No. 57 August 2019

STEEL CONSTRUCTION TODAY & TOMORROW

http://www.jisf.or.jp/en/activity/sctt/index.html

Feature Articles

Latest Technological Trends in Port and Harbor Structures

Published Jointly by

The Japan Iron and Steel Federation

JSSC Japanese Society of Steel Construction

Outline of Revision of Technical Standards and Commentaries for Port and Harbour Facilities in Japan

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Introduction

Technical Standards and Commentaries for Port and Harbour Facilities in Japan[1] (hereinafter referred to as *"TSCPHF"*) is regarded as the *bible* for design of port/harbour facilities such as breakwaters in Japan. In May 2018, it was entirely revised (hereinafter referred to as *"TSCPHF2018"*) for the first time in 11 years. *TSCPHF2018* is consisted of Technical Standards for Port and Harbour Facilities (hereinafter referred to as "*TS*") and Commentaries for the *TS*.

Outline of *TS*, Position of *TSCPHF2018* and Japanese/English Versions

• Outline of *TS*

The Port and Harbour Act (Article 56-2-2) in Japan stipulates that "waterways and basins, protective facilities for harbours, mooring facilities, and other port facilities that the Cabinet Order prescribes (hereinafter referred to as "port facilities subject to the *TS"*) must be constructed, improved, and maintained so as to comply with the *TS*."

A content of the *TS* is stipulated by Ministerial Ordinances and related public notices. The content stipulated by ministerial ordinances is composed of the reason (purpose) why a facility is required and the performance that the facility should exhibit (performance requirement). Contents of public notices are provisions that concretely describe the performance requirement (performance criteria). (Refer to Fig. 1) Further, standard performance verification methods that confirm whether facilities satisfy the performance criteria or not, are described in the *TSCPHF*.

The current *TS* stipulates only the performance that is exhibited by port facilities subject to the *TS*, and is called as 'performance-based design framework' that does not stipulate the detailed process of design. Within this framework, the *TS* stipulates only the purpose, performance requirement and performance criteria as mandatory provisions. On the other hand, the performance verification method is optional. Therefore, within this framework, it has become possible for designers to introduce various design methods based on their own judgement.

• Position of *TSCPHF2018*

The *TSCPHF2018* is a technical document (2,218 pages in total) supervised by the Ports and Harbours Bureau of the Ministry of Land, Infrastructure, Transport and Tourism. An outline of its contents is shown in Table 1.

In the *TSCPHF2018,* provisions of the *TS*, "interpretation" and "commentary" are published. The "interpreta-

Fig. 1 Legal Framework for *Technical Standards for Port and Harbour Facilities in Japan*

Port and Harbour Act
(Article 56-2-2)
Technical Standards for Port and Harbour Facilities
(Article 56-2-21)
Issuing Recommendations to Bodies Managing Specified Port Infrastructure subject to *Technical Standards*
(Article 2-5)
Definitions: Port Infrastructure

Cabinet Order of Port and Harbour Act
(Article 19)
Facilities subject to *Technical Standards*

Ministerial Ordinance of Port and Harbour Act
(Article 28)
Stipulation of Facilities Excluded from Coverage
(Article 28-22)
Specified Facilities subject to *Technical Standards*

Technical Standards for Port and Harbour Facilities in Japan
Ministerial ordinance to prescribe Technical Standards establishing Technical Standards for Port and Harbour Facilities
- The Public Notice to set forth the details necessary for *Technical Standards*
- The Public Notice to set forth the details necessary for construction of the facilities subject to *Technical Standards*
- The Public Notice to set forth the details necessary for maintenance of the facilities subject to *Technical Standards*

Design methods designated by the proviso stated in the Article 56-2-2 (3) of the Port and Harbour Act

Table 1 Outline of Contents of *Technical Standards and Commentaries for Port and Harbour Facilities in Japan* (Revised in 2018)

Part I General
Chapter 1 General Rules
Chapter 2 Construction, Improvement, or Maintenance of Facilities Subject to the *Technical Standards*
Chapter 3 Environmental Considerations on Facilities Subject to the *Technical Standards*

Part II Actions and Material Strength Requirements
Chapter 1 General
Chapter 2 Meteorology and Oceanography
Chapter 3 Geotechnical Conditions
Chapter 4 Earthquakes
Chapter 5 Earth Pressure and Water Pressure
Chapter 6 Ground Liquefaction
Chapter 7 Ground Subsidence
Chapter 8 Ships
Chapter 9 Environmental Actions
Chapter 10 Self Weight and Surcharge
Chapter 11 Materials

Part III Facilities
Chapter 1 General
Chapter 2 Items Common to Facilities Subject to the *Technical Standards*
Chapter 3 Waterways and Basins
Chapter 4 Protective Facilities for Harbours
Chapter 5 Mooring Facilities
Chapter 6 Port Transportation Facilities
Chapter 7 Cargo Sorting Facilities
Chapter 8 Storage Facilities
Chapter 9 Facilities for Ship Service
Chapter 10 Other Port Facilities

Part IV Reference Technical Information
[For Part I]
Chapter 1 Major reference documents
Chapter 2 Reliability-Based Design
Chapter 3 Environmental Considerations
[For Part II]
Chapter 1 Observations, Investigations and Tests
Chapter 2 Investigations and Tests after Large Earthquake with Tsunami Attack
[For Part III]
Chapter 1 Basic Information on Seismic Design
Chapter 2 Dedicated Use Barthes
Chapter 3 Planning Method of Port Transportation Facilities
Chapter 4 Tables and Charts for Design Calculations

tion" denotes the practical concepts that are considered appropriate at the stage of a practical application of the *TS*, and the content to be strongly recommended in application (content to be observed in the case of governmental organizations) is covered. In addition, in the "commentary," two items are published—technical information that serves as a reference at the stage of implementing construction, improvement or maintenance of facilities subject to the *TS*, and examples of design methods that are considered standard at that stage. However, it is possible for designers to adopt other design methods based on their own judgement because the "commentary" section is an optional item.

• Publication of Japanese/English-version *TSCPHF*

Table 2 shows recent publications of the Japanese/English-version *TSCPHF*. The first Japanese version was issued in 1979, and since then a revised version was issued approximately every 10 years. The English version is issued within two years after the publication of each Japanese version.

The English version has thus far been used in designs of many overseas port/harbour facilities constructed using Japan's official development assistance (ODA). The latest English version of *TSCPHF* is available to download free from the publisher's website[2], and thus interested readers are recommended to refer to it. The English-version *TSCPHF2018* is scheduled for publication in spring 2020.

Outline of Key Revisions of *TSCPHF2018*

• Revision Content pertaining to Strengthening of International Competitiveness

In order to enhance marine transport efficiency, technical information for ship dimensions was renewed so as to meet trends toward the increasing size of container and cruising ships, and, corresponding to such a trend, a revision was also made pertaining to auxiliary equipment for mooring facilities such as mooring posts and fender materials. The revision allows for a response to ship dimensions of container ships with a loading capacity of 20,000 TEUs or more and cruising ships with 220,000 GT or more. Also, in order to determine the scale of mooring basins, descriptions were added so that ship track analysis by means of automatic identification system (AIS) can be used as a reference.

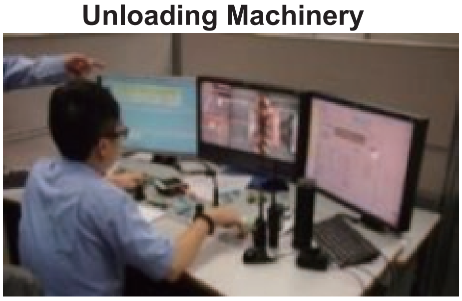
Further, the descriptions were added pertaining to measures for preventing crane overrun caused by wind and accidents occurring during ship-mooring works. It is expected that these revisions will not only promote the acceptance of larger-size ships but also secure safety and improve efficiency of loading/unloading operations and contribute to strengthening and securing international competitiveness of Japanese industry.

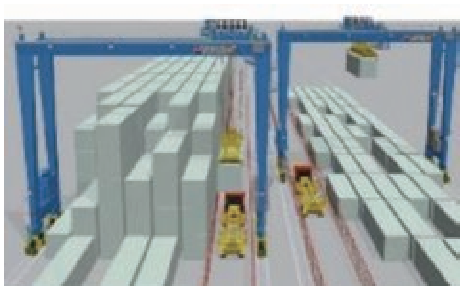
In addition, in the current revision, remote-control movable loading/unloading equipment was added to port facilities subject to the *TS* (Fig. 2). In the *TS*, 'performance requirement' and 'performance criteria' are also added in order to secure safe and efficient port/harbour functions. The movable loading/unload-

Table 2 History of *TSCPHF* (Japanese Version and English Version)

Japanese version		English version
Issue year	Pages	Issue year
1979	692	1980
1989	968	1991
1999	1,181	2002
2007	1,485	2009
2018	2,218	2020 (planned)

Fig. 2 Image of Remote-control Operation of Movable Loading/Unloading Machinery





ing equipment mentioned here are rubber-tired gantry cranes (RTG), automated guided cargo vehicles (AGV) and straddle carriers.

• Revision Content pertaining to Maintenance and Countermeasures against Deterioration

Considering the situation of ongoing deterioration of social infrastructure constructed within the high economic growth period, maintenance items for which due considerations are to be made at design stage were well described, such as the installation of inspection holes and catwalks (Fig. 3) contributing to properly maintaining port facilities. Further, various measures were incorporated that prolong service life with the introduction of structural materials with high durability and performance.

Also, application of information and communication technology (ICT) and three-dimensional data in a serial process from design and construction to maintenance was promoted, and the concept of upgrade design for existing facilities was enriched.

Fig. 3 Example of Design with Consideration to Maintenance Stage (Inspection Catwalk Applied in Jacket-type Wharf)

Installation of inspection catwalk from the design stage so as to allow for easy maintenance

• Revision Content pertaining to Design Methods

Considering that the working population is forecasted to decline in Japan and how to improve on-site productivity is an urgent issue, basic philocaly involved in productivity improvement was newly described in the *TSCPHF2018*. In this regard, the reliability-based design method (partial factor method) has been revised from the original method that was incorporated in *TSCPHF2007*, since the original method was too complicated for designers to apply in the practical design work.

Specifically, revision has been made from the former 'partial factor method based on the material factor approach' where each material or other individual design parameter is multiplied by a corresponding partial factor respectively, to a 'partial factor method based on load and resistance factor approach' where each integrated value of various loads or resistant capacities is multiplied by the corresponding load factor or resistance factor respectively (Fig. 4). One notable advantage cited for the use of a 'partial factor design method based on load and resistance factor approach' is that designers can easily image the most likely behavior of structures up to the final stage of design. The main aim of the current revision of the partial factor method is to improve efficiency of design work and to create an environment that promotes further introduction of free ideas and new technologies. Please see the references[3), 4)] for details in the revision on the load and resistance factor design approach.

Meanwhile, in reliability analysis, Monte Carlo simulation (MCS) was applied instead of the conventional first-order reliability method (FORM). This was because the introduction of reliability analysis by means of MCS offers many advantages: easy incorporation of optional probability distributions, easy response to diverse issues involved in strong nonlinearity and the possibility to create an environment in which level 3 reliability-based design (RBD) can easily be applied. These advantages will enhance for designers to apply RBD more widely on a design of a new structural type or an existing facility. In other words, the reliability analysis using MCS has a great extensibility in the future.

In the calculation of load and resistant factors, MCS results were also applied. With MCS results, these factors can easily be calculated by using the positioning relationship between the characteristic value (the representative value of sum of resultant forces and resistance capacities) and the design point (the point where collapse is most likely to occur). These factors can be calculated by dividing design point coordinate by the characteristic value coordinate (Fig. 5).

