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Revision of Corrosion Protection and Repair Manual for Port and Harbour Steel Structures

by Hiroshi Yokota
Professor Emeritus, Hokkaido University; Councilor, Coastal Development Institute of Technology

Hiroshi Yokota: After finishing the master course at the Tokyo Institute of Technology, he entered Ministry of Transport in 1980. Then, he served as professor at the Hokkaido University in 2009. He assumed his current position as Councilor of Coastal Development Institute of Technology in 2021.

Introduction

In Japan, Port and Harbour Act was revised in 2013, which stipulates basic rules on maintenance and repair for port and harbor facilities. At the same time, Guidelines for Inspection and Diagnosis of Existing Port and Harbor Facilities[1] and Guidelines for Formulating Maintenance and Repair Plans of Port and Harbour Facilities[2] were published to support the laws and regulations so that more strategic maintenance and repair can be realized for facilities in offshore and coastal regions. In addition, Technical Standards and Commentaries for Port and Harbour Facilities in Japan[3] and Technical Manual for Maintenance and Repair of Port and Harbour Facilities[4] were revised in May and July 2018, respectively, which describe the technical aspects of maintenance and repair of port and harbor facilities.

To follow the trend to strengthen the maintenance and repair work for port and harbor facilities, Corrosion Protection and Repair Manual for Port and Harbour Steel Structures (hereinafter referred to as "the Manual") was revised in 2022 for newly constructed steel structures with corrosion protection in accordance with the revised Technical Standards and existing steel structures that should be well maintained from the viewpoint of steel corrosion. At the same time, recent technological development should be thoroughly considered for the revision to make corrosion protection more rational and secure. This article presents the major points of the revision of the Manual.

Policy of Revision

The revision policies of the Manual are summarized as follows:

(1) to align with Technical Standards and Commentaries for Port and Harbour Facilities in Japan[3];
(2) to align with Technical Manual for Maintenance and Repair of Port and Harbour Facilities[4];
(3) to align with Guidelines for Inspection and Diagnosis of Existing Port and Harbour Facilities[1] and Guidelines for Formulating Maintenance and Repair Plans of Port and Harbour Facilities[2];
(4) to respect international standards; and
(5) to reflect the current levels of corrosion protection and its repair technologies.

Structure of Manual

Steel structures in offshore and coastal regions are exposed to very severe corrosive environments because of seawater splashing and tidal changes. We have elucidated the mechanisms of steel corrosion and examined various corrosion protection techniques for port and harbor steel structures from long ago. As results of these efforts, the Manual provides latest information on selection, design and execution of necessary corrosion protection methods to ensure structural performance over the requirements and to efficiently conduct inspection, diagnosis and interventions including repair.

The Manual consists of four parts and eleven appendices, as summarized in Table 1.

Table 1 Structure of Corrosion Protection and Repair Manual for Port and Harbour Steel Structures

Part I General
- 1 Outline
- 2 Characteristics of steel corrosion in marine environment
- 3 Influential factors on corrosion in seawater

Part II Design and execution of corrosion protection
- 1 General
- 2 Design and execution of cathodic protection
- 3 Design and execution of corrosion protection coating (execution in factory)
- 4 Design and execution of corrosion protection coating (execution on site)

Part III Maintenance and repair of corrosion protection
- 1 General
- 2 Maintenance and repair of cathodic protection
- 3 Maintenance and repair of corrosion protection coating (factory coating)
- 4 Maintenance and repair of corrosion protection coating (on-site coating)

Part IV Performance evaluation and repair of corroded steel structures
- 1 Performance evaluation of steel structures without corrosion protection
- 2 Repair

Appendix
- 1 Terms and definitions
- 2 Comparison with other domestic and international standards on cathodic protection
- 3 Design examples of cathodic protection
- 4 Design examples of repair and strengthening
- 5 Execution examples of repair for corrosion protection
- 6 Life cycle cost calculation for corrosion protection
- 7 Sheet of inspection and investigation results (reference)
- 8 Standards for substrate preparation
- 9 Underwater welding tests
- 10 Products relating to corrosion protection and repair
- 11 Introduction of site exposure tests conducted by research institutes in Japan

Major Points of Revision

• Influential Factors on Corrosion Caused by Macro-Galvanic Cell

The following four factors to have an influence on macro-galvanic cell corrosion that is a major reason of concentrated corrosion are discussed: (1) corrosion in the tidal zone, (2) intrusion of river water, (3) level of lower end of the concrete superstructure, structural type and water depth, and (4) marine organisms and local detachment of rust layer.

• Corrosion Rates of Steel Embedded in Seabed Soil, in Rubble and in Backfilling Stone

The corrosion rates of steel embedded in seabed soil and in rubble and in direct contact with backfilling stone are believed to be sufficiently low. Moreover, it is difficult to inspect the corrosion state of steel there. However, we have been reported that concentrated corrosion sometimes occurs under certain conditions. Accordingly, the Manual recommends that, if possible, we conduct excavation survey on those parts of steel members particularly when we plan to extend the lifespan of the structures.

• Selection of Corrosion Protection Coating Methods

Table 2 lists the classification of corrosion protection coatings with their updated information in which applicability, expected service life, initial costs and records of past application are provided only as guides. The information was compiled from the records of past application and the results of long-term exposure tests. When using the table, it should be reminded that the applicability actually depends on the environmental conditions and regional characteristics.

Table 2 Applicability of Typical Corrosion Protection Coating Methods

Methods		Conditions	Applicability Zone					Applicability Member type					Expected service life	Initial application cost *1	Record of past application
			Marine atmospheric zone	Splash zone	Tidal zone	Submerged zone	Under seabed	Pipe pile	Sheet pile	Pipe sheet pile	Jacket	Members joint			
Factory coating	Painting	Marine thick epoxy resin coating	○	○	○	○	△	○	○	○	○	○	○	◉	◉
	Heavy duty anticorrosion coating	Polyethylene coating	○	○	○	○	△	△	–	–	–	–	○*2	○	◉
		Urethane elastomer coating	○	○	○	○	△	○	○	○	–	–	○*2	○	◉
	Super thick film coating	Super thick epoxy coating	○	○	○	○	△	○	○	○	○	○	○	○	◉
		Super thick polyurethane coating	○	○	○	○	△	○	○	○	○	○	○	○	○
	Corrosion resistant metal coating	Seawater-resistant stainless steel coating	○	○	○	○	△	△	–	–	○	△	◉	○	◉
		Thin titanium clad steel coating	○	○	○	○	△	△	–	–	○	△	◉	△	○
		Thick clad steel coating	○	○	○	○	△	○*3	–	–	○	△	◉	△	△
On-site coating	Underwater coating	Painting-type coating	△	○	○	○	–	○	○	○	○	○	△	●	◉
		Putty-type coating	△	○	○	○	–	○	○	○	○	○	△	●	◉
		Wetting area-type coating	○	○	○	○	–	○	○	○	○	○	△	●	○
	Petrolatum coating	Fiber reinforced plastics cover	○	○	○	○	–	○	○	○	○	△	○	●	◉
		Corrosion resistant metal protective cover	○	○	○	○	–	○	○	○	○	△	○	●	○
	Mortar coating	Fiber reinforced plastics cover	○	○	○	○	–	○	○	○	○	○	○	●	◉
		Corrosion resistant metal protective cover	○	○	○	○	–	○	○	○	○	△	○	●	◉
	Reinforced concrete coating	Removing form type	○	○	○	○	–	○	○	○	○	○	○	▲	◉
		Stay-in-place form type	○	○	○	○	–	○	○	○	○	△	○	▲	◉

<Note>

Applicability (zone) ○: Applicable △: Generally unapplicable –: Unapplicable
Applicability (member type) ○: Applicable △: Depending –: Unapplicable
Expected service life ◉: Approx. 50 years ○: 30-35 years △: 20-25 years
Initial application cost (factory) ◉: Less costly ○: Medium △: Costly
Initial application cost (on-site) ●: Medium ▲: Costly
Record of past application ◉: Many ○: Medium △: Few

*1) Factory application is generally less costly than on-site application.
*2) Expected service life of the heavy duty anticorrosion coating is for only pipe pile, and that is △ for sheet pile.
*3) Thick clad steel coating is applicable for bending pipe, while it is unapplicable for spiral pipe and electric resistance welded pipe.

• Selection of Corrosion Protection Systems

The corrosion protection systems that should be applied to port and harbor steel structures are schematically shown in Fig. 1. The Technical Standards and Commentaries for Port and Harbour Facilities in Japan[3] stipulate the combination of coating and cathodic protection as depicted in the figure, among which system (A) is regarded as a standard corrosion protection measure. The Manual follows the Technical Standards but specifies that the lower end of corrosion protection coating is variable depending on seawater quality etc. within the principle of the standard, while it is specified to be L.W.L.–1 m in the Technical Standards.

