (dimensions: 150 × 300 × 2 mm; material:

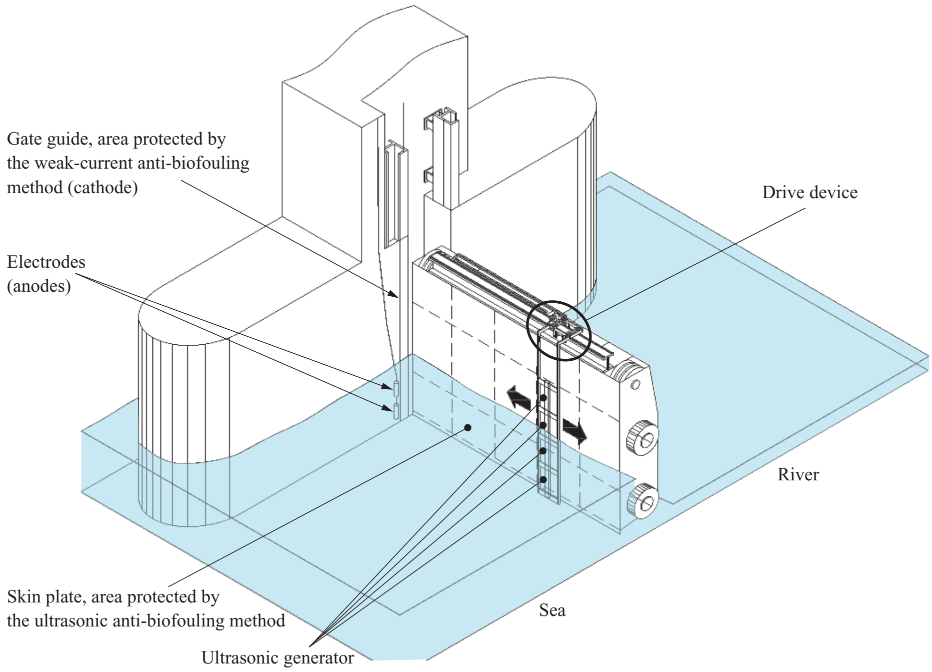


Fig. 1 Conceptual image of application of anti-biofouling method for roller gates

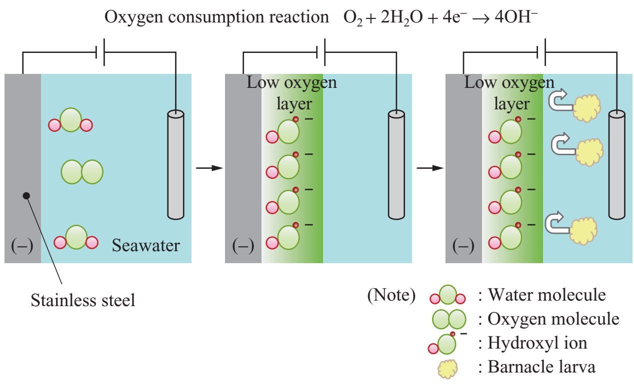


Fig. 2 Principle of weak electric current anti-biofouling method

SUS316) to which the weak-current anti-biofouling system had not been applied (**Fig. 3-(a)**). In contrast, almost no marine organisms attached themselves to the test piece to which the system had been applied (**Fig. 3-(b)**).

After that, the system was tested on a rising sector gate, as shown in **Fig. 4**. The test was conducted over the course of one year with an electric current (i.e. the method) being applied to the gate guide on one side (the one on the left bank) but not to the gate guide on the other side (the one on the right bank). **Figure 5** compares the degree to which the marine organisms attached themselves to either gate guide. As was the case with the test results for the test pieces shown in **Fig. 3**, barnacles and other marine organisms attached themselves to the gate guide on the right bank, to which the anti-biofouling system had not been applied (**Fig. 5-(a)**), but almost no marine organisms attached themselves to the gate

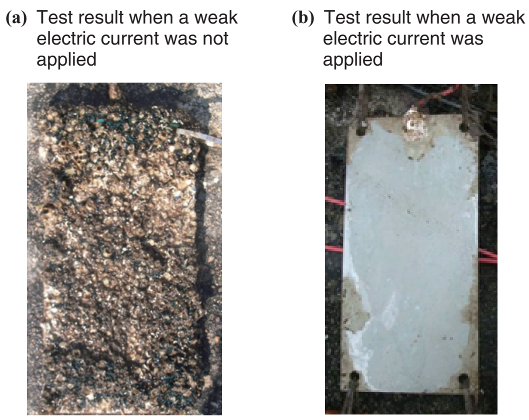


Fig. 3 Result of immersion test for weak electric current anti-biofouling method during breeding season of attached organisms