Fig. 4 Difference between Material Factor Approach and Load and Resistance Factor Approach

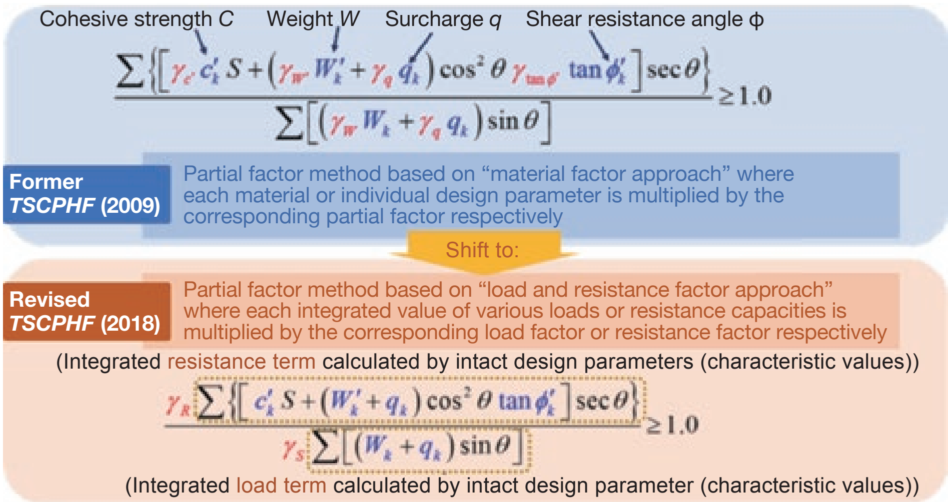
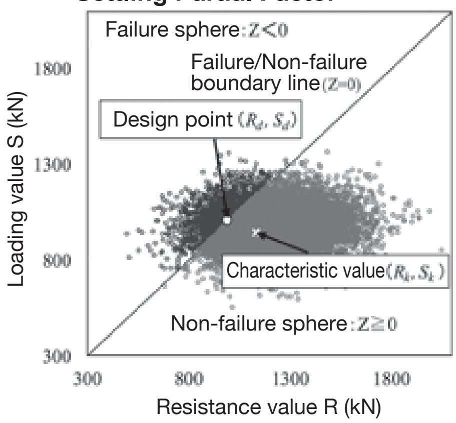


Fig. 5 Evaluation of Collapse Probability, and Relation between Design Point and Characteristic Value Applied in Settling Partial Factor



• Revision Content pertaining to Disaster Prevention and Mitigation

In order to prepare for large-scale disasters due to such as 'Nankai Trough earthquake' or 'Tokyo epicentral earthquake' forecasted to occur in the near future, descriptions about disaster prevention and mitigation measures to treat major earthquakes and tsunamis were added based on new knowledge and lessons obtained from the Great East Japan Earthquake of March 2011.

In the field of seismic design, a bending strength of steel pipe piles used for wharves was reexamined. As a result, designs that take into account robustness or redundancy of steel pipe piles can be made for the level 2 seismic ground motion (largest-class seismic ground motion). As the ratio of the diameter (D) to the wall thickness (t) of steel pipe piles increases, their bending strength becomes smaller than full plastic moment obtained by simple calculation. Further, as the axial force ratio increases, the above-mentioned trend becomes more apparent. To that end, the bending strength performance of steel pipe piles, which takes into account these effects, was introduced in the *TSCPHF2018*.

With the above-mentioned method, designers can determine the proper combination of diameter and thickness of steel pipe pile that does not cause lowering of bending strength up to a range of large curvature against large-scale earthquake.

In tsunami-resistant design, it is necessary to examine the persistent breakwater structure. To meet such a need, various new technical information was added, such as a method that assesses tsunami wave force, a design method for breakwater with installation of backfill (reinforcing embankment) in the rear, and a design method that takes into account the lowering of bearing capacity due to tsunami flowing-in inside the mound of breakwater foundations (Fig. 6). These descriptions will make it possible to promote effective disaster prevention/mitigation measures and at the same time will lead to securing safety and security in the hinterland of ports and harbours.

•Revision Content pertaining to Environmental Considerations

Aiming at attaining sustainable development of ports and harbours and restoration and preservation of natural environments, new technical information was added, such as practical examples of living creature symbiosis-type structures (port facilities that possess not only basic functions for port structures but also living functions for creatures inhabiting in tidal flats and shore reefs, refer to Fig. 7); nature restoration technologies for tidal flats; shoals and seaweed forests; and eco-friendly application of recycled materials.

The main purpose targeted by these revisions is not only to incorporate environmental considerations into every function of ports and harbours but also to create affluent sea area environments and places of recreation and relaxation. ■

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Fig. 6 Image of Persistent Breakwater in Tsunami-resistant Design

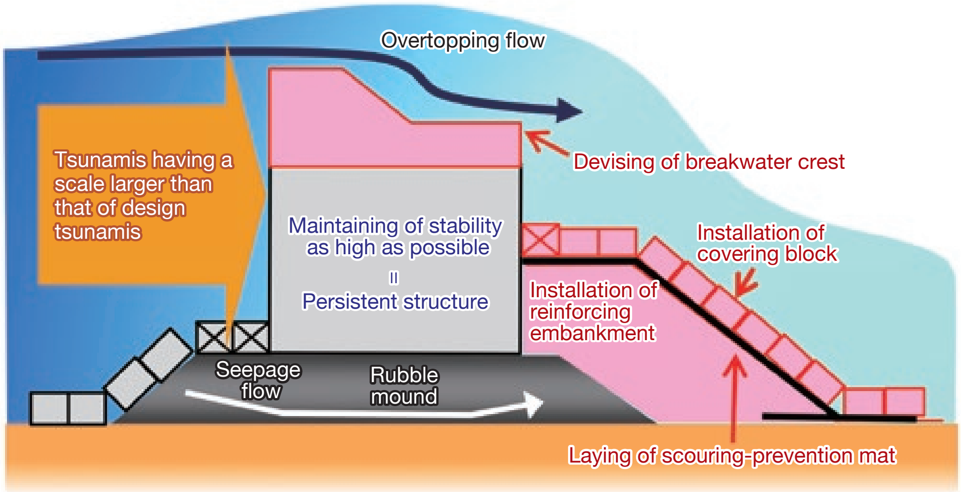
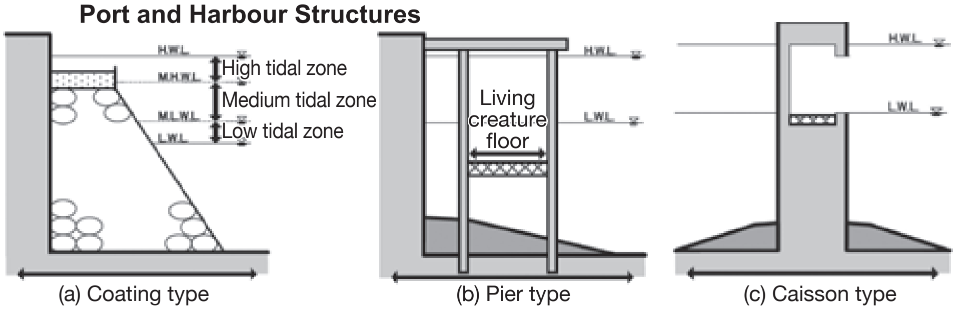


Fig. 7 Examples of Structural Types of Living Creature Symbiosis-type Port and Harbour Structures



Infrastructure Maintenance, Renovation and Management—Research and Development of Government Programs in Japan

by Yozo Fujino
Distinguished YNU Professor
Yokohama National University

Yozo Fujino: After receiving the Ph. D from the University of Waterloo, Canada, he became Assoc. Professor in 1982 and Professor in 1990 of the Faculty of Engineering, the University of Tokyo. He assumed his current position as Distinguished YNU Professor of the Institute of Advanced Science, Yokohama National University in 2014. He received the Japan Academy Prize in 2019. He serves as the Program Director of the Cross-Ministerial Strategic Innovation Promotion Program (SIP) of the Cabinet Office.

Introduction

The Cross-Ministerial Strategic Innovation Promotion Program (SIP), in which the Council for Science, Technology and Innovation (CSTI) plays the role of playmaker, has been established to realize scientific technology innovations (Fig. 1). As a cross-ministerial and cross-field program, SIP will drive forward with the focus ranging from basic research to commercialization/industrialization.

"Infrastructure maintenance, renovation and management" (hereinafter referred to as "SIP infrastructure") is one of the issues currently under the focus of the programs. Civil infrastructures, such as roads, railways, harbors and airports, support our everyday life and social economic activities. Many of them, however, were built during the high economic growth period. As they get older, the increase in maintenance and repair expenditures, along with the possibility of a serious accident occurring during the service, become serious social issues. This program aims at preventing accidents and reducing the burden of maintenance by constructing a systematic infrastructure management that utilizes the most advanced information and robotics technologies.

Unlike mass-produced products, such as vehicles and laptop computers, infrastructures are single products that are designed, constructed, and manufactured individually. Initial conditions of infrastructures vary depending on the time and condition they were built. As a result, in addition to the difference in usage environment, the speed of infrastructure deterioration also varies. Some infrastructures that have been used for several tens of years may pose a higher risk of accident due to damage. To allow for an effective and efficient preventive maintenance management of infrastructures and to establish a safe and secure infrastructure system, it is therefore crucial to have technologies that can precisely diagnose and take appropriate measures by closely examining large number of infrastructures individually on-site. It is also essential to minimize the hazards and risks associated with manual handling in the workplace.

Fig. 1 Council for Science, Technology and Innovation

For infrastructure management run by local governments, cost reduction is also a particularly important viewpoint. Currently, infrastructures are being constructed across Asia; however, maintenance has already become a big issue. "SIP infrastructure" aims at introducing new exciting advanced technologies into the range of infrastructure management technologies. Specific examples include the following: support from or replacement with robots for infrastructure inspection; on-site damage detection inside concrete members; inspection of tunnels and bridges by mobile sensors that do not require traffic control; technologies to aerially detect damage/deformation of river levees, dams, and harbors; highly accurate deterioration estimation technology for concrete; developing ultra-high durable repair materials; efficient infrastructure management technology using big data processing; and artificial intelligence.

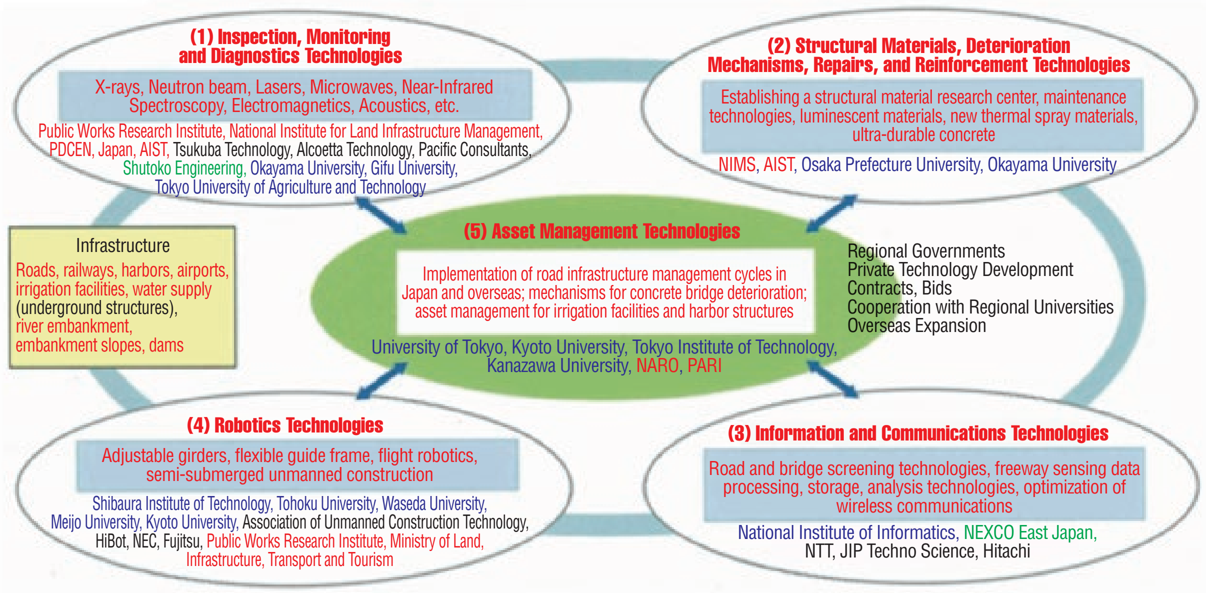
Japan's infrastructure stock is estimated to be over 800 trillion yen. Infrastructures should function for several decades. Our responsibility to the future is to create an infrastructure information platform and to pass on the infrastructures that can be used safely with a minimum maintenance burden to the next generation. The objective of "SIP infrastructure" is to establish the system and we will work hard to achieve it. (Fig. 2)

Outline

In Japan, amid the aging of infrastructures, emerging risk of a serious accident such as the Sasago tunnel accident in 2012 and the increase in maintenance and repair expenditures are topics of concern. Systematic infrastructure management utilizing new technologies is essential both for preventing accidents based on preventive maintenance system and minimizing life cycle cost of infrastructures under the conditions of the tight financial grounds and the decreasing number of skilled engineers. Particularly, technologies that utilize the world's most advanced ICRT are expected to create new business opportunities in the existing infrastructure maintenance market and to offer business expansion opportunities into Asian countries that face similar problems

To achieve this, we will improve the standard of maintenance by using low-cost preventive maintenance while stressing the necessity to match the needs of infrastructure maintenance with the seeds of technical development, and developing new technologies into more attractive technologies that can be used on-site. By achieving this, we aim at contributing to regional revitalization, as well as maintaining the important internal infrastructures to high standard while backing up a variety of regional economic activities. Furthermore, we will create an attractive and ongoing maintenance market and build a base for overseas expansion based on successful regional examples.