• Design and Execution of Corrosion Protection Coating (Factory Coating)

Marine epoxy glass flake coating system has been merged in marine thick epoxy coating (Table 2). The target steel member has been changed to which polyethylene coating can be applied (Table 2). The period during which corrosion protection is thoroughly expected for super thick film coating has been updated to be 35 years based on marine exposure tests. Expected life extension of super thick film coating is specified when weather resistance topcoat is applied. Furthermore, the thick clad steel coating has been added in the corrosion resistant metal coating method (Table 2).

• Design and Execution of Corrosion Protection Coating (On-site Coating)

The period during which corrosion protection ability was confirmed in marine exposure tests has been added (Table 2). A reinforced concrete coating has been included in the scope of application of the corrosion protection methods (Table 2). The details of the design and execution of the reinforced concrete coating that is applied for the recovery of mechanical performance of steel members are described in Part IV of the Manual.

Regarding the petrolatum coating, since the earlier version of the Manual only described the specifications of the protective cover, an example of its specifications has been added. Moreover, by distinguishing between protective covers currently applied and those previously applied, the Manual improves convenience at the selection of protective covers. In the description of the substrate treatment, reference photos are provided for each surface preparation grade to easily identify the differences. In addition, commentaries are given that a residual film after substrate treatment does not cause any problems on corrosion protection ability in the petrolatum coating.

• Harmonization with ISO 12944 Series

Revisions to ISO 12944 series titled "Paints and varnishes—Corrosion protection of steel structures by protective paint systems" has been reflected in the Manual regarding the classification of corrosive environments. Standard corrosion rate of as 200 to 700 μm is provided for the extreme corrosive environment.

• Design and Execution of Cathodic Protection

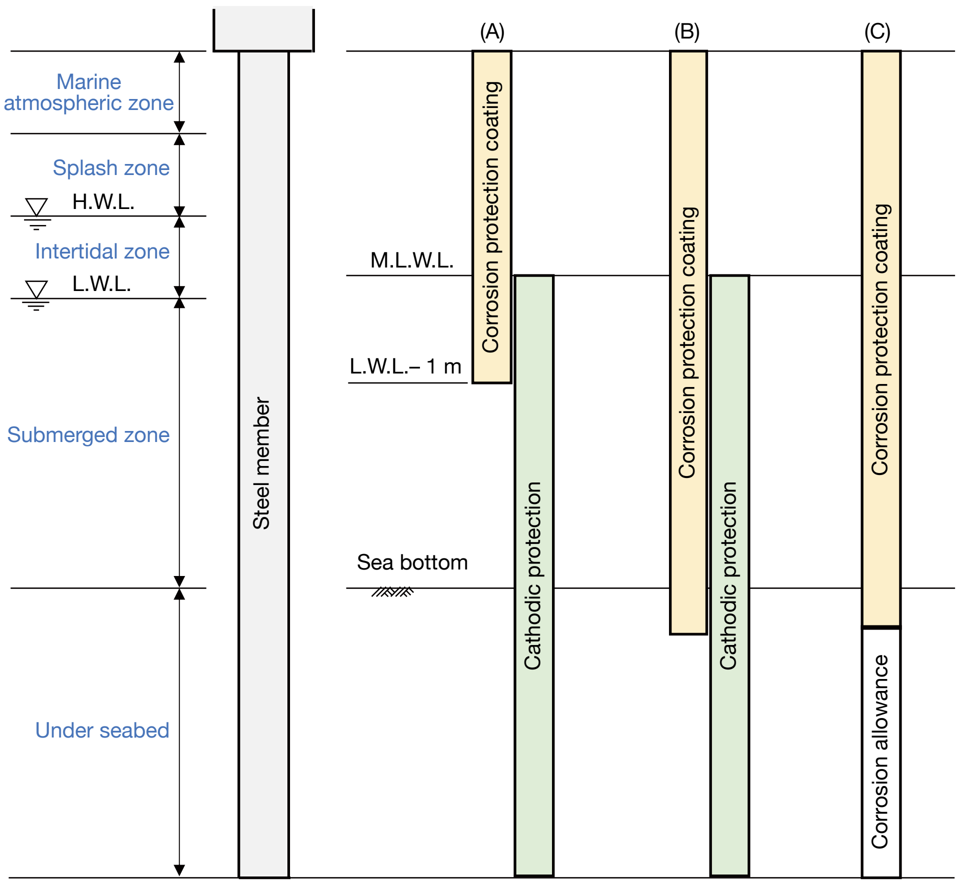
Factors to be considered when determining the current density of corrosion protection are identified: (1) classification of clean sea area and polluted sea area, (2) high current flow, (3) high wave, (4) buried parts, such as under seabed, in rubble and in direct contact with backfilling stone, (5) rust layer formed due to long-term non-corrosion protection, and (6) the effects of corrosion protection coating and concrete superstructure.

Corrosion protection, such as cathodic protection, is not generally applied for the part of steel member in direct contract with backfilling stone because the corrosion rate there is generally low. However, particular corrosion protection should be required when the corrosion rate of steel is high under special environments. The following two examples are provided for such the corrosion protection measures: (1) cathodic protection with impressed current using an external power supplier applied to tie rods and anchorage piles and (2) cathodic protection with small aluminum sacrifice anodes applied to ring joints and turnbuckles of tie rods.

Regarding the corrosion protection efficiency, it is necessary to determine an appropriate value based on the actual corrosion protection efficiency in the target environment. In addition, it has been added that the efficiency of cathodic protection can be evaluated using the corrosion rate during corrosion protection when the corrosion protection efficiency cannot be directly obtained.

The reference values of the coefficient of the initial corrosion protection current density related to the reduction current of corrosion in clean seawater are provided.

Fig. 1 Corrosion Protection Systems for Port and Harbor Steel Structures



• Maintenance and Repair of Corrosion Protection Work

The classification of inspection and diagnosis of port and harbor structures is specified by adding the concept of maintenance work for highly prioritized facilities.

Photos of damages with corrosion are provided for examples.

Examples of the application of latest information and communication technologies (ICT) that have high potentials for use in inspection and diagnosis have been added.

Furthermore, the threshold potential for the judgment of corrosion protection ability of cathodic protection at the initial inspection has been corrected from –800 mV to –780 mV. In addition, it is noted that it takes long for the corrosion protection current to reach the steady-state when a steel member is in a non-corrosion protection state.

As a detailed investigation method, electrochemical impedance measurement technique has been added.

To avoid galvanic corrosion, it is recommended that the potential measurement of cathodic protection be performed every 1 to 2 years. In addition, thickness measurement of corrosion resistant metal has been added to an inspection and diagnosis item.

• Performance Evaluation and Repair of Unprotected Steel Structures

The flow of maintenance and repair from inspection and diagnosis of steel members to the evaluation of structural performance for decision making on the necessity of repair is shown in Fig. 2. Specifications and commentaries on the process according to the flow in the figure have been added.

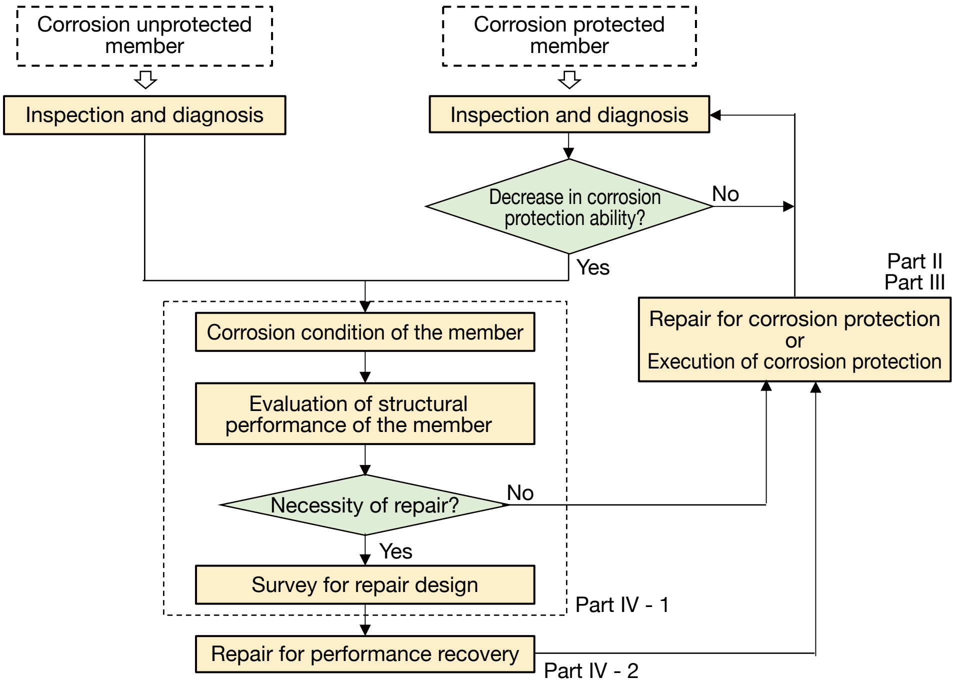
The commentaries on the reduction rate of 70% in on-site underwater welding have been modified. In addition, the considerations for an underwater welding test have been updated.