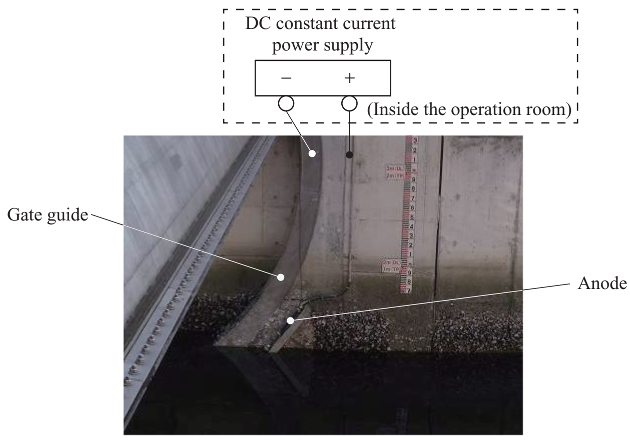


Fig. 4 Example of application to a rising sector gate

	(a) When electric current was not applied	(b) When electric current was applied
Full view of the gate guide		
Portion of the gate guide just above the sea surface		
Portion of the gate guide under the sea		

Fig. 5 Result of immersion test after application of weak electric current anti-biofouling method for one year

guide on the left bank, to which the anti-biofouling system had been applied (**Fig. 5-(b)**).

There was a significant difference between the test results obtained when the anti-biofouling system was applied and those obtained when it wasn't applied. Thus, we have confirmed that the weak-current anti-biofouling system has an excellent anti-biofouling effect.

Figure 6 shows the energization states for the tested gate guide as visualized through numerical analysis (FEM analysis). Because the analysis results are almost in accordance with the actual electric potential measurements, it can be said that simulation using FEM analysis is an effective tool for predicting the distribution of electric potential. In addition, because numerical analysis can also be used to estimate the electric current density distribution, it can be used in combination with test data under actual energization conditions to plan the installation positions for electrodes on the protected object facilities.

Figure 7 shows the SUS304 test piece (dimensions: 150 × 300 × 2 mm) that was subjected to the immersion test during the breeding season for marine organisms. After all of the marine organisms had been removed from the test piece,

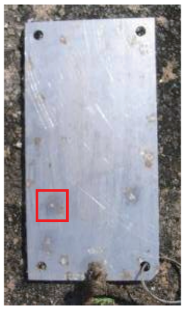
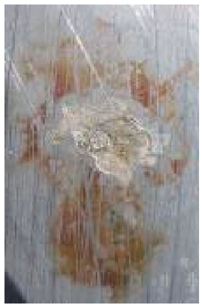
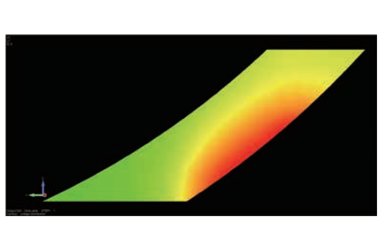
(a) Test piece after the immersion test	(b) Test piece after the removal of marine organisms (An example of pitting corrosion is enclosed in a red square.)	(c) Enlarged view of the pitting corrosion
		

Fig. 7 Sea immersion result of SUS304 test piece

	(a) When electric current was not applied	(b) When electric current was applied
External view		
Simulation		
Actual measurement of electric potential	−0.845 V (vs. SCE)*1	−1.22 V (vs. SCE)*1
Simulated electric potential	−0.842 to −0.851 V (vs. SCE)*1	−0.966 to −1.088 V (vs. SCE)*1

(Note) *1 : Measured using a Saturated Calomel Electrode (SCE) as a reference

Fig. 6 Numerical-analysis result while electric current is flowing pitting corrosion was found in locations where barnacles had attached themselves (**Figs. 7-(b)** and **-(c)**). In contrast, pitting corrosion was not found on the test piece to which the weak-current anti-biofouling system had been applied since no marine organisms attached themselves to it (**Fig. 3-(b)**). In conclusion, we have confirmed that the weak-current anti-biofouling system offers an effective means of preventing pitting corrosion (crevice corrosion).

3. Ultrasonic anti-biofouling system[4]

3.1 Principles and system configuration

Figure 8 shows the process by which marine organisms attach themselves to a structure.[5] The process starts when organic substances (protein and polysaccharide) attach themselves to the surfaces of the structure, after which bacteria attach themselves to these organic substances and begin to grow (1st and the 2nd stages). Following this, a slime layer forms when organic substances in the seawater accumulate in a bacterial layer (3rd stage). It is estimated that it takes no more than one day to reach the 3rd stage of the process. After this, sea algae attach themselves to the slime layer (4th stage). Finally, the larvae of marine organisms such as barnacles and mussels attach themselves to the sea algae, where they then proliferate and grow (5th stage).