Fig. 2 SIP Research and Development for Infrastructure Maintenance, Renovation, and Management Technologies



*Infrastructure Operations and Management Overview (participating organizations as of November 13, 2014

UAV for Bridge Inspection: Drones and Others

After the Sasago tunnel accident, visual and hands-on inspection of bridges, tunnels and other facilities in highways and roads became mandatory. The interval is 5 years and hammering is to be done if necessary.

Hands-on bridge inspection of bridge from the back side and high piers needs special equipment and hence can be very expensive. It is also labor consuming. To overcome these problems, applying UAV to bridge inspection, at least to its screening is a natural choice. In SIP-infrastructure, various types of unmanned aerial vehicle (UAV) including drones are being developed for inspection of bridges and tunnels (Fig. 3).

One of the advantages of use of UAV is to capture the surface conditions of bridge components such as RC bridge decks by video and/or camera and can be stored in digital data. Automatized process to identify cracks in concrete surface from the photos is also being developed.

Ultrasensitive Magnetic Nondestructive Testing for Evaluation of Steel Infrastructure

Professor Tsukada’s team is developing a nondestructive testing (NDT) method using highly-sensitive magnetic measurements for evaluation of steel infrastructure such as bridges. To ensure the safety of infrastructure, simple and accurate inspection methods are essential. Conventional magnetic testing techniques are simple and inexpensive; however, they can only detect surface defects. In this study, we developed a magnetoresistance (MR) sensor based on two types of NDT instruments that can detect not only surface defects but also inner defects.

To detect the thinning depth caused by corrosion of thick steel plate, extremely low-frequency eddy current testing (ELECT) with an applied magnetic field ranging from 1 Hz to 1 kHz was developed. The steel thickness was estimated by analysis of the magnetic spectroscopy, which was traced using the obtained multi-frequency magnetic vector signals as shown in Fig. 4. As a result, steel plate thinner than 20 mm could be measured within 0.1 mm resolution. Moreover, the shape of the back-side corrosion was determined by scanning with a magnetic probe. Compared with ultrasonic testing, ELECT has the advantage of noncontact, which enables detection even on rough, corroded or coated surfaces. ■

Fig. 3 Drones Being Developed in SIP for Inspection of Bridge Girders and Piers

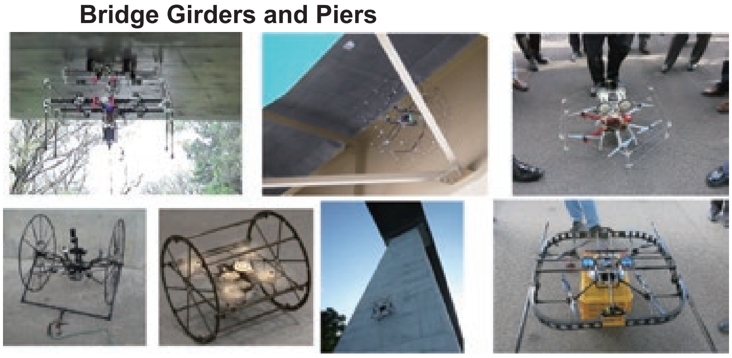
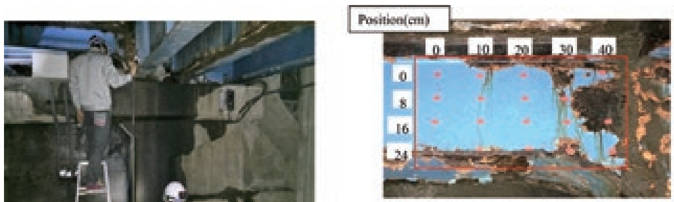


Fig. 4 Bridge Corrosion Investigation Using ELECT



Position (cm)	Estimated thickness (%)				
	y = 0	10	20	30	40
x = 0	86	73	59	53	53
8	53	73	59	57	40
16	53	59	56	56	39
24	43	50	54	45	46

Development of Life-cycle Management System for Port and Harbor Facilities: Integrated Framework from Inspection to Assessment

—SIP Infrastructure Maintenance, Renovation and Management—

by Ema Kato
Port and Airport Research Institute

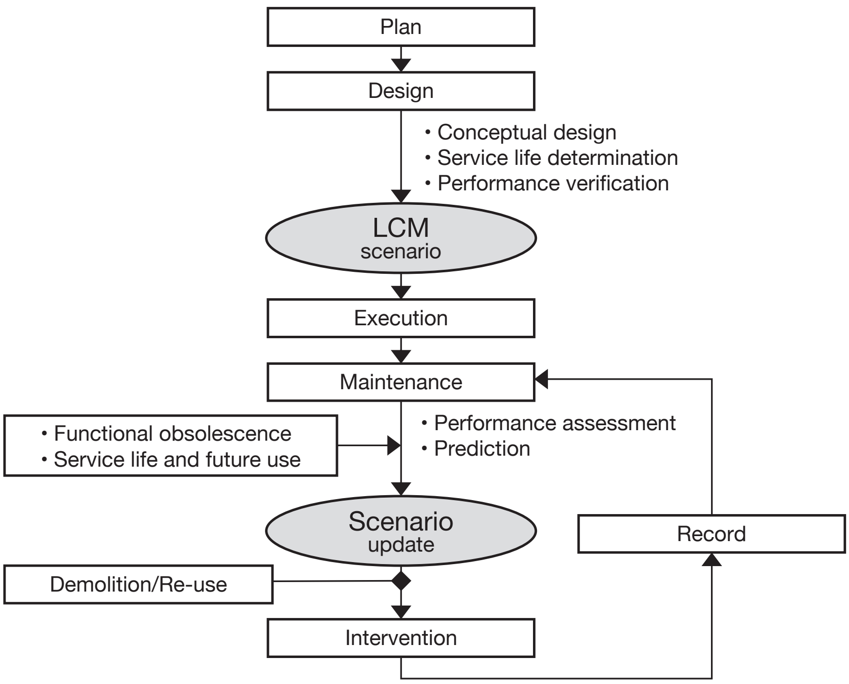
Ema Kato: After graduating from the School of Engineering of the Tokyo Institute of Technology in 1997 and receiving the degree of Ph. D from the University of Tokyo in 2002, she entered the Port and Airport Research Institute (PARI). She served as chief researcher at PARI's Life Cycle Management Research Center in 2007 and assumed her current position as group leader at PARI's Structural Engineering Department in 2013. Her specialization is concrete engineering.

SIP (Cross-ministerial Strategic Innovation Promotion Program) and LCM System for Port and Harbor Facilities

In order to realize the strategic maintenance of port and harbor facilities, the author is proceeding with examinations that aim at establishing the life-cycle management (LCM) system for the facilities shown in Fig. 1 and improving the elemental technologies involved in it. The LCM system has two major purposes: the sure implementation of collaborative work between respective stages of planning, design, construction, maintenance, demolition and renewal of port and harbor facilities; and the enhancement of elementary technologies such as for inspection, diagnosis, prediction, assessment and countermeasure in the stage of maintenance of port and harbor facilities.

The author engaged in promoting a research project in FY2014~2018 titled "Development of Life-cycle Management System for Port and Harbor Facilities: Integrated Framework from Inspection to Assessment" to examine the inspection and diagnosis technologies and the asset management approach targeted for piers. Of the results obtained in this research project, two technologies were introduced as follows—a PTC Sensor, a monitoring sensor that is targeted at petrolatum-lining corrosion protection applied in port and harbor steel structures, and SAMSWING, an inspection system that makes the remote monitoring of sensors possible.

Fig. 1 Life-Cycle Management System for Port and Harbor Facilities[1)]



PTC Sensor (Nakabohtec Corrosion Protecting Co., Ltd.)

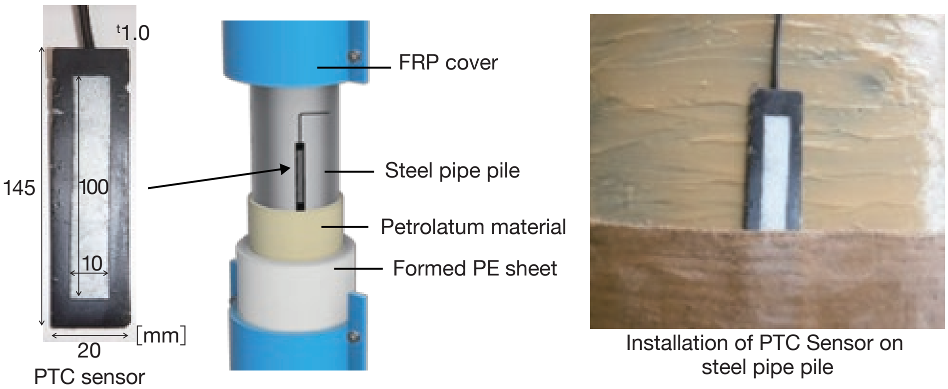
The inspection and diagnosis for the petrolatum lining corrosion protection is still depending on the visual observations of protective cover and materials for fixing the protective cover to the steel substructure. When the deformation is observed on those parts, the steel surface is directly observed after partially removing the corrosion protection.

In this study, an approach has been developed that quantitatively assesses the performance of petrolatum-lining corrosion protection employing a PTC Sensor. Moreover, the maintenance threshold (cumulative current) was proposed to judge the deterioration of corrosion-protection performance. (Refer to Fig. 2)

SAMSWING (TOA CORPORATION)

SAMSWING (sensor-aided maintenance system with information technology) is a maintenance system that opens the sensor data to the user (port and harbor construction and administration organs, professional engineers) on a website. It was developed by TOA CORPORATION in 2004. SAMSWING has two features in terms of performance: a performance

Fig. 2 PTC Sensor and Petrolatum Lining System



that automatically sends warnings to the user when some abnormalities are detected by the sensors installed in the target structures, and a performance that indicates some comments on the judgements against the abnormalities and the countermeasure to be taken based on the professional engineers.

In this study, the existing SAMSWING system has been improved to make it possible to apply to the following four kinds of sensors; one is a sensor that assesses the durability of reinforced concrete, two kinds of sensors that confirm the corrosion-protection condition of steel pipe piles (one of two sensors is the PTC Sensor mentioned above), and the other one is an environment measurement sensor (temperature, humidity, wave height and velocity etc.). (Refer to Fig. 3)

Promotion of Improved Inspection Technologies

In order to diffuse and firmly establish these improved inspection technologies, it is essential to consolidate a basis that introduces these technologies while at the same time taking into account the features of prevailing maintenance systems for port and harbor facilities. To that end, we are striving to reflect these inspection technologies in the *Guidelines for Inspection and Diagnosis of Port Facilities* (partially revised in June 2018), the *Maintenance Manual for Port Facilities* (supervised in July 2018) and other maintenance guidelines published and supervised by the Ports and Harbours Bureau of the Ministry of Land, Infrastructure, Transport and Tourism. Additional endeavors being promoted are to diffuse these developed technologies at the national training course and lecture meeting for the staff under the Ministry's direct control and for port/harbor administrators.

Meanwhile, the maintenance guidelines mentioned above have been prepared by assuming their application in port and harbor facilities in service in wider areas in Japan. They only indicate the standard maintenance plans required for maintaining the performance of each facility and the technological standards pertaining to inspection, diagnosis and maintenance measures.