• Appendices

The appendices of the earlier version of the Manual have been updated. In Appendix 3, design examples of cathodic protection according to the Manual are compared to those according to DNV-RP-B401[5] and ISO 13174[6]. The Manual calculates less number of sacrifice anodes than the other standards mainly because of the difference in effective current capacities of the anodes.

Appendix 11 "Introduction of site exposure tests conducted by research institutes in Japan" has been added.

Fig. 2 Flow of Maintenance and Repair of Corrosion Protected and Unprotected Steel Members



Conclusions

The revision work was conducted as a collaborative study between the Coastal Development Institute of Technology and the Society of the Research for Corrosion Protection Technology for Maintenance. A revision committee was established, which was composed of researchers, practical maintenance engineers, government officials, port managers, and engineers concerned with the manual, to make the Manual even more practical and reliable. All the committee members hope that the Manual will be of help to those in charge of design, construction, and maintenance and repair work for port and harbor steel structures.

Acknowledgments

The author, as a chair of the revision committee, would like to extend his sincere appreciation to all the committee members. A special thank goes to Mr. Hiroaki Suwa, Researcher of CDIT, for drafting this article.

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Abrasive Water-jet Treatment (AWT)

—New Surface Preparation Technology for High-speed, Extreme Removal of Salts and Corrosion Products from Severely-corroded Steel Structures—

by Shigenobu Kainuma
Professor, Kyushu University

Shigenobu Kainuma: After completing the master course at the Graduate School, Hosei University, he served as Assistant Professor at Nagoya University in 1994 and then as Associate Professor at Gifu University in 2001. He became Associate Professor at Kyushu University in 2004 and then Professor in 2022.

Needs for AWT Development

In steel structures exposed to air-borne salt environments, severe corrosion with high corrosion development rates is likely to occur in the structural members where nearly no effect of rain washing on the adhered salt is observed and the sea salt is accumulated. Once the steel member has undergone severe corrosion, corrosion products including the salts in the corrosion pit bottom cannot be removed by the use of power tools. Even when blast treatment is applied, it is difficult to fully remove the salts in the bottom of the corrosion pit[1]. In particular, it is also difficult to secure an appropriate quality of surface preparation in the corner and narrow sections and the gaps between bolts/nuts and bolt joint splice plates. As a result, under-film corrosion frequently occurs due to the salts and corrosion products remaining on the steel product surface in an earlier period after recoating.

In the case of applying heavy-duty corrosion-protection coating, because of the high durability of the coating film and its high adhesion to the steel substrate, corrosion does not develop on the steel product surface but is liable to develop to the thickness direction. Due to such corrosion development behavior, when under-film corrosion occurs, it becomes difficult to remove salts and corrosion products by means of surface preparation at the stage of recoating.

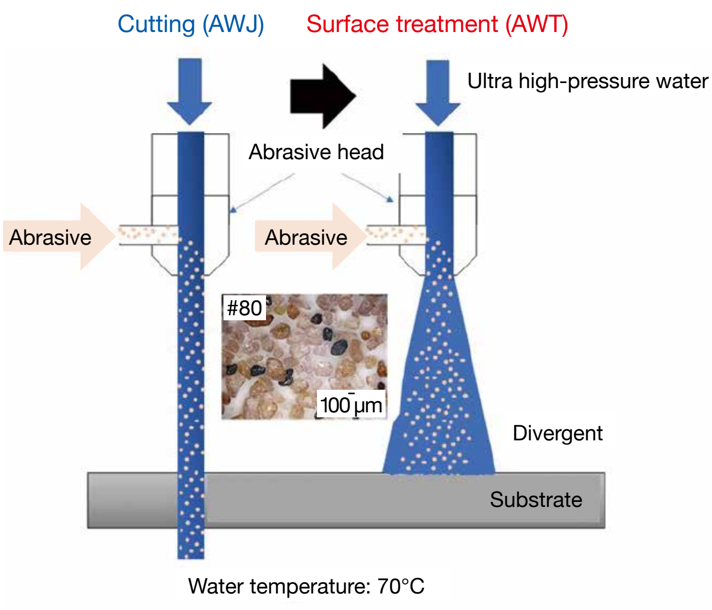
Particularly for weathering steel applied in bridge construction, when unusual corrosion occurs due to salt damage, surface preparation (the preparation of the substrate) is required with the change of specifications from uncoating to coating. However, a dense and firm corrosive product layer is formed in weathering steel, and a larger amount of salt is liable to remain in such layers compared to ordinary carbon steel[1]. This makes it more difficult to remove salts and corrosion products in weathering steel than in ordinary carbon steel.

In order to cope with these situations, we developed a new technology—AWT (abrasive water-jet treatment)[2] that breaks through diverse tasks imposed on conventional surface preparation methods for severely-corroded members and allows for the highly-efficient and thorough removal of salts and corrosion products in severely-corroded members and narrow structural sections over conventional technologies. Further, AWT aims at significantly improving surface preparation efficiency and reducing the generation of industrial waste in comparison with the blast treatment method.

In this development, we noticed an ultrahigh-pressure water multiphase fluid prepared by mixing the abrasive into the ultrahigh-pressure water that is applied to conventional AWJ (abrasive water jet) technology for cutting high-hardness high alloys and CFRP-metal composite materials at high speed with high precision. In addition, we newly focused on the following two aspects: the water wedge effect to allow the high-speed peeling and removal of corrosion products by infiltrating ultrahigh-pressure water into cracks inside the corrosion product layer[2] while at the same time exposing these cracks; and the water flow action to allow the efficient removal of corrosion products in narrow and gap sections, which was impossible by means of blast treatment. Fig. 1 shows a schematic diagram of abrasive water-jet treatment (AWT).

This article introduces part of the basic interdisciplinary examinations employing convergence-type nozzles (AWJ nozzles) for use for cutting[2], which were made in the process of developing AWT, and the applicability of diffusion-type nozzles (AWT nozzles) for use for surface treatments on the severely-corroded sections, which were newly developed based on the basic knowledge obtained from these basic examinations:

Fig. 1 Schematic Diagram of AWT



Testing Methods

• Surface Treatments

A carbon steel product (JIS G3106 SM490A, 70×70×6 mm) was adopted as the test specimen material. Garnet (grain diameter: #30/60) was used as the abrasive material. Table 1 shows the standoff distance and treatment conditions of AWT (abrasive water-jet treatment). Further, blast treatment was applied to compare with AWT. In the blast treatment, the standoff distance was set at 200 mm, the pressure at 0.7 MPa, the angle at 90° and the time at 5 sec. The AWJ nozzle was used as the nozzle in AWT processing. The AWT specimens with standoff distances of 100, 200 and 300 mm are called AWT-1, AWT-2 and AWT-3 respectively.

• Measurement and Analysis Methods

The surface property of the steel substrate subjected to AWT and blast treatment was observed by means of a digital microscope. The surface roughness and the cross-section profile of specimens were measured employing a 3D laser microscope. A micro-Vickers hardness meter was used to measure the microhardness value HV of steel substrate. The surface morphology after surface preparation was observed employing the microscope.

In order to make a relative comparison of the compressive residual stress of the specimen surface after respective surface treatments, the surface was analyzed by means of the x-ray diffraction (XRD) method. For the XRD measurement conditions, the x-ray source was set at Cu-Ka ray, and the voltage and current of bulb output at 40 kV and 30 mA. In addition, the scan range was set at 40°~90°.