Ultrasonic waves have been widely used in the washing of a wide variety of goods ranging from commodities to electronic appliances. The ultrasonic wave frequency is adjusted in accordance with the type of fouling and the object to be washed. For example, low-frequency ultrasonic waves are suitable for removing fouling through cavitation impact, while high-frequency ultrasonic waves are suitable for removing fouling by oscillating the surrounding water. To prevent the attachment and proliferation of marine organisms, the method that we have developed uses the detergent effect of ultrasonic waves in a manner that irradiates the slime layer with ultrasonic waves (**Fig. 9**).

The ultrasonic anti-biofouling system involves the use of an ultrasonic vibrator and a control device.

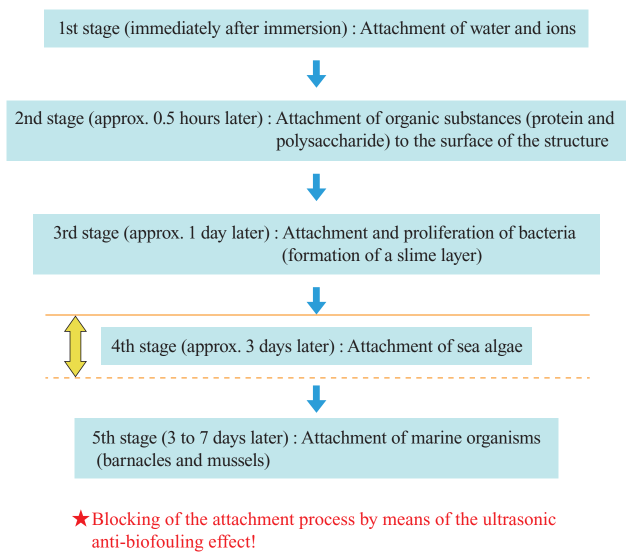


Fig. 8 Adhesion process of oceanic organisms

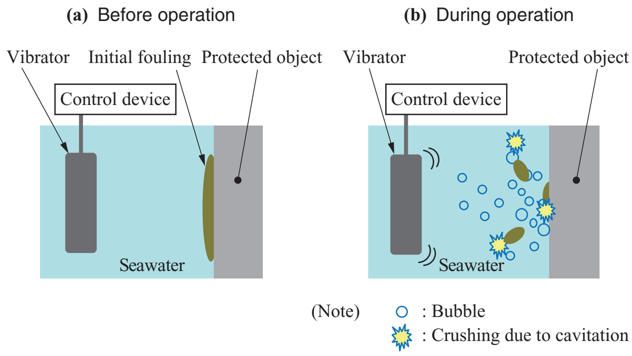


Fig. 9 Principle of ultrasonic anti-biofouling method

3.2 Effects

The effects of the ultrasonic anti-biofouling system were tested using 8 test pieces (individual dimensions: 200 × 300 × 1.6 mm), as shown in **Table 1**. These test pieces included 2 made of different types of stainless steel (SUS316 and SUS304) and 6 made of common steel. The different types of paint systems that were employed were ones that have been frequently used for existing gate facilities and are stipulated in "Kikaikoji toso youryo-doukaisetsu" (the Practical Guide for Painting Mechanical Facilities (Draft); published April 2010) as paint systems suitable for new construction work. **Figure 9** illustrates the principles of the ultrasonic anti-biofouling system. **Figure 10** shows the test conditions for the ultrasonic anti-biofouling system. At a test facility, ultrasonic waves were applied to the test pieces intermittently for a period of one year. **Figure 11** shows fouling on the test

Table 1 Material list for test

	Process	Paint system
No. 1: Corresponds to A-1 in the Practical Guide (Draft)	1st layer	Epoxy zinc-rich resin primer
	2nd layer	Epoxy resin paint primer (for immersed area)
	3rd layer	Epoxy resin paint primer (for immersed area)
	4th layer	Epoxy resin paint top coat
No. 2: Corresponds to A-2 in the Practical Guide (Draft)	1st layer	Epoxy zinc-rich resin primer
	2nd layer	Epoxy resin paint primer (for immersed area)
	3rd layer	Epoxy resin paint primer (for immersed area)
	4th layer	Fluorine resin paint top coat
No. 3: Corresponds to A-3 in the Practical Guide (Draft)	1st layer	Epoxy zinc-rich resin primer
	2nd layer	Epoxy resin paint primer (for immersed area)
	3rd layer	Epoxy resin paint primer (for immersed area)
	4th layer	Polyurethane resin paint top coat
No. 4: Corresponds to B-1 in the Practical Guide (Draft)	1st layer	Epoxy zinc-rich resin primer
	2nd layer	Epoxy resin paint primer (for immersed area)
	3rd layer	Epoxy resin paint primer (for immersed area)
No. 5: Corresponds to D-1 in the Practical Guide (Draft)	1st layer	Paint primer containing glass flakes
	2nd layer	Vinyl ester resin glass flake paint
	3rd layer	Vinyl ester resin glass flake paint
No. 6: Corresponds to D-2 in the Practical Guide (Draft)	1st layer	Epoxy zinc-rich resin primer
	2nd layer	Epoxy resin glass flake paint
	3rd layer	Epoxy resin glass flake paint
No. 7 SUS316	—	No paint
No. 8 SUS304	—	No paint