For the practical maintenance of port and harbor facilities, it will be necessary that the maintenance plan is worked out to take into account the service plan, location conditions, structural materials applied and construction conditions peculiar to respective facilities, and that the worked-out plan is steadily implemented. In its implementation, the less cost and labor the better. To attain these goals, it is considered extremely important to surely implement collaborative works between the respective stages of planning, design, construction and maintenance of port and harbor facilities that will be built in the future. ■

Reference

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Fig. 3 Outline of SAMSWING

Study of the Introduction of Steel Pipe Piles to Pile Foundations in Southeast Asia

by Yoshiaki Kikuchi
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Introduction

The concrete piles have been mainly used for foundation piles in Southeast Asian nations. However, when taking into account the easy availability of large-diameter, long-length piles, concerns about the corrosion of concrete piles applied in port and harbor areas and redundancy for the bending of piles to be applied for piers, it is expected that the application of steel pipe piles will increase in the future in Southeast Asian nations.

In this study, the main target was directed towards the following three areas:

- Comparison of the estimation methods for pile vertical bearing capacity that are applied in Japan, the US and EU nations. These methods are likely to be applied in Southeast Asian nations;
- Examination on the toe bearing capacity mechanism of open-ended steel pipe piles; and
- Understanding of design and construction conditions in Southeast Asian nations pertaining to how pile bearing capacity is assessed

Study Content

Table 1 compares the representative static bearing capacity estimation equations that are applied to estimate the axial-direction resistance of piles[1), 2), 3)]. It is generally accepted that pile bearing resistance is examined by dividing it into shaft resistance and pile toe resistance and that the ground condition is examined by dividing it into sandy soil ground and cohesive soil ground. Accordingly, under these conditions, an international comparison of pile bearing capacity estimation methods can relatively easily be made. Among these conditions, the difference of estimation methods for pile toe resistance on sandy soil ground greatly affects the estimation results for pile bearing capacity, which was therefore subjected to examination.

Table 1 International Comparison of Static Bearing Capacity Estimation Equations for Steel Pipe Piles

		Technical Standards and Commentaries for Port and Harbor Facilities in Japan (JSPH)	Eurocode 7 (EC7)	US Army Corps of Engineers (USACE)
Sandy soil ground	Toe resistance q_p (kN/m^2)	$300N$	$N_{qs}\sigma'_{v0}$	$N_q\sigma'_{v0}$
	Shaft resistance q_s (kN/m^2)	$2N$	$K_s\sigma'_{v0}\tan\delta$	$K_s\sigma'_{v0}\tan\delta$
Cohesive soil ground	Toe resistance q_p (kN/m^2)	$6c_u$	$9c_u+\sigma'_{v0}$	$9c_u$
	Shaft resistance q_s (kN/m^2)	c_u	αc_u	αc_u

Notes
N: SPT-N value; c_u: shear strength of the ground; Nq: bearing capacity coefficient; σ'_{v0}: effective over burden pressure; K_s: earth pressure coefficient; α: adhesion factor; δ: shaft friction angle between pile and ground

While the estimation methods for pile toe resistance on sandy soil ground in the US (USACE: US Army Corps of Engineers) and EU nations (EC7: Eurocode 7) are theoretical methods, it can be said that the method in Japan (JSPH: Technical Standards and Commentaries for Port and Harbor Facilities in Japan) is an empirical method. However, as can be seen in Fig. 1, the difference between the bearing capacity coefficients applied in the US and EU nations reaches about double at higher internal friction angles, and thus it cannot currently be said that these theoretical methods do not always excel to others.

Regarding pile toe bearing capacity estimation methods, the method based on cavity expansion theory is also known, and the following equation is proposed by Yasufuku[4)].

$$q_p = \frac{\sigma'_v}{1-\sin\varphi'_{cv}} \cdot \frac{3(1+\sin\varphi'_{cv})}{3-\sin\varphi'_{cv}} \cdot \frac{(1+2K_0)}{3}$$

$$\times \left\{ \frac{G/\sigma'_v}{((1+2K_0)/3)\tan\varphi'_{cv} + 50\left(((1+2K_0)/3)\tan\varphi'_{cv}\right)^{1.8} \cdot (G/\sigma'_v)^{-0.8}} \right\}^{\frac{4\sin\varphi'_{cv}}{3(1+\sin\varphi'_{cv})}}$$

Where, K_0: coefficient of earth pressure at rest (=0.5); and G: shear rigidity ($G=7000\,N^{0.72}$, N: SPT-value). Further, the shear resistance angle ϕ'_{cv} is to be at a level from 28° to 32°.

Fig. 2 shows the comparison of four estimated values of pile toe bearing capacity on sandy soil ground, obtained by using the equation specified in JSPH, USACE and EC7 and based on cavity expansion theory. In this figure, while the internal friction angle is required to obtain the bearing capacity coefficient, the value was estimated by using the Japanese method (the JSPH's method to estimate the shear resistance angle using the N value). According to the comparison results, the EC7 has a tendency to excessively assess the bearing capacity, and the JSPH has a tendency in which the change of bearing capacity to a depth direction cannot be indicated.

Further, Fig. 3 shows the comparison between measured and calculated values of pile toe resistance. It can be under-

Fig. 1 Comparison of Bearing Capacity Coefficients between Eurocode 7 and US Army Corps of Engineers
(Both upper limit value USACE-U and lower limit value USACE-L are specified in US Army Corps of Engineers)

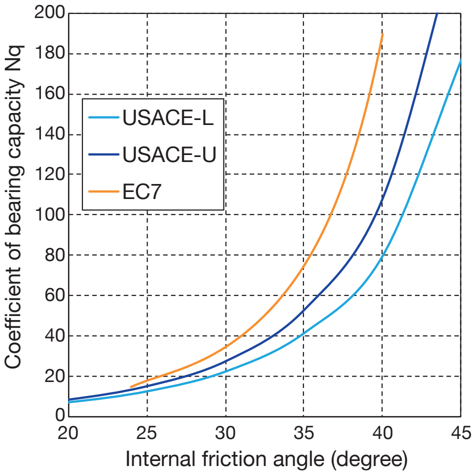


Fig. 2 Comparison of Estimation Results for Pile Toe Bearing Capacity in the Case of N Value of Ground=50

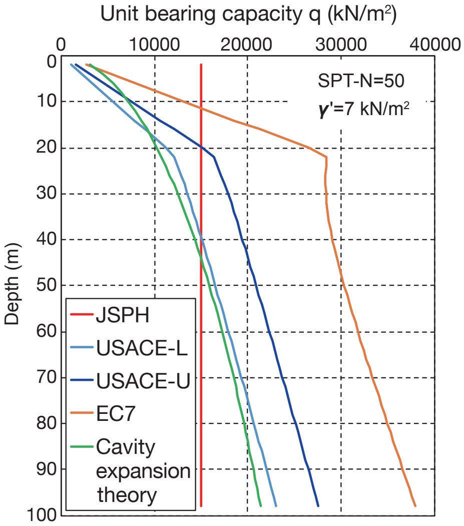
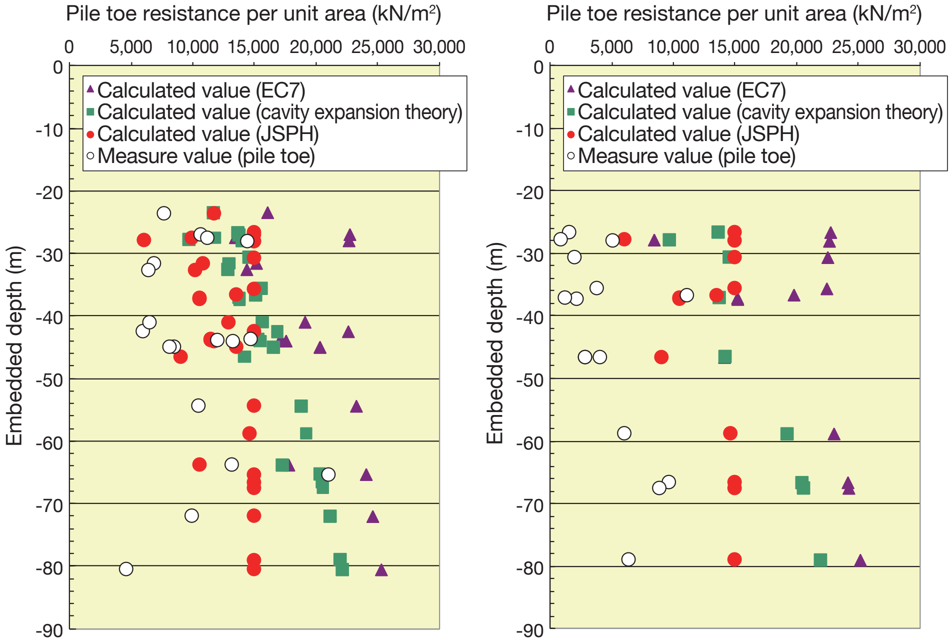


Fig. 3 Comparison between Measured Pile Toe Resistance and Calculated Pile Toe Resistance



(a) Pile diameter: 1,000 mm or lower (b) Pile diameter: More than 1,000 mm

stood from Fig. 3(a) that the EC7 has a tendency towards excessive assessment and that the JSPH or cavity expansion theory serves as a comparatively appropriate estimation method. However, as shown in Fig. 3(b), when the pile diameter surpasses 1,000 mm, the measured value becomes considerably smaller than the calculated value, and the effect of partial soil plugging inside the pipe pile becomes apparent.

From these comparison results, it becomes necessary to examine a more rational method that estimates the pile toe resistance of open-ended piles like the steel pipe piles. The open-ended pile toe resistance R_{open} will be demonstrated by the total of the toe resistance R_p of the substantial pile section and the frictional force R_{fl} between the pile internal skin and the soil inside the pile (Fig. 4). In this case, how to appropriately assess R_{fl} become the most important task. When Yamahara's assumption[5), 6)] is applied, the vertical earth pressure σ_v inside the pile in the section apart by x to the axial direction from the pile toe at the stage where the pile is embedded up to z is expressed in the following equation.

$$\sigma_v=\left(\frac{R_{fl,z}}{A_{in}}+\frac{\gamma_t D_{in}}{4\mu K_h}\right)\exp\left(-4\mu K_h\frac{x}{D_{in}}\right)-\frac{\gamma_t D_{in}}{4\mu K_h}$$

Where, $R_{fl,z}$: total value of pile internal skin resistance; A_{in}: sectional area of pile internal cross section; D_{in}: pile inside diameter; γ_t: unit volume weight of soil inside the pile; μ: friction coefficient of wall surface; and K_h: earth pressure coefficient inside the pile.

In this equation, the most critical problem is that the value of μK_h is unknown. Then, it was decided to obtain the value by experiment. The experiment was undertaken by penetrating piles with an outside diameter of 50 mm and wall thicknesses of 2, 3 and 4 mm into dry sandy soil ground (relative density Dr=80%).

As a result of this experiment, the μK_h inside the pile in the case of penetrating by 100 mm was estimated as shown in Fig. 5. It was learned from the experimental results that μK_h has two tendencies: the nearer to the pile toe, the larger the μK_h becomes, and the high-

Fig. 4 Pile Toe Resistance of Open-ended Piles

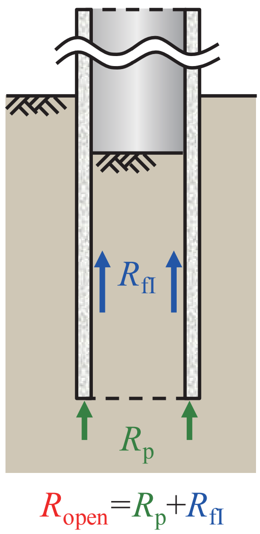
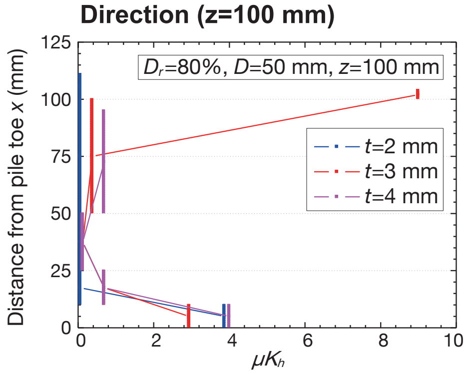


Fig. 5 Estimated μK_h along Pile Axial Direction (z=100 mm)



er up from the pile toe, the smaller the μK_h becomes. It was also learned that the μK_h does not change even when the wall thickness changes. In addition, because the friction coefficient μ takes a value of around 0.5, it was learned that K_h in the vicinity of pile toe takes the value of around 7~10. In the future, experiments will be made by changing the pile diameter and the ground density to examine how these changes will affect the K_h.