Test Results

• Surface Roughness

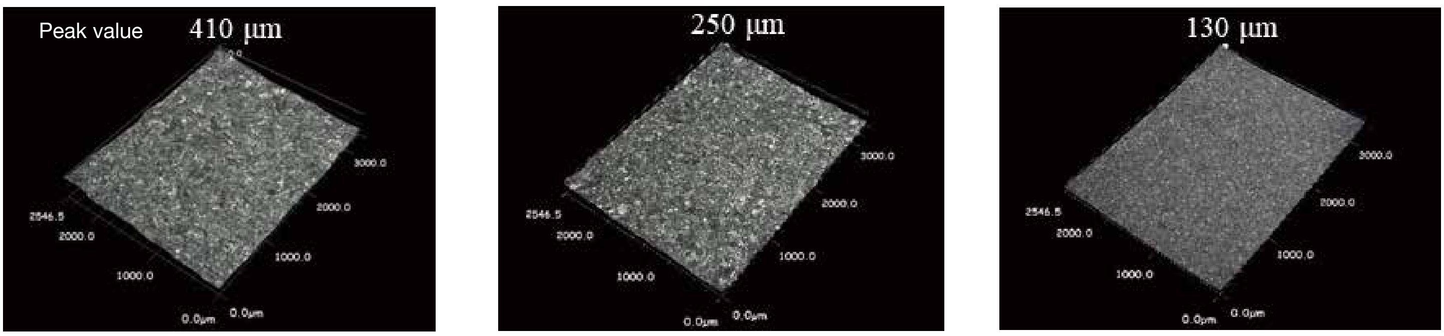
Fig. 2 shows the microstructures of steel substrate surfaces subjected to AWT (abrasive water-jet treatment) and blast treatment. The peak value of surface roughness of the AWT specimens was about 2 times higher than that of the blast-treatment specimens. In particular, the AWT-1 specimen showed the highest peak value of 410 μm, and as the standoff distance decreased from AWT-3 to AWT-1, the peak value tended to increase. This was attributable to the fact that, as the standoff distance decreased, the energy and energy density that collided with the steel surface increased, and as a result the erosion depth increased.

Fig. 3 shows the cross-section profile of the specimens subjected to AWT and blast treatment with a standoff distance set at 200 mm. The figure shows the results of the surface roughness assessed in terms of the contour diagram and surface roughness profile. The peak/valley range and surface roughness of AWT-2 showed considerably higher values compared to those of the blast-treatment specimens.

Table 1 Test Parameters for AWT Process

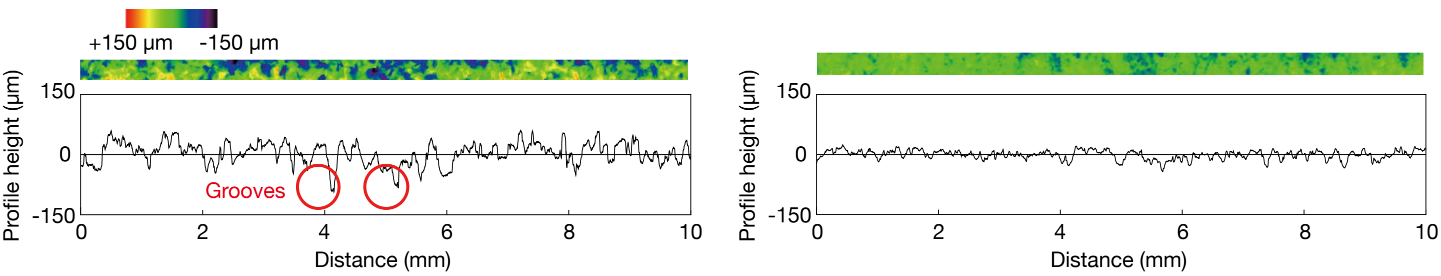
Specimen	Standoff distance (mm)	Abrasive supply (g/min)	Pressure (MPa)	Traverse speed AWT machining (m/min)	Nozzle diameter (mm)	Water flow (L/min)
AWT-1	100	600	230	1	2	11.9
AWT-2	200	600	230	1	2	11.9
AWT-3	300	600	230	1	2	11.9

Fig. 2 Surface Morphologies[2)]



(a) AWT-1 (b) AWT-2 (c) Blast treatment

Fig. 3 Cross-section Profile[2)]



(a) AWT-2 (b) Blast treatment

Fig. 4 shows the surface roughness Ra and Rzjis of the specimens subjected to AWT and blast treatment. The AWT specimen showed a surface roughness about 2 times higher than that of blast-treatment specimens, and as the standoff distance increased, the surface roughness tended to slightly decrease. It was assumed that this was attributable to the fact that the collision energy for the steel substrate of AWT specimens was higher than that of blast-treatment specimens.

Fig. 5 shows the cross-section profile and the maximum erosion depth of the specimens subjected to AWT and blast treatment. It was assumed from the cross-section profile of AWT-2 that a lip was formed on the trench edge shown in Fig. 5(a) due to the occurrence of plastic flow. On the other hand, a lip was not formed with blast treatment.

Fig. 5(b) shows the maximum erosion depth. The maximum erosion depth of AWT specimens became larger than that of blast-treatment specimens regardless of the standoff distance of 100~300 mm. The maximum erosion depth of the specimens subjected to AWT by setting a standoff distance at 200 mm was 1.5 times or more that of blast-treatment specimens.

• Microhardness Values and Cross-section Profiles

In AWT, it is possible to perform surface treatment by the use of abrasive-derived collision energy that is obtained by mixing the abrasive into ultrahigh-pressure water and is considerably higher than the collision energy in blast treatment. In light of this, the energy absorbed by steel plates subjected to AWT was assessed based on the change of microhardness and microstructure beneath the surface of specimens, the results of which are introduced below:

Fig. 6 shows the microhardness of respective specimens. The mean hardness of untreated specimens (basic material) was 150~200 HV. After being subjected to AWT, the hardness of the specimens increased and reached the maximum level at their surface. The maximum hardness of AWT-1 with a minimum standoff distance of 100 mm was 268 HV. The maximum hardness of AWT-2, AWT-3 and the blast-treatment specimen was 253, 242 and 224 HV respectively.

Fig. 7 shows the plastic deformation of steel product specimens after surface preparation. Regardless of the surface treatment methods applied, the hardness of the specimens increased due to the formation of a surface layer that caused plastic deformation. In the case of applying AWT, as the collision energy of the abrasives increased, the hardness increased, and the maximum compressive residual stress appeared at the sections in which the maximum plastic deformation occurred. In the AWT specimen, as the standoff distance became shorter, the

Fig. 4 Surface Roughness[2)]

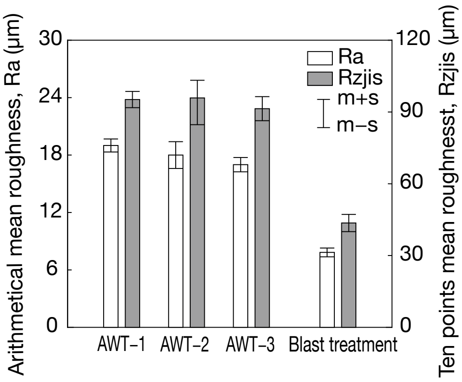
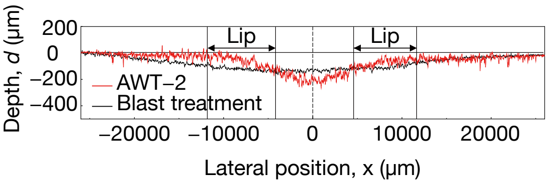
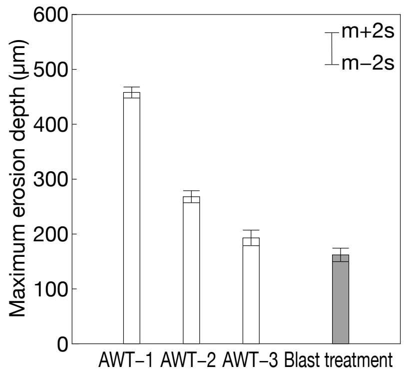


Fig. 5 Trench Profile[2)]



(a) Cross-section profile



(b) Maximum erosion depth

Fig. 6 Microhardness Values, HV[2)]

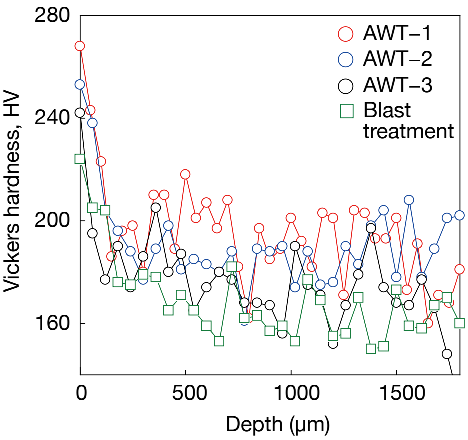
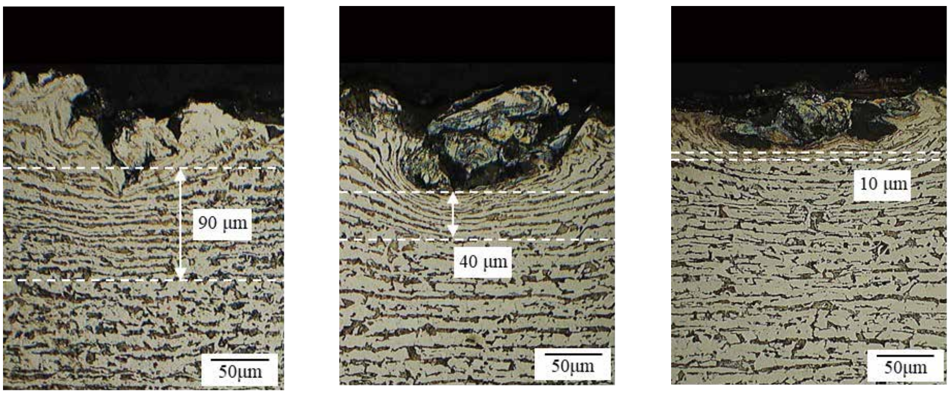


Fig. 7 Microscopic Images of Cross Sections of Microstructures[2)]



(a) AWT-1 (b) AWT-2 (c) Blast treatment

plastic deformation on the surface and in the inner layer became larger. However, the depth and range of plastic deformation for blast treatment were less than those for AWT.