(a) External appearance of the test facility   **(b)** Installation conditions for the test piece

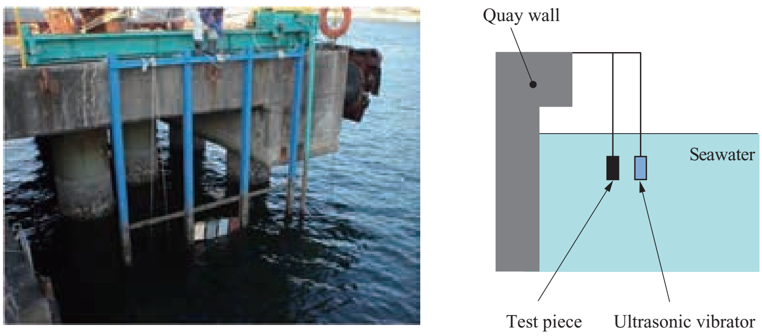


Fig. 10 Ultrasonic system test environment

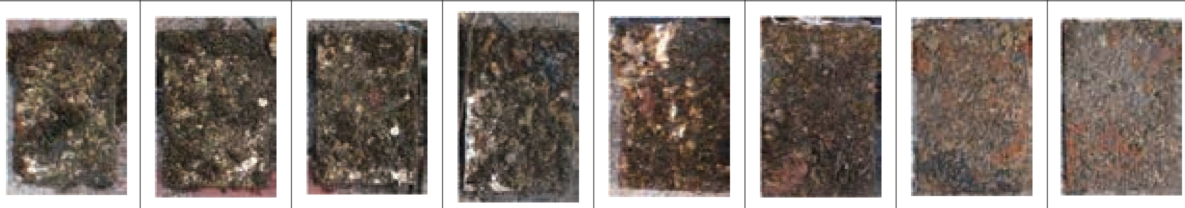
Test piece No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
Initial condition								
Test piece when the ultrasonic anti-biofouling method was not applied								
Test piece when the ultrasonic anti-biofouling method was applied								

Fig. 11 Result of immersion test after application of ultrasonic anti-biofouling method for one year

pieces after one year had elapsed.

Barnacles and other marine organisms attached themselves to the entire area of the test pieces to which the ultrasonic anti-biofouling system had not been applied. In contrast, the attachment of marine organisms was curbed on the test pieces to which the ultrasonic anti-biofouling system had been applied. Some parts of the test pieces were not sufficiently irradiated with ultrasonic waves, so these areas were excluded from the test pieces used in the evaluation. Because no damage or deterioration resulting from ultrasonic cavitation was found on the test pieces to which the paint had been applied, we were able to confirm that the ultrasonic anti-biofouling system can be applied not only to stainless steel, but also to painted steel.

4. Conclusion

The anti-biofouling system was developed for the protection of gate facilities that have been seriously affected by the fouling of marine organisms. Our test results confirmed that both the weak-current anti-biofouling system and the ultrasonic anti-biofouling system offer an extremely effective means of preventing fouling by marine organisms.

The system is extremely effective in protecting gate facilities located at river mouths, and it can also contribute to the following: improved maintenance performance and reduced maintenance costs due to labor savings; improvements to the appearance of facilities; and reduced environmental impact.

The anti-biofouling system can also be applied to other marine structures situated in similar environments to gate facilities, such as conduit pipes at thermal and nuclear power plants, offshore wind power generators and floating breakwaters. Going forward, we aim to further improve the practical applications of this system.

— Acknowledgements —

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REFERENCES

(1) Japan Patent 4131055 (06, April, 2008)
(2) Japan Patent 4126513 (23, May, 2008)
(3) Japan Patent 5506592 (28, March, 2014)
(4) Japan Patent 5572538 (04, July, 2014)
(5) A.Kawabe : Kaiyouseibutsu-no-futyakugensyou-to-sonohonsitsu Nipponkaisuigakkai zairyou kouzoukenkyukaisiryo (1991. 5) pp. 1-29