Surveys were made of eight pipe pile foundation projects in six countries undertaken in Southeast Asian nations. The port and harbor facilities completed in these eight projects are all piers. The standards applied to calculate the pile bearing capacity were three from British Standards, two each from API Specifications and Technical Standards of Japan (JSPH), and one from the US Army Corps of Engineers. The reason why the number of standards does not coincide with the number of projects is that both JSPH and the British Standards were applied in one project.

Table 2 shows the ground conditions and loading tests applied. In all eight projects, plural dynamic loading tests were implemented. Further, static or rapid loading tests were also implemented in most of the projects. In light of the ground conditions, it seems that whether the ground conditions were good or bad was not necessarily a determining factor for whether or not loading tests were to be implemented. Regarding the static loading tests, it seems that they were implemented, as a rule, in accordance with a policy of confirming the provision of a bearing capacity twice the working load. There was only one project in which the design was revised as a result of these loading tests. In principle, it seems that the loading tests were applied to confirm the appropriateness of the design.

In addition, a loading test was applied for pile driving depth control. For pile driving depth control, while the Hiley formula is applied, the formulae is revised by every piling site as follows: At the time of piling start, both the static (rapid) and the dynamic loading tests are implemented, and the test results are correlated with the Hiley formula to revise the pile driving depth control formula. Then, the dynamic loading tests are applied usually to 20% of the total piles driven, and piling work is undertaken while at the same time confirming whether or not the prescribed bearing capacity is secured. This piling work system is commonly implemented in most nations.

When large-diameter steel pipe piles will be applied in the future, it is considered that the soil plugging level inside open-ended pipe piles will come to largely affect the estimation of pile bearing capacity. Therefore, it will be necessary to propose a method that can appropriately estimate the bearing capacity of open-ended piles so that steel pipe piles will become easy to apply even in Southeast Asian nations.

Table 2 Ground Conditions and Loading Tests Applied

Project number	Loading tests applied: Static loading test	Rapid loading test	Dynamic loading test	Ground condition
1	○		◎	Solid cohesive soil
2			◎	Good
3		○	◎	Bad
4	◎	◎	◎	Cohesive soil
5	○		◎	Soft
6	○		◎	Sandy soil
7	○		◎	Sandy soil
8	○		◎	Hard cohesive soil/Soft rock

Note: ◎: Plural tests, ○: Singular test

Conclusions

The conclusions obtained from this study are summarized as follows:

- When applying steel pipe piles with diameters of 1,000 mm or lower, while both the Japanese method (JSPH) and the cavity expansion theory can be said to be the appropriate method that estimates the pile toe bearing capacity even without consideration to the soil plugging level of the pile end, the method prescribed in the Eurocode 7 has a tendency where the pile toe bearing capacity is excessively assessed. On the other hand, in applying large-diameter steel pipe piles with diameters of 1,000 mm or more, when the soil plugging level of the pile end is not taken into account, the bearing capacity cannot appropriately be assessed.
- Due to the above, when examining the bearing capacity of open-ended piles, it is necessary to examine the mechanism that manifests the pile internal skin friction force. In its examination in this study, the concept by Yamahara was applied. However, in the case of following this concept, it has become clear that consideration should be made to the fact that the earth pressure coefficient inside the pile changes along to the pile axial direction. In this regard, future examination will be required.
- As a result of surveys of steel pipe pile application examples in Southeast Asian nations, it was learned that the design standards of the EU, the US and Japan were applied. Further, it became clear that the combined use of various loading tests was made to confirm the design and to implement piling work control. In order to promote the application of steel pipe piles in Southeast Asian nations, it is considered important to supply a method that allows the highly precise estimation of bearing capacity even of large-diameter steel pipe piles. ■

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Assessment of Long-term Durability of Various Metallic Construction Materials by Means of Exposure Tests at Okinotorishima and Suruga Bay

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Okinotorishima, an atoll located in the southernmost tip of Japan, is located in the tropical zone, where not only temperature, humidity and sunshine radiation but also tidal currents and wave heights are high. Further it is constantly subjected to seawater splashing. In this way, the corrosive environment there is far stricter than the sea area of the Japan mainland. In order to develop a corrosion-protection technology targeting offshore steel structures and to assess their long-term durability, the Public Works Research Institute and the Japan Iron and Steel Federation jointly conducted offshore atmospheric exposure tests for metallic construction materials over 19.5 years at Okinotorishima (Fig. 1).

In parallel with this, in order to understand the long-term durability of these materials in a sea area in the vicinity of the mainland, they also conducted offshore atmospheric exposure tests over 24 years at the Marine Engineering Research Facility in Suruga Bay (Fig. 1), installed 250 m off the coast of Yaizu, Shizuoka Pref. In this article, the exposure test results between two different corrosive environments are compared and studied.

Exposure Test Methods

At both test sites, a total of 28 kinds of materials in groups A~D were exposed (Table 1). Plate-shaped test specimens with sizes of 210×30~75 mm and thicknesses of 1.2~9 mm were prepared. The test specimens were exposed at an angle of 5° (60°) using exposure racks oriented to face south with a height of 15 m (13 m) from sea level (the values in brackets show those at Suruga Bay). Table 2 shows the major environmental conditions at both test sites, and Table 3 shows the survey items by material.

Exposure Test Results and Studies

• Ordinary Carbon Steel (Group A)

After exposure tests, while pitting corrosion was found on the surface of many specimens at Okinotorishima, nearly no pitting corrosion was found at Suruga Bay. Further, when calculating the corrosion rate using the corrosion loss after exposure, while the rate at Okinotorishima was 0.18 mm/a, that at Suruga Bay

Table 1 A List of Test Specimens Used for Exposure Tests

Group	Type of materials	Specimen No.
A: Ordinary carbon steel		
	Ordinary carbon steel (SS400)	A-01
B: Stainless steel		
Austenitic type	18Cr-8Ni (SUS304)	B-01
	17Cr-12Ni-2.5Mo (SUS316L)	B-02
	19Cr-13Ni-3.5Mo (SUS317L)	B-03
	18Cr-13Ni-3Mo-0.15N	B-04
	20Cr-25Ni-5Mo-Ti	B-05
	20Cr-17Ni-4.5Mo-N-L.C	B-06
	20Cr-18Ni-6Mo-0.7Cu-0.2N (SUS312L)	B-07
	25Cr-13Ni-0.9Mo-0.3N (SUS317J2)	B-08
	25Cr-22Ni-4.5Mo-0.2N	B-09
	22Cr-23Ni-5Mo-1.5Cu-0.2N	B-10
Dual-phase type	25Cr-6Ni-3.5Mo-0.2N (SUS329J4L)	B-11
	25Cr-7Ni-3.5Mo-0.5Cu-0.16N (SUS329J4L)	B-12
Ferritic type	19Cr-2Mo-Ti-Nb-Zr (SUS444)	B-13
	26Cr-4Mo	B-14
C: Nonferrous metal		
Titanium	Titanium [JIS H 4600 TP35H(KS50)]	C-01
Copper	Copper [C-1220]	C-02
Aluminum alloy	Aluminum alloy [5083]	C-03
D: Coated/lined steel plate		
Metallic coating	Aluminized stainless steel plate	D-01
	Hot-dip galvanized steel plate	D-02
	Zinc-aluminum alloy-sprayed steel plate	D-03
	Aluminum-sprayed steel plate	D-04
Polymer lining	Polyethylene-lined steel plate	D-05
	Polyurethane-lined steel plate	D-06
	Ultra high build epoxy resin-lined steel plate	D-07
Heavy-duty corrosion-protection coating	(Epoxy resin/polyurethane resin)-coated steel plate	D-08
	(Epoxy/fluororesin)-coated steel plate	D-09
	(Epoxy resin/acrylic silicone resin)-coated steel plate	D-10

Table 2 Main Environmental Conditions at Exposure Test Sites (Implementation of Exposure Test: Marine Atmospheric Zone)

Exposure test site	Location	Annual average			Annual time of wetness (ISO 9223)	Sunlight radiation index (setting Suruga Bay as 1.0)
		Temp. (°C)	Seawater temp.(°C)	Humidity (%)		
Okino-torishima	20°25'N 136°5'E	27.2*	28*	73*	4476 hrs	1.3
Suruga Bay	34°47'N 138°19'E	16.6**	21**	67**	1392 hrs	1.0

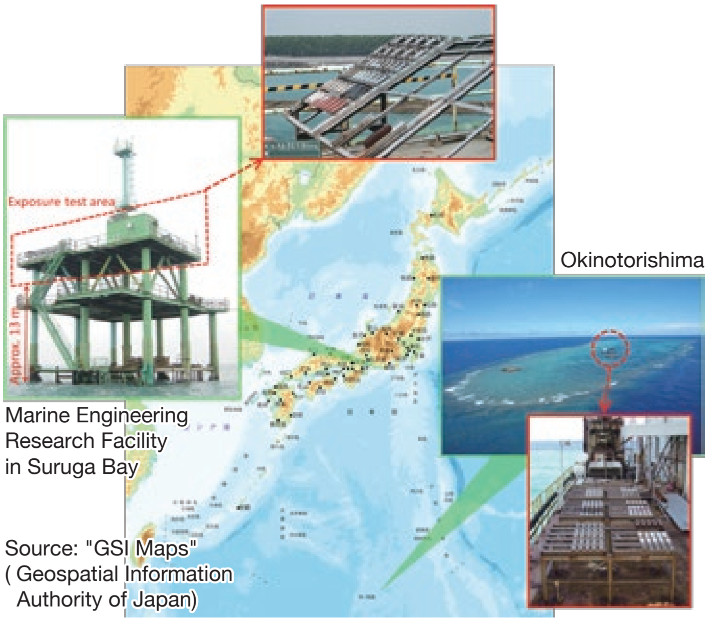
Note: Data *JAMSTEC (2001) ** Japan Meteorological Agency (2001)

Table 3 Major Survey Items at Exposure Tests

Survey item	Ordinary carbon steel (A)	Stainless steel (B)	Non-ferrous metal (C)	Coated/lined steel plate (D)		
				Metallic coating	Polymer lining	Heavy-duty coating
Appearance observation	○	○	○	○	○	○
Mass loss	○	○	○	○		
Local corrosion depth	○	○	○			
Film thickness				○	○	○
Insulation resistance (volume resistivity)					○	○
Coating section observation (SEM)				○	○	○

was 0.015 mm/a, which means that the corrosion rate at Okinotorishima was about 12 times that at Suruga Bay.

Fig. 1 Overview of Exposure Test Sites



• Stainless Steel (Group B)

At the Suruga Bay, slight pitting corrosion occurred and crevice corrosion occurred at the gap between the insulation washer and the specimen for the specimens excluding B-07, both of which were not assessed as notable corrosion loss. Meanwhile, at Okinotorishima, slight pitting corrosion and crevice corrosion occurred for every type of stainless steel material, which showed a trend of a corrosion depth higher than that at Suruga Bay.

The maximum pitting corrosion depth at general sections of all specimens and their maximum crevice corrosion depth at the washer-specimen gap were arranged using the pitting resistance equivalent number (PREN: [Cr(%)]+[3.3×Mo(%)]+[16×N(%)]), and it was learned from the arrangement results that there was a loose correlation between the maximum pitting corrosion depth or maximum crevice corrosion depth and the PREN (Figs. 2 and 3).

In the arrangement results at Suruga Bay, when the PREN was 30 or more, both the maximum pitting and crevice corrosion depths reached 100 μm or less. Meanwhile, at Okinotorishima, when the PREN was 30 or more, the maximum pitting corrosion depth at the general section reached 100 μm or less in the same way as at Suruga Bay, but it was the case with a PREN at 40 or more that the maximum crevice corrosion depth reached 100 μm or less.

While the difference of maximum pitting corrosion depth between Suruga Bay and Okinotorishima was slight, the maximum crevice corrosion depth at Okinotorishima was clearly higher than that at Suruga Bay. The reason for these phenomena seems to be attributable to a higher average temperature, by 11°C, and a longer wetting time at Okinotorishima than at the Suruga Bay.