Fig. 8 shows the x-ray diffraction (XRD) patterns of the untreated specimen and the specimens subjected to AWT and blast treatment. Every specimen had 3 high peaks including (110), (200) and (211) α-ferrite surfaces. The diffraction angle of the specimens subjected to AWT and blast treatment slightly shifted to the low side vs the α-Fe peak at every surface of the untreated specimens. It can be said from these results that compressive residual stress occurs on the surface of steel products. Further, because the plastic deformation reached the highest level in AWT-1, the highest compressive residual stress occurred here, and the shift of α-Fe peak became the highest. These results mean that the highest compressive residual stress was introduced in AWT-1.

Applicability of AWT Nozzle to Severely-corroded Structural Sections

The applicability of the AWT nozzle developed based on basic knowledge obtained in the above tests is introduced below:

The target section is salt damage-induced severely-corroded bolted joints collected from an uncoated weathering steel bridge built in an air-borne salt environment. The thickness of layered rust was about 10 mm or higher.

Fig. 9 shows the AWT processing of steel substrate of a corroded bolted joint and the surface condition of the bolted joint after AWT. As shown in Fig. 9(a), the comparatively thick corrosive product layer could be peeled and removed by means of the water wedge effect of ultrahigh-pressure water introduced above. Further, as shown in Fig. 9(b), corrosion products and salts could be completely removed with one AWT processing, and as a result, the amount of adhered salt decreased to 0~2 mg/m^2 or lower.

In the case of applying the surface preparation to the corroded section of the target bridge and then adopting the coating specification for the corroded bridge, it was necessary to reduce the amount of adhered salt to the standard level (50 mg/m^2) or lower by the use of 9 processes—removal of coarse rust using a hammer and chipper and then repeating blasting and water-washing about 4 times. Capitalizing on AWT, the total of 9 processes thus required by the conventional surface preparation method could successfully be reduced to one process and at the same time the high-speed removal of corrosion products and salts could be attained.

The high applicability of AWT to the salt damage-induced severely-corroded sections of steel structures has been verified for several uncoated weathering steel bridges, which has made clear that not only steel substrate quality but construction efficiency can be significantly improved by means of AWT over the use of blast treatment.

Fig. 8 X-ray Diffraction Patterns[2)]

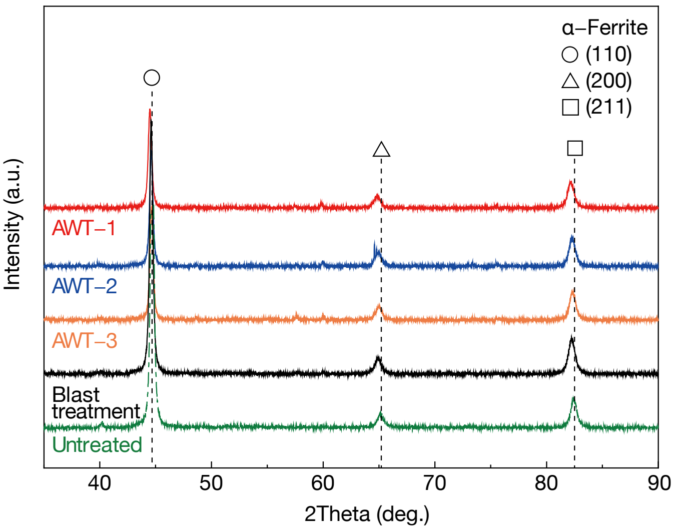


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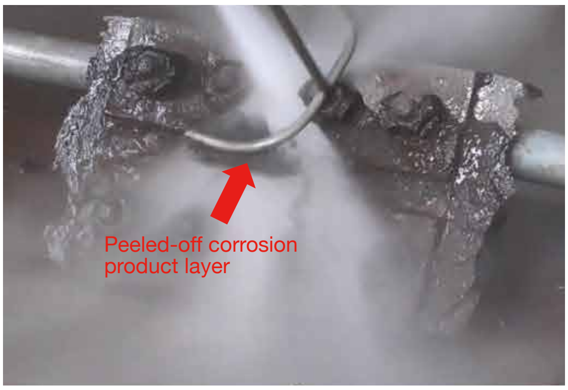
Fig. 9 Applicability of AWT to Severely-corroded Bolted Joint Collected from Weathering Steel Bridge



(a) AWT processing

(b) After treatment

Integration of Monitoring and Numerical Modeling for Rapid Post-Earthquake Assessment

by Tomonori Nagayama
Department of Civil Engineering, the University of Tokyo

Tomonori Nagayama: After obtaining his Ph.D. at the University of Illinois at Urbana-Champaign, USA, he started as an assistant professor at the School of Engineering, the University of Tokyo in 2007. He assumed his current position as a professor at the University of Tokyo in 2022. His areas of expertise cover structural dynamics and monitoring.

Introduction

It is important to quickly assess the damage to bridges after an earthquake from the viewpoints of safety and economy. When a large-scale earthquake occurs, it is essential to assess the structural damage to determine whether emergency vehicles can travel, to identify evacuation routes, and to prepare for recovery plans. On the other hand, when a medium-scale earthquake hits and temporarily halts the operation of railroads or highways but does not cause damage to the structures, the economic and social impacts can be mitigated by quickly assessing the condition of the structures and resuming their services as soon as possible. For example, it took a long time for railroads to be put back into service after the 2018 earthquake in northern Osaka and the October 2021 earthquake in the Tokyo metropolitan area. In Japan, which is an earthquake-prone country, the effect of reducing the duration of outages due to earthquakes is not small.

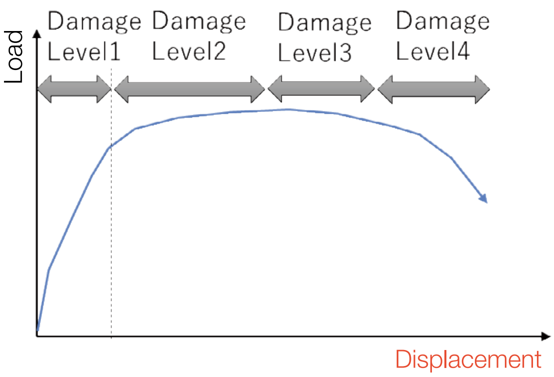
Although seismic intensity information is helpful in estimating the overall degree of damage in corresponding areas, it is difficult to estimate the damage to individual structures from seismic intensity information alone because each structure has different dynamic characteristics. It is possible to assess the seismic response of individual structures by using seismic response spectra or to estimate the degree of damage by simulation based on observed ground motions and numerical models of each structure. However, there are accuracy limitations in the assessment due to uncertainties in the structural models. Although the accuracy of the earthquake response estimation can be improved by updating the linear numerical model using small and medium earthquakes and microtremors, nonlinear characteristics do not appear until large earthquake motion occurs; it is difficult to validate the model in nonlinear regions where structures may be damaged unless a large earthquake occurs. Thus, there are limitations in accurately modeling the nonlinear characteristics and evaluating the degree of seismic damage through simulation.

With recent advances in ICT and sensing technologies, it has become easier than ever before to measure seismic motion and seismic responses[1)] (Fig. 1). Therefore, a new approach to structural damage assessment taking advantage of seismic response measurement is being studied. The approach could be more effective than the conventional framework of damage assessment based on seismic intensity, seismic response spectrum, or forward simulation. In the case of damage assessment based on seismic motion, the uncertainty of the structure directly affects the damage assessment. In the case of existing structures, the uncertainties may also be influenced by the aging of the structure and earthquake motions experienced in the past. On the other hand, if seismic response measurements can be used, information on structural uncertainties can be partially included in the measured seismic responses, thus reducing the uncertainties in the seismic motion and structural characteristics and providing a more reliable damage assessment.