• Nonferrous Metal (Group C)

No corrosion including pitting corrosion at the general section and crevice corrosion at the washer-specimen gap was observed for pure titanium (C-01) at either test site. Regarding copper (C-02) and aluminum alloy (C-03), while a loss of mass due to corrosion was not found, pitting corrosion at the general section and crevice corrosion at the washer-specimen gap were observed. It was impossible to clearly understand a trend in the differences in levels between pitting corrosion and crevice corrosion occurring due to the differences in corrosion environments.

• Coated and Lined Steel Plates (Group D) —Metallic Coating

While the formation of corrosion products was observed on aluminized stainless steel plate (D-01) at both testing sites, the aluminum coating layer remained, and thus it is considered that the plate had a sound corrosion-protection performance even at the completion of the exposure tests (Fig. 4(a)). Meanwhile, while the coating layer of hot-dip galvanized steel plate (D-02) remained in the exposure test at Suruga Bay, it nearly disappeared in the test at Okinotorishima (Fig. 4(b)).

Regarding the zinc-aluminum alloy-sprayed steel plate (D-03) and the aluminum-sprayed plate (D-04), while the formation of corrosion products was observed, the sprayed layer remained, and thus it is considered that these two plates

Fig.2 Relation between Maximum Pitting Corrosion Depth at General Section and PREN of Stainless Steel

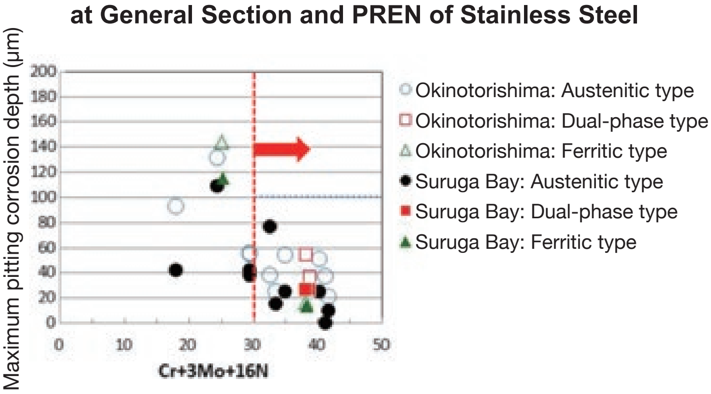


Fig. 3 Relation between Maximum Crevice Corrosion Depth at Washer-Specimen Gap and PREN of Stainless Steel

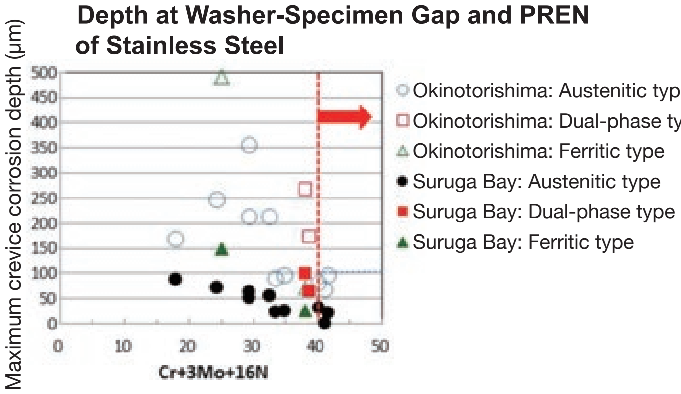
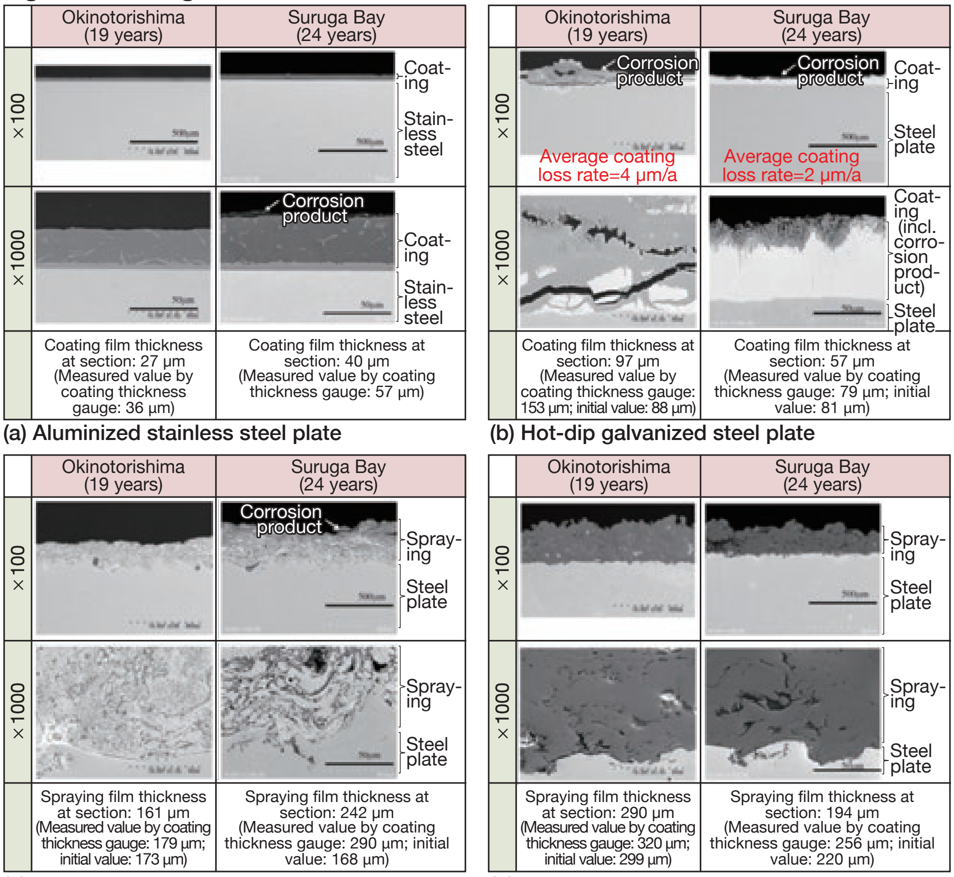


Fig. 4 SEM Images of Sections of Metallic-coated Steel Plates



(a) Aluminized stainless steel plate
(b) Hot-dip galvanized steel plate
(c) Zinc-aluminum alloy-sprayed steel plate
(d) Aluminum-sprayed steel plate

a high insulation resistance of $10^{10}\Omega$/cm or more—the value reported as no corrosion occurrence in the steel material under coating—at both testing sites and in every type of steel materials, and thus it is considered that they maintained corrosion-protection performance even at the completion of the exposure tests (Fig. 5). Because the fall of insulation resistance due to exposure at Okinotorishima was larger than that at Suruga Bay, it is assumed that Okinotorishima is in a harsher environment that causes the deterioration of lined/coated layers.

It was the polyurethane-lined steel plate that showed the highest value in terms of annual average film loss (difference of film thickness before and after exposure÷exposure year), and the loss at Okinotorishima was 1.5 times that at Suruga Bay, which nearly coincided with the ratio of sunlight irradiation of 1.3 (Fig. 6). In other types of lined and coated steel plates, the loss at Okinotorishima was larger than that at Suruga Bay, but according to the test results, the film loss only of epoxy resin/acrylic silicone resin-coated steel plates was larger at Suruga Bay than that at Okinotorishima.

had a sound corrosion-protection performance even at the completion of the exposure tests (Fig. 4(c) and (d)). The film thickness of the zinc-aluminum alloy-sprayed steel plate after exposure was increased from the thickness before exposure due to the formation of corrosion products. The increased level at Suruga Bay was higher than that at Okinotorishima. Similarly the film thickness of the aluminum-sprayed steel plate increased due to exposure, but the difference of the increase in film thickness between Suruga Bay and Okinotorishima was unclear.

—Polymer Lining and Heavy-duty Coating

At both testing sites, the polyethylene-lined steel plate (D-05) showed considerable peeling-off of lined polyethylene from the plate edge due to possibly inferior quality of edge sealing materials, and thus the plate was excluded from the assessment target. In other polymer-lined/coated steel plates (D6~D10), the lined/coated layer remained on all the plates. While the insulation resistance (volume resistivity) of the lined/coated layer lowered due to exposure, they showed

Useful Exposure Test Results

Offshore atmospheric exposure tests were conducted at two site having different corrosive environments, and it was indicated even from the test results for the corrosion rate of ordinary carbon steel that the corrosive environment at Okinotorishima is harsher than that at Suruga Bay. Of the test results, regarding stainless steel, nonferrous metal and metallic-coated material excluding galvanized material, there was no notable differences in corrosion deterioration attributable to the corrosive environment and they showed high corrosion resistance. Regarding organic lining and heavy-duty corrosion-protection coating, while it is considered from the value of insulation resistance (volume resistivity) that the corrosion resistance is maintained, the fall of insulation resistance was larger at Okinotorishima. ■

Fig. 5 Insulation Resistance (Volume Resistivity) of Polymer Lining and Heavy-duty Coating

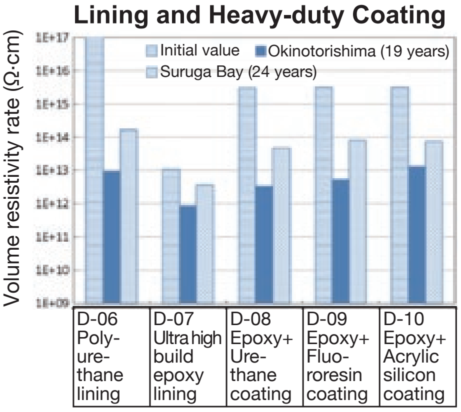
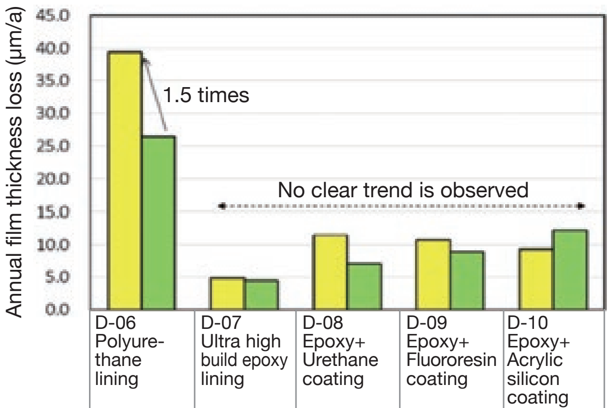


Fig. 6 Film Thickness Loss of Polymer Lining and Coating (Lower Table: Total Loss/Site)



	D-06	D-07	D-08	D-09	D-10
Okinotorishima (after 19 years)	748 µm	92 µm	217 µm	204 µm	176 µm
Suruga Bay (after 24 years)	635 µm	108 µm	169 µm	214 µm	294 µm

Proposals Conducive to "Building National Resilience" Employing Steel Structures

The Japan Iron and Steel Federation

Triggered by the Great East Japan Earthquake of March 2011, the "Basic Act for National Resilience Contributing to Preventing and Mitigating Disasters for Developing Resilience in the Lives of the Citizenry" was established in Japan in December 2013. Then in June 2014, the Japanese cabinet approved the "Fundamental Plan for National Resilience" in conformity with the Basic Act.

In order to keep up with these government policies, the Japanese steel industry launched the Committee on National Resilience in April 2014 within the Japan Iron and Steel Federation. Destined for regional development bureaus of the Ministry of Land, Infrastructure, Transport and Tourism and local governments as well, the committee has thus far promoted diverse activities to propose steel-structure technologies and methods conducive to preventing and mitigating natural disasters.

Because diverse natural disasters have occurred in succession in Japan, the government revised in the Fundamental Plan in December 2018 through the emergency inspection of important infrastructure carried out in November 2018, and the Japanese cabinet approved the "Three-year Emergency Measures for Disaster Prevention/Mitigation and Building National Resilience." In order to accelerate the reinforcement of the functions of important infrastructure used for disaster prevention nationwide, a sum of ￥7 trillion (US$62.5 billion) will be intensively invested over the next three years under the Three-year Emergency Measures.

Aiming at contributing towards building national resilience through extensive applications of disaster-preventive steel-structure technologies and methods, the Committee on National Resilience has promoted diverse activities—continued proposal of these technologies and methods for regional development bureaus and local governments, promotion of understanding of the high performance peculiar to steel structures and grasping of emerging needs. Further, based on knowledge newly obtained from activities of various research committees and subsidy systems for steel-structure research and training of the Japan Iron and Steel Federation, the committee is striving to examine the content of proposals to diverse tasks and to further organize and enrich related data. An outline of these proposals is introduced below:

National Measures to Improve Disaster-resistant Social Infrastructure

The Ministry of Land, Infrastructure, Transport and Tourism is promoting positive measures for not only the restoration and reconstruction of Great East Japan Earthquake-stricken areas but also preparations for serious natural disasters that are forecast to occur in the near future such as Tokai, Tonankai and Nankai great earthquakes and large-scale floods. In addition, the Ministry is tackling the renewal of superannuating social infrastructure stock and the reinforcement and promotion of disaster-preventive measures. Specifically, the following four measures are being promoted:

- Promotion of seismic retrofitting and tsunami countermeasures for public facilities (embankments, bridges, highways, port/harbor facilities, airport facilities, railway facilities, river facilities, houses, buildings, etc.)
- Reinforcement of preventive maintenance and renewal of flood-control countermeasures (three major metropolitan areas in Tokyo, Osaka and Nagoya and major cities in flooding areas)
- Reinforcement of disaster-preventive measures in areas where serious flooding and earth/sand-induced damage has occurred
- Securement of the safety of houses and buildings (promotion of seismic retrofitting, construction of tsunami-evacuation buildings)

Steel-structure Technologies and Methods Conducive to Improving Disaster-resistant Social Infrastructure

Steel products have high performance that satisfies the need for highly stabilized quality in addition to the high toughness and workability required of construction materials. Steel structures employing these high-performance steel products offer the following application advantages:

- Possible to reduce on-site construction terms
- Possible to construct on narrow congested sites and soft ground due to the application of lightweight steel structures made available by the use of steel products
- Flexibility in design such as curved structural design
- Flexibility and simplicity in combined use with concrete, lumber, glass and other structural materials
- Possible to produce flexible spaces and structures with consideration paid to landscaping

Making the most of the performance offered by steel products, the Japan Iron and Steel Federation presents practical proposals that can allow earlier improvements and construction of disaster-resistant social infrastructure by applying accumulated steel-structure technologies and methods high in terms of disaster-preventive performance, application advantage and eco-friendliness. Typical examples are introduced below:

Proposals of Steel-structure Technologies and Methods to Improve Disaster-resistant Public Facilities and Disaster-preventive Bases

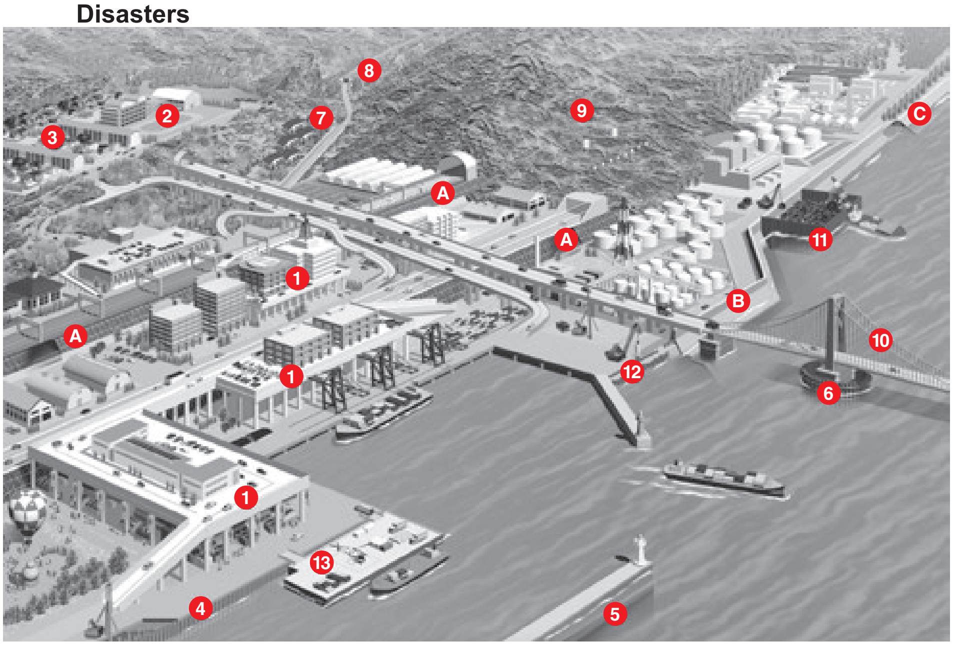
Table 1 and Fig. 1 show the disaster-preventive technologies and methods employing steel structures, proposed by the Japan Iron and Steel Federation (JISF), among which are:

- Improvement of disaster-resistant public facilities and disaster-preventive bases (new structural system buildings employing innovative structural materials, steel-structure buildings used as disaster-preventive bases, earthquake/tsunami-resistant manmade platforms, steel-structure school facilities)
- Earthquake-resistant houses (steel-framed houses, etc.)
- Early restoration and improvement of port/harbor and coastal facilities, and earthquake/tsunami-resistant measures (port/harbor facility renewal methods employing steel products, seismic reinforcing methods for piers, revetments and breakwaters employing steel products, water-cutting off revetments employing steel pipe piles and sheet piles, high tide/tsunami-resistant methods employing steel products)
- Renewal, improvement and seismic retrofitting of bridges (bridges applying bridge high-performance steel, reinforcing methods for existing bridge foundations using

Table 1 Proposed Steel-structure Technologies and Methods Resistant to Disasters

Proposed technologies and methods \ Application fields	Tsunami evacuation building, disaster-prevention base during damaging	Seismic retrofitting and multi-purpose application of public facility	Reconstruction and seismic retrofitting of house	Repair and improvement of breakwater and tide embankment	Tsunami measure for coastal facility	Improvement and seismic retrofitting of bridge	Measure for liquefaction	Restoration of ground sunken/flooded area	Measure for flooding/earthquake-induced collapse of river embankment	Slope stabilization and measure for debris flow
1-1 New structural system building using innovative steel materials	○	○	○							
1-2 Steel-structure disaster-prevention base	○	○								
1-3 Seismic/tsunami resistant manmade platform	○	○	○		○			○		
2 Steel-structure school facility	○	○								
3 Steel-framed house			○							
4 Port renewal method using steel product				○						
5 Seismic reinforcing of pier, revetment and breakwater using steel product				○	○		○			
6 Reinforcing of existing bridge foundation using steel pipe sheet pile and pipe pile						○				
7 Embankment reinforcement using steel sheet pile									○	
8 Permeable debris flow-control dam using steel pipe										○
9 Land slide-prevention method using steel product										○
10 Bridge applying bridge high-performance steel						○				
11 Cut-off revetment using steel sheet pile and steel pipe sheet pile				○				○		
12 Measure for side liquefaction of revetment in coastal area				○			○			
13 Floating disaster-prevention base	○									
A Measure for liquefaction and earthquake using steel sheet pile							○	○		
B Measure for high tide and tsunamis using steel product				○	○					
C Measure for high tide using steel product (double wall-cofferdam sheet pile method)				○	○					

Fig. 1 Application of Steel-structure Technologies and Methods Resistant to Disasters



steel pipe sheet piles and steel pipe piles)

- Measures for land liquefaction (measures for the side liquefaction of revetments in coastal areas, measures for liquefaction and earthquakes using steel sheet piles)
- Afforestation and flood-control measures (permeable-type debris flow-control dams using steel products, land slide-suppressing measures using steel products)

By making the most of collaborative relationships with the Japanese Society of Steel Construction and other related organizations and an industry-academia-government tie-up system, JISF has fostered steel-structure countermeasure technologies and methods that protect the national land from natural disasters and mitigate disasters. To that end, JISF considers that these technologies and methods will not only allow for the realization of proactive town-making that is highly resistant to disasters and conducive to promoting industrial development but will also contribute to the restructuring of safe and secure Japan.

Examples of Countermeasure Technologies and Methods Attracting Close Attention

At the regional development bureaus and local governments to which the Committee on National Resilience has thus far promoted proposal activities, they are concerned not only with new facility construction but also maintenance methods for existing facilities and their repair and reinforcement. Further, because of the recent and frequent large-scale flood damage in Japan, the importance of countermeasures against such damage is growing. Some of the technologies and methods that are closely related to the above are introduced below:

• Maintenance Technologies for Port and Harbor Steel Structures

Port and harbor steel structures are subjected to severely corrosive environments. Accordingly, in order to secure higher performance than the required performance, technologies are required that suppresses the corrosion of steel products and appropriately assess their soundness, and maintenance and repair methods are required that restore deteriorated steel products and corrosion-protection performance to the original level, examples of which are shown in Figs. 2, 3 and 4 and introduced below:

—Corrosion-protection methods

Coating and lining corrosion protection: Corrosion-protection methods with which steel products are covered directly with coating/lining materials to shut out corrosion factors. These are classified into coating, organic/inorganic lining and petrolatum lining and are applied mostly in low tidal areas (L.W.L.) or higher areas.

Cathodic corrosion protection: The corrosion-protection method with which corrosion-protection current is continuously supplied from an external source to steel products. Two methods are in use: anodic and external power source methods, which are applied mainly in submerged and sea bottom zones.

—Repair and reinforcing methods

In the case of reinforcing steel structural members: The method with which section loss sections are reinforced using steel plates or reinforced concrete

In the case of entirely repairing corrosion-protection measure: On-site repairing method that uses mortar covering, petrolatum lining and underwater hardening-type coating

In the case of partly repairing corrosion-protection measure: The method that recoats polyurethane-deteriorated sections with repairing polyurethane

● Measures to Control Debris Flows Employing Steel Pipes

With debris flow-control measures employing steel pipes, mountain stream environments (continued slope of river beds) are preserved while retaining the capturing space by passing soil and running water through debris flow-control steel structure during normal times, and at the time of occurrence of debris flows, the debris flow and driftwood are surely captured by separating the debris flow into running water and the soil/rock and driftwood, examples of which are shown in Photo 1. Among major features are:

—Sure capturing of debris flows

In arranging vertical and lateral steel pipes, the capturing space is set at 1.5 times the maximum diameter of on-site conglomerates; demonstration of high impact absorption capacity in the case of direct hits by debris flows; and the sure capturing of debris flow

—Capturing of driftwood flown out together with sand/rock

Effective capturing of driftwood by separating the debris flow into running water and driftwood

—Retention of capturing space

Retention of capturing space by flowing earth/soil through capturing space during normal times because of the adoption of permeable-type structures

—Preservation of mountain stream environments

Eco-friendly structure that secures continued slopes for riverbeds without dividing mountain stream

After occurrence of debris flows, it is

Fig. 2 Type of Corrosion-protection Measures for Port/Harbor Steel Structures

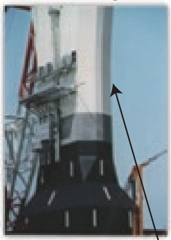
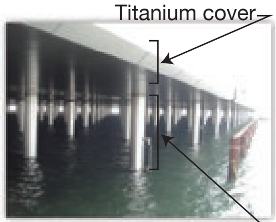
Coating, lining, cladding			Cathodic protection
Coating	Organic lining	Metal cladding	
 Coating	 Polyurethane lining	 Highly corrosion-resistant stainless steel cover	 Anodic system