The maximum response displacement, residual displacement, and hysteretic characteristics can be used as evaluation indices of the damage condition. As shown in Fig. 2, the damage level can be estimated based on displace-

Fig. 1 An IoT Node to Measure Acceleration Response Continuously

Fig. 2 Displacement and Damage Level (Image)



ment. Direct monitoring of displacement is a possible method for estimating displacement. A system that measures the relative horizontal displacement at the girder ends and alerts, when the displacement exceeds a threshold value, has been developed and is considered to be effective for rapid damage assessment. However, it is difficult to measure the displacement of the bridge piers relative to the ground because the reference point for displacement measurement cannot be easily obtained. Instead, absolute displacement is expected to be calculated by numerical integration of ground motion and response acceleration, and relative displacement is estimated by the difference between them. The difficulty is that long-period components cannot be estimated due to integration errors. If a high-pass filter is applied to reduce the integration error, the residual displacement component is also removed, making it impossible to evaluate the nonlinear response.

Therefore, a method to estimate displacement response has been developed by using data assimilation techniques such as Kalman filter where ground motion and response acceleration are observed and analyzed with a numerical model. In the forward simulation, the response is calculated based only on the ground motion and the numerical model. On the other hand, in the data assimilation, response observation can also be utilized. Even if the numerical model contains errors, response observations can be used to mitigate the effects of modeling errors and estimate state variables.

In this article, the method of displacement estimation using data assimilation is explained.

Displacement Estimation Using Data Assimilation

A Kalman filter alternates between a prediction step, which represents the forward analytical model in state space, and a filtering step, which uses observed data to correct the prediction. Even if the prediction step is inaccurate due to model uncertainty, it can be corrected in the filtering step. However, if the model error is large, the correction by the filtering step is limited. Therefore, a method that combines an ordinary Kalman filter with optimization of the model parameters of a state-space model has been developed (Fig. 3)[2]. The target structure is represented as a nonlinear single-degree-of-freedom (SDOF) system, and a trilinear model is employed as the hysteresis characteristics (Fig. 4). The parameters of the trilinear model are identified using a genetic algorithm.

The target structure is a finite element model of steel bridge piers shown in Fig. 5, in which a kinematic hardening law is set for the shell element. The hysteretic characteristics of the pier, experienced during a large seismic motion, are shown in Fig. 6. The acceleration response of the finite element model was treated as measurement data in order to evaluate the displacement. On the other hand, when the displacement is estimated, a simple SDOF tri-

Fig. 3 Overview of the Displacement Estimation Method

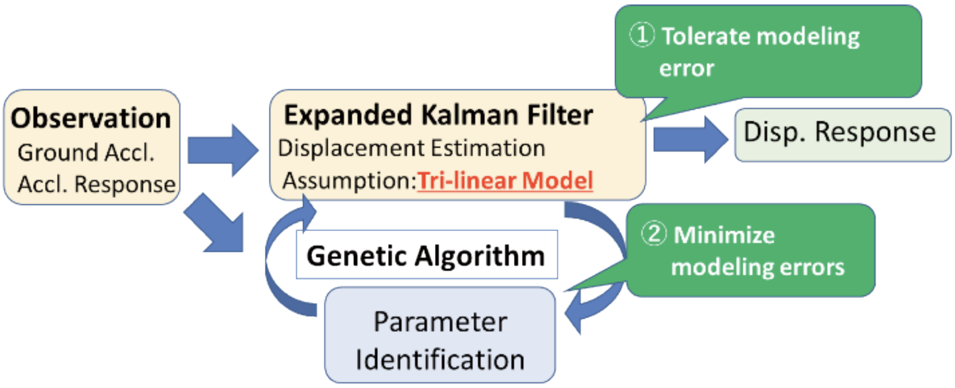


Fig. 4 Trilinear Model Employed in the Estimation Algorithm and Its Parameters

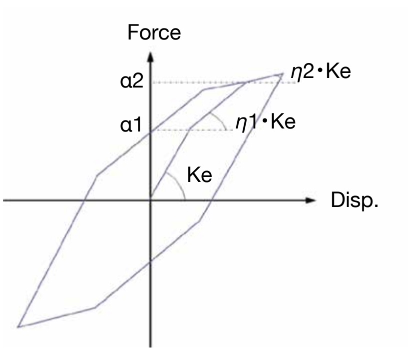


Fig. 5 Target Steel Pier Model

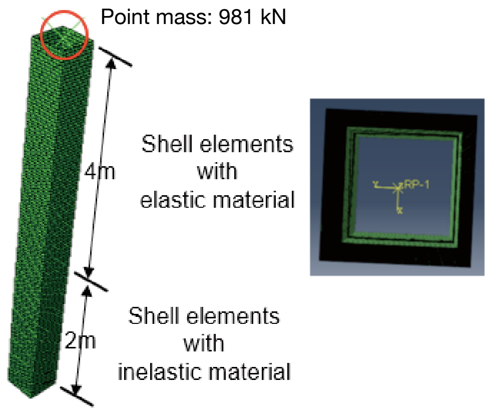
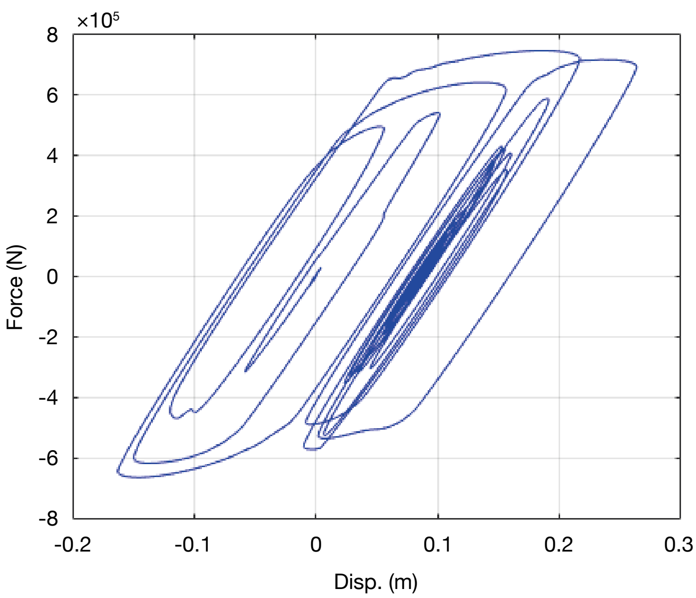


Fig. 6 Nonlinear Hysteretic Characteristics of the Pier Model



linear model with parameter uncertainties is used. The estimated displacement in Fig. 7 shows a good agreement with the reference value including the residual deformation component. The accuracy of the displacement estimation was evaluated by applying this method to various input earthquake motions, and it was found that the maximum displacement can be estimated accurately as shown in Table 1.

Displacement Estimation Combining Data-driven Model Identification and Data Assimilation

While the aforementioned method represents the structure of interest as a SDOF trilinear model, the hysteretic characteristics of a real structure can be more complex. Various hysteretic characteristics models are employed in the forward simulation. However, only Markov process models, i.e., nonlinear models with no hysteretic dependency, can usually be employed for data assimilation employing the state-space model; the state-space equation describes the time evolution based only on the current state variables. Hysteretic models cannot be easily dealt with in the state space. Although the Bouc-Wen model is available as a hysteretic model that can be expressed in state space, most of the hysteretic models used in the forward simulation cannot be employed in state space.

Therefore, a data-driven state-space model[3)] is employed in this displacement estimation framework. A finite element model with complex hysteretic characteristics is used to calculate the responses to various earthquake motions, and the input earthquake motion and response acceleration are used to identify the state-space model. The target structure is the finite element model of steel bridge piers shown in Fig. 5. A forward simulation is performed with Takatori, Northridge, and JMA Kobe earthquake waves as inputs, and the acceleration velocity and displacement response data are used as training data to identify the governing equations for this system in the state space. More than 100 polynomials are assumed as the basis functions of the governing equation and their coefficients are identified (Fig. 8). As Fig. 9 shows the identified coefficients for all of the basis function polynomials, the identified

Fig. 7 Estimated Displacement Time History

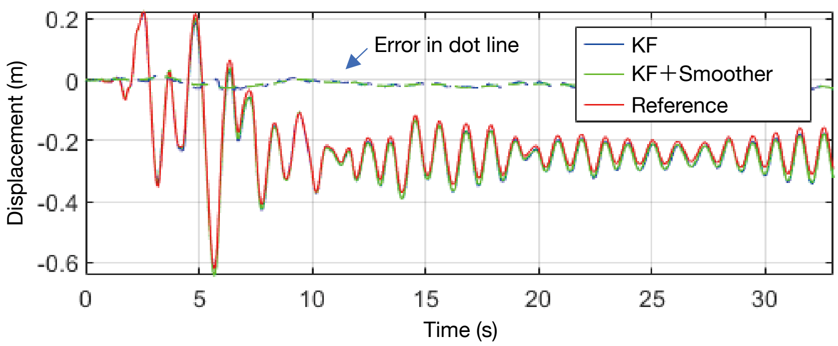


Table 1 Displacement Estimation Error for Various Ground Motion

Ground motion	Takatori 800 gal		San Fernando 800 gal		Northridge 800 gal		Kobe JMA 800 gal		Imperial valley 800 gal	
	Max.	Res.	Max.	Res.	Max.	Res.	Max.	Res.	Max.	Res.
Error	3.5%	3.2%	4.0%	6.6%	7.2%	7.0%	10.4%	17.9%	4.2%	0.0%

* Max: maximum estimation error, Res: residual displacement estimation error with respect to the maximum displacement

Fig. 8 Identification of State-Space Model

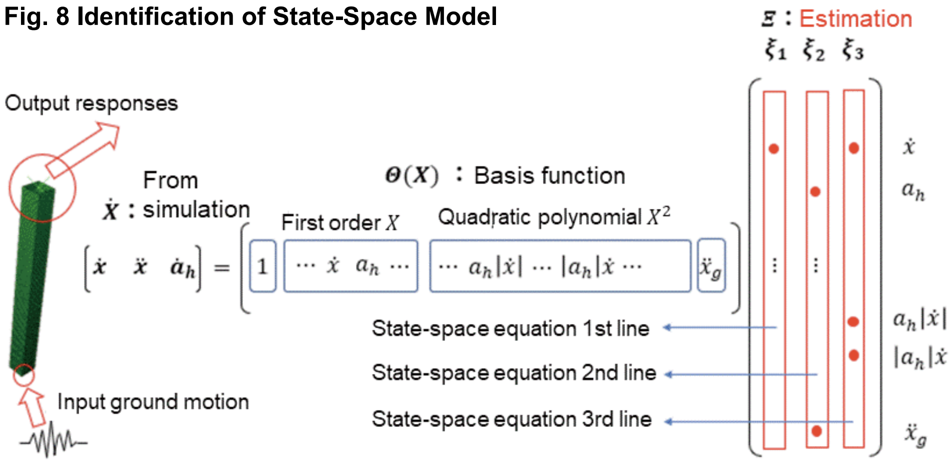
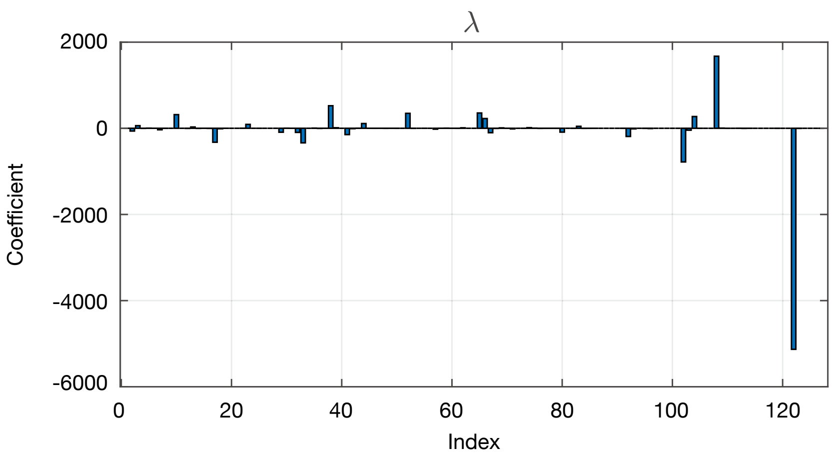


Fig. 9 Sparse Regression Results of Polynomial Coefficients



parameters are sparse. The coefficients are estimated by sparse regression using the LASSO algorithm.

Forward simulation using the identified state-space model[3] alone has limited estimation accuracy, and the deviation from the true value is not small, as shown in Fig. 10. Therefore, an Unscented Kalman filter (UKF), one of the nonlinear Kalman filters, is applied to the identified state-space model, so that error in the forward simulation can be compensated through the update steps. The proposed method obtained displacement estimates that were almost equal to the true values (Fig. 10). Table 2 shows the maximum displacement estimation error and root-mean-square error for the training and test data, indicating that the combination of data-driven state-space model estimation and the Kalman filter enables accurate displacement estimation.

Fig. 10 Displacement Estimation Using Data-driven State-Space Model and Nonlinear Kalman Filter

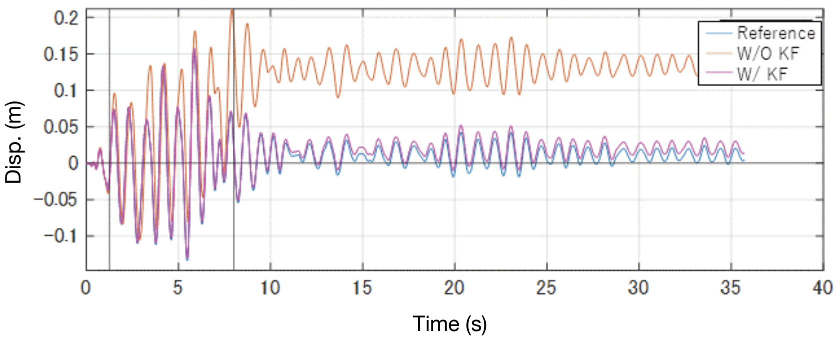


Table 2 Displacement Estimation Using the Data-driven State-Space Model Identification

	Ground motion	Maximum error (%)		RMSE (%)	
		Without UKF	With UKF	Without UKF	With UKF
Training data	Takatori	15.1	1.4	2.8	0.4
	Northridge	22.6	3.7	9.5	1.5
	JMA Kobe	5.1	1.3	1.6	0.4
Test data	San Fernando	10.1	2.0	3.6	1.2
	Imperial Valley	6.6	3.0	1.0	1.1

Conclusion

A method for estimating displacement responses by using the seismic acceleration responses of structures has been studied. The method has become a reality with the recent development of ICT and sensing technologies. Displacement estimation can be accurate by fusing observation data and numerical structural models even for problems where the numerical models are difficult to validate, such as the nonlinear response characteristics of real structures. Although the earthquake response of bridge piers has been studied so far, it is necessary to estimate the displacement of the entire bridge system as well as to consider the nonlinear behavior of movable bearings to understand the seismic damage of real infrastructure. Numerical analysis and monitoring techniques are both becoming more and more sophisticated, and we would like to realize a data-based framework for rapidly understanding earthquake damage by integrating the two into this data assimilation framework.

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Strategy for the Construction Industry in the Age of Digital Transformation

by Kazuyoshi Tateyama
Professor, Ritsumeikan University

Kazuyoshi Tateyama: Dr. Kazuyoshi Tateyama is Professor, Research Organization of Science and Technology, Ritsumeikan University. He has taken on the research and development on the rationalization of construction for many years and has engaged in many committees of governments and academic societies, among which are the member of i-Construction related committees of the Ministry of Land, Infrastructure, Transport and Tourism and the chairperson of the committee for construction robotics at the Japan Society of Civil Engineers.

Emerging Tasks in the Construction Industry

In terms of examining the future of Japan, the projection for population trends constitutes an extremely important point at issue. Fig. 1 shows a projection for the population transition of Japan[1]. According to this projection, both the total population and the working-age population (ages:15 to 64 years old) in Japan will continue to decline, and in 2050, about 30 years from now, it follows that the Japanese society will have to be supported with the working age population with an estimated decrease to 71.5% that in 2020.

Currently, the construction industry is struggling to secure necessary workers. In the future, we cannot help but think that the construction industry will be forced into an increasingly difficult situation in securing these workers.