Fig. 3 Examples of Assessment of Soundness of Port/Harbor Steel Structures

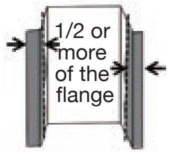
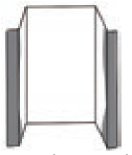
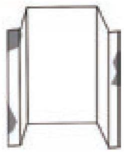
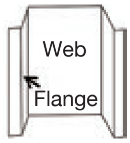
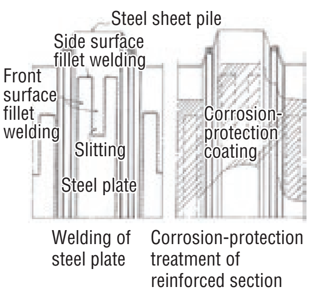
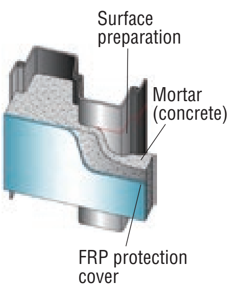
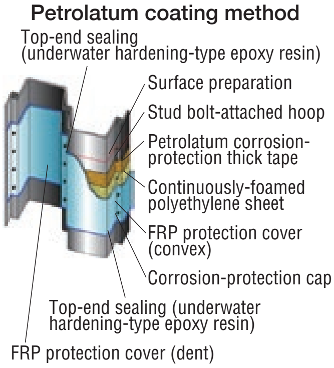
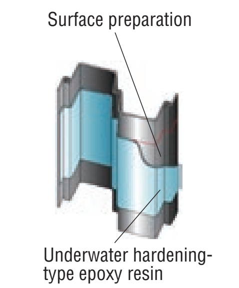
Application condition of corrosion-protection measures		Loss of function ← Deterioration level → Maintaining of function			
		Entire repair	Partial repair	No need for repair	No need for repair
	Lining corrosion-protection (example of urethane-lined steel sheet pile)	 Peeling-off and loss of lined material are notable, steel product is exposed, and rusting occurs	 Damage that reaches steel product occurs in part of corrosion-protection measure, and occurrence of rusting is judged	 Many damages that do not reach steel product are observed	Coated/lined section  Nearly no change from initial condition is seen, and lined section shows sound condition
	Cathodic corrosion-protection (example of anodic system)	 Example in which anode completely disappears	Whether or not the corrosion-protection electric potential (−800 mV) is maintained		 Anode in initial conditions

Fig. 4 Examples of Repair and Reinforcement of Port/Harbor Steel Structures

In the case of reinforcement of steel member	In the case of entire repair of corrosion-protection measure			In the case of partial repair of corrosion-protection measure
Reinforcement using steel plate 	**Mortar coating method**  Mortar is filled inside FRP protective cover	**Petrolatum coating method**  Steel member is coated with petrolatum and covered with FRP buffer material	**Underwater hardening-type coating method**  Steel member is coated with underwater hardening-type epoxy resin	**Repair method using repairing polyurethane**  Repairing polyurethane is coated on polyurethane coating-deteriorated section

Note: Source of information on Figs. 2, 3 and 4—Extraction and compilation of data from:
1) Manual for Corrosion Protection and Repair of Port and Harbor Steel Structures (1999, 2009), Costal Development Institute of Technology
2) Handbook on Practical Applications of Port and Harbor Steel Structures, Research Working Group on Corrosion Protection and Repair

necessary to recover the performance of debris flow-control steel structures to the original level, and thus repair and reinforcement measures are applied depending on the level of damage of steel pipe members. Fig. 5 shows an assessment of the soundness of debris flow-control steel structures and their repair measures.

● Application of Weathering Steel in Bridge Construction

In weathering steel, a dense rust layer is formed on its surface at the initial stage of application, and this protective layer suppresses the further development of corrosion. Capitalizing on this protective rust layer, weathering steel demonstrates high corrosion resistance without coating. Photo 2 shows an example of applications of weathering steel for bridges. Major application advantages are:

—Reduction of lifecycle costs: Elimination of recoating
—Mitigation of environmental load: Applicability without coating
—Harmonization with the environment: With the lapse of time, the protective rust layer produces a stately appearance that harmonizes with nature.

In order to continuously demonstrate the property peculiar to weathering steel, it is necessary to conduct the periodic inspection of rust layers and make soundness assessments so that favorable rust conditions are maintained. The rust layer soundness is assessed using appearance ratings from 1 to 5 depending on the rust condition. With ratings 3~5, the rust condition is assessed as favorable; with rating 2, follow-up observation is required; and with rating 1, detailed inspection is carried out, and as the need arise, repair is required to take. Fig. 6 shows examples of the soundness assessment of weathering steel.

During ordinary time: Passing of earth and sand and running water

Condition of capturing of debris flow

Photo 1 Examples of debris flow-control measures using steel pipes

Photo 2 Application of weathering steel bridge in remote mountainous area

Fig. 5 Soundness Assessment of and Repair Methods for Debris Flow-control Measures Using Steel Pipes

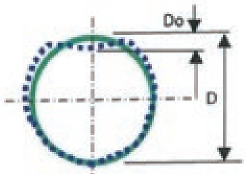
Inspection and Soundness Assessment

Damage level	Performance-deteriorated level and definition	Repair measure	Judgement (hollow pipe)
Level 1: Sound	No lowering of performance compared to the level at completion and no obstacle in use	No need for repair	Deformation rate of steel pipe: less than10% of steel pipe diameter
Level 2: Damaged	Lowering of member durability and fears for lowering of performance compared to the level at completion	Examination of need for repair by means of structural verification	Deformation rate of steel pipe: 10% or more to less than 40% of steel pipe diameter
Level 3: Collapsed	Loss of performance and impossible to demonstrate performance when design load subsequently works	Sure implementation of repair	Deformation rate of steel pipe: 40% or more of steel pipe diameter

*Extraction from Design Handbook on Steel Erosion-control Structures, Sabo & Landslide Technical Center

Before debris removal | After debris removal

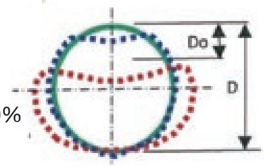
Level 1
Deformation rate: $D_0/D<10\%$



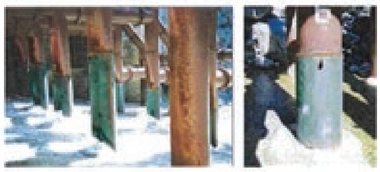
Because of no damage, service is continued without repair

*Extraction from the website of Research Group on Erosion-control Steel Structure

Level 2
Deformation rate: $10\%\leq D_0/D<40\%$

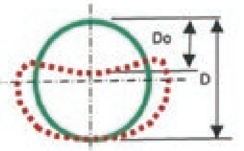


Structural verification is conducted, and the section in which occurrence stress surpasses yield stress is repaired by welding two semicircular-divided steel pipes on damaged section



*Extraction from Design Handbook on Steel Erosion-control Structures, Sabo & Landslide Technical Center

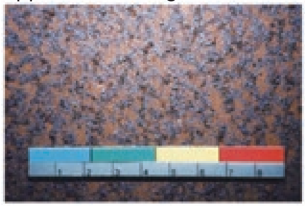
Level 3
Deformation rate: $D_0/D\geq40\%$



Damaged section is on-site cut and repaired by on-site welding factory-manufactured new members

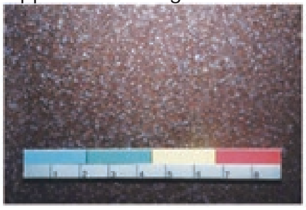
Fig. 6 Examples of Assessment of Soundness of Weathering Steel (Examples of bridge with lapse of more than 10 years after erection)

Appearance rating 5



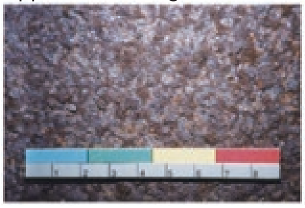
Rust amount is less, and appearance presents comparatively bright color (Standard for future treatment: no need) (Less than about 200 μm)*

Appearance rating 4



Rust particle size is about 1 mm or lower, and rust is fine and uniform (Standard for future treatment: no need) (Less than about 400 μm)*

Appearance rating 3

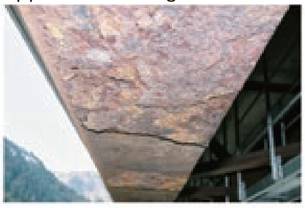


Rust particle size is 1~5 mm, and rust is coarse (Standard for future treatment: no need) (Less than about 400 μm)*

Appearance rating 2

Rust particle size is 5~25 mm, and rust is scale-shaped (Standard for future treatment: need for follow-up observation) (Less than about 800 μm)*

Appearance rating 1



Layered peeling off of rust occurs (Standard for future treatment: measurement of plate thickness) (More than about 800 μm)*

*Figures in parenthesis show standard rust thickness measured as a supplementary means for assessing rust appearance.

• Embankment Reinforcing Method Employing Steel Sheet Piles

With this method, the embankment collapse factor occurring during flooding and earthquake is shut out by driving steel sheet piles into the slope of embankments or into the embankment so that the collapse of the embankment can be prevented. Fig. 7 shows examples of embankment reinforcement using steel sheet piles. Specific measures are:

—Countermeasures against seepage at embankment base

In the case where the ground under an embankment is composed of sand and gravel, when high water levels continue, the embankment causes collapse due to the penetration of water flow into the embankment base. Steel sheet piles are driven into the embankment slope to cut off the penetration of water flow into the ground so that embankment collapse is prevented.

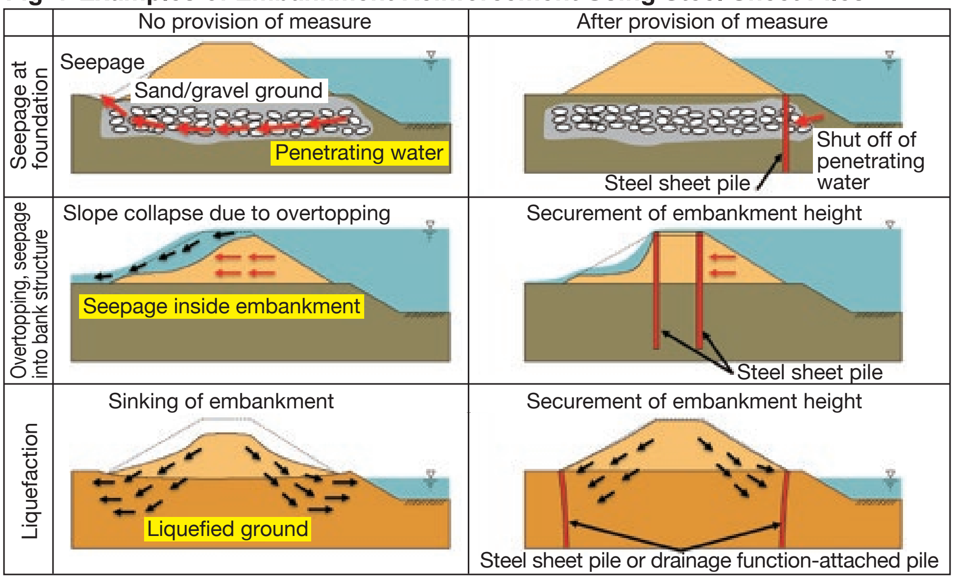
—Countermeasures against overtopping and embankment seepage

In order to break off the embankment collapse cycle—embankment slope erosion due to overtopping→lowering of embankment height→increasing overtopping→enhancing collapse, the lowering of embankments due to overtopping is prevented by driving steel sheet piles at both sides of the embankment so that the collapse of embankments is prevented. Pile driving into embankments is also effective in preventing seepage into the embankment.

—Countermeasures against liquefaction occurring during earthquakes

Ground deformation in the liquefied layer of embankments is effectively treated by steel sheet piles embedded into the non-liquefying layer in the vicinity of embankment slopes, thereby demonstrating the effect of suppressing embankment collapse occurring during earthquakes. ■

Fig. 7 Examples of Embankment Reinforcement Using Steel Sheet Piles



JISF Operations

Lecture Delivery at SEAISI Forum

The South East Asia Iron and Steel Institute (SEAISI) held the 2018 ASEAN Iron and Steel Sustainability Forum in Ho Chi Minh city in Vietnam on November 26, 2018, to which the Japan Iron and Steel Federation (JISF) dispatched Dr. Masahide Takagi of Nippon Steel Corporation (formerly known as Nippon Steel & Sumitomo Metal Corporation) to participate in a lecture meeting. He delivered a lecture titled "Introduction of Weathering Steel & Actual Application for Bridge Structure."

The lecture was delivered in reply to a request from the SEAISI's Sub-Committee on Steel Application in Construction Sector. It is one of the lectures delivered at the Session titled "Steel Construction: Developments and Applications" in the Forum. In the lecture, diverse aspects of weathering steel were introduced—specific properties, trends in application in bridge construction in Japan, cares to be paid in application, inspection of corrosion conditions and repair approaches for corroded sections and practical application examples. JISF participates in the Sub-Committee as an observer. ■

STEEL CONSTRUCTION TODAY & TOMORROW

Published jointly by

The Japan Iron and Steel Federation
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URL http://www.jssc.or.jp/english/index.html

Edited by
Committee on Overseas Market Promotion, The Japan Iron and Steel Federation
Chairman (Editor): Kazuhito Tsujimoto

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