On the other hand, while the construction of new social infrastructure will lose its momentum in line with a decreasing trend in the total population of Japan, the construction work required for maintaining existing infrastructure that supports the activities and lives of people will follow a steady increase in the future. Fig. 2 shows a recent trend in investment into new construction and the maintenance and repair of social infrastructure in Japan[2]. As can be seen in the figure, while investment into new infrastructure construction decreased to 60% or less compared to the level in the 1990s, the share accounted for by existing infrastructure maintenance and repair that are more complicated and difficult than new infrastructure construction increased, and this trend is fore-

Fig. 1 Projection of Japanese Population[1]

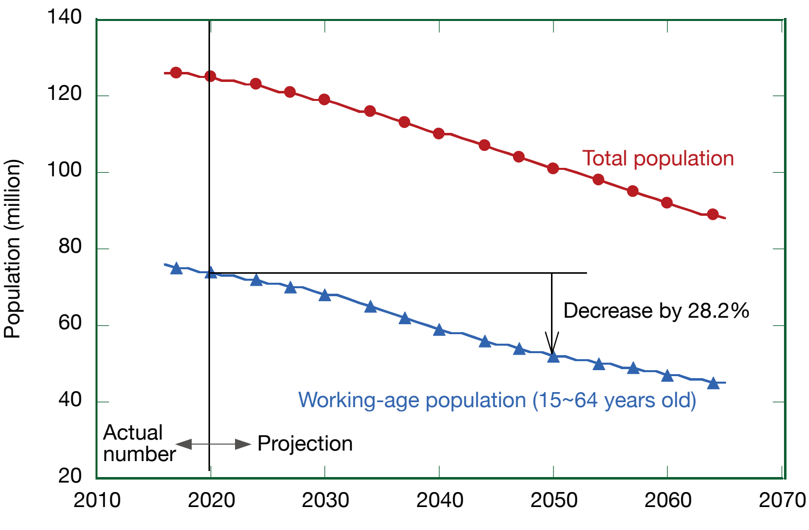
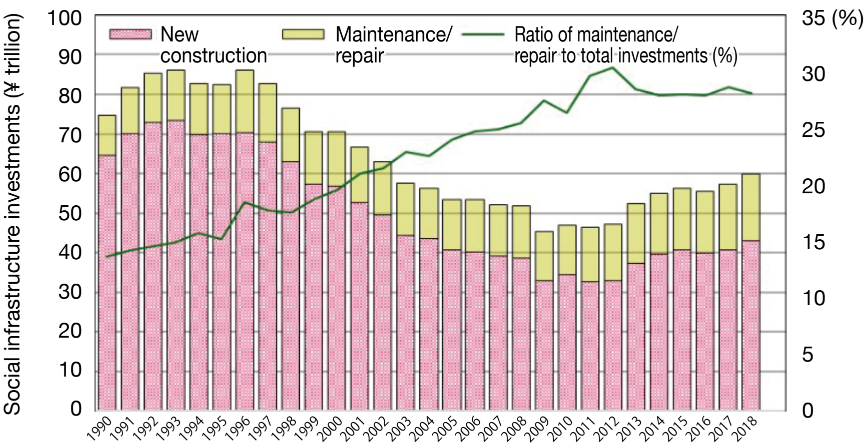


Fig. 2 Trend of Infrastructure Investments[2]



cast to continue in the future.

In addition to the above, the construction industry faces the strict task of how to deal effectively with natural disasters. Fig. 3 shows the annual frequency of heavy rains (50 mm/h or more) in Japan[3]. While there are years with a lot of rains and others with little rains, the rainfall trend shows that the frequency of heavy rains exceeding 50 mm/h is steadily increasing year by year. The natural disasters such as not only heavy rains but also earthquakes and volcanic eruptions occurring in Japan are becoming more serious.

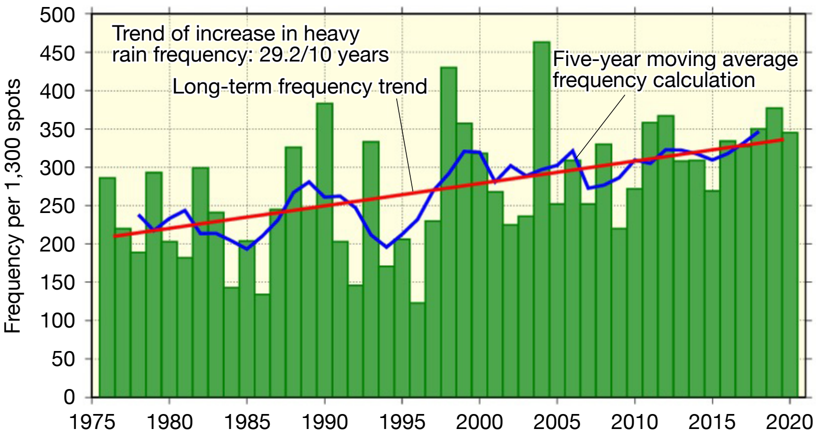
In the situation of growing restrictions imposed on securing necessary manpower and budget, the construction industry faces operating conditions in which it must not only manage construction works that are more complicated and difficult than ever such as the maintenance, repair and renewal of existing infrastructure but must also tackle the strengthening of disaster countermeasures. As the construction industry examines how to cope with these problems employing conventional or similar approaches, it is considered that the industry is falling into the critical condition of being unable to stably supply infrastructure to society in future years.

The working environment and condition of the construction industry that bears these construction works are steadily being improved, but its level of wage and working hour is lower than that of the all-industry average. In addition, the number of deaths that occurred during work in the construction industry accounts for 1/3 that of all industries[2]. (Refer to Fig. 4)

In other words, it should be stated that the construction industry has not yet removed itself from hard working conditions—the so-called 3D (dirty, danger and demeaning) conditions. It is thus feared that the securement of human resources to support the construction industry will become more and more difficult in the future.

One of the reasons considered to be attributable to the above is the slumping labor productivity of the construction industry. Fig. 5 shows the trend of labor productivity by industry[2]. Since the 1990s, the manufacturing industry has extended wide-ranging approaches represented by the introduction of automated and other new operating technologies into production lines, which has led to notable productivity improvements for past 20 years. On the other hand, in the situation of annually decreasing infrastructure investment, the need to improve productivity has not been recognized in the construction industry due to its oversupply of labor force, and as a result the construction industry has lapsed into the condition for productivity to decline rather than to rise.

Fig. 3 Annual Frequency of Heavy Rains (50 mm/hour or higher)[3]



Source: Japan Meteorological Agency

Fig. 4 Comparison of Working Conditions and Environments by Industry[2]

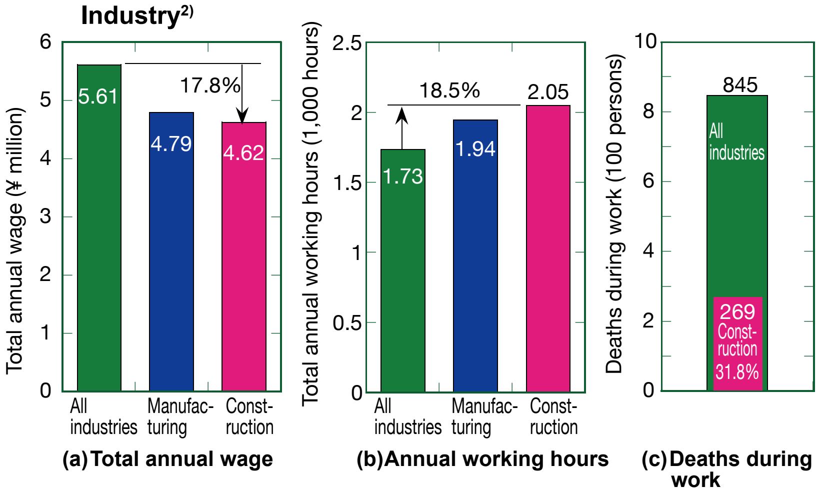
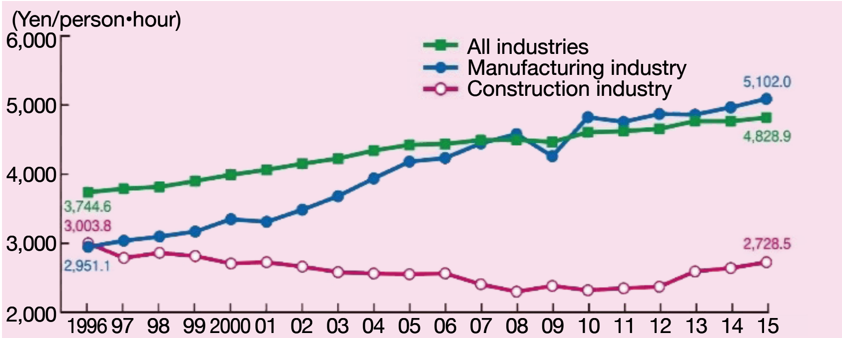


Fig. 5 Trend of Labor Productivity by Industry[2]



Note: Labor productivity=Real gross value added (2011 price)/ (Number of workers × Total annual working hours)

Source: Cabinet Office — Calculation of National Economy; Ministry of Public Management, Home Affairs, Posts and Telecommunications — Survey of Labor Forces; Ministry of Health, Labour and Welfare — Survey of Monthly Work Statistics

Towards the Improvement of the Operating Structure of the Construction Industry—Start of "i-Construction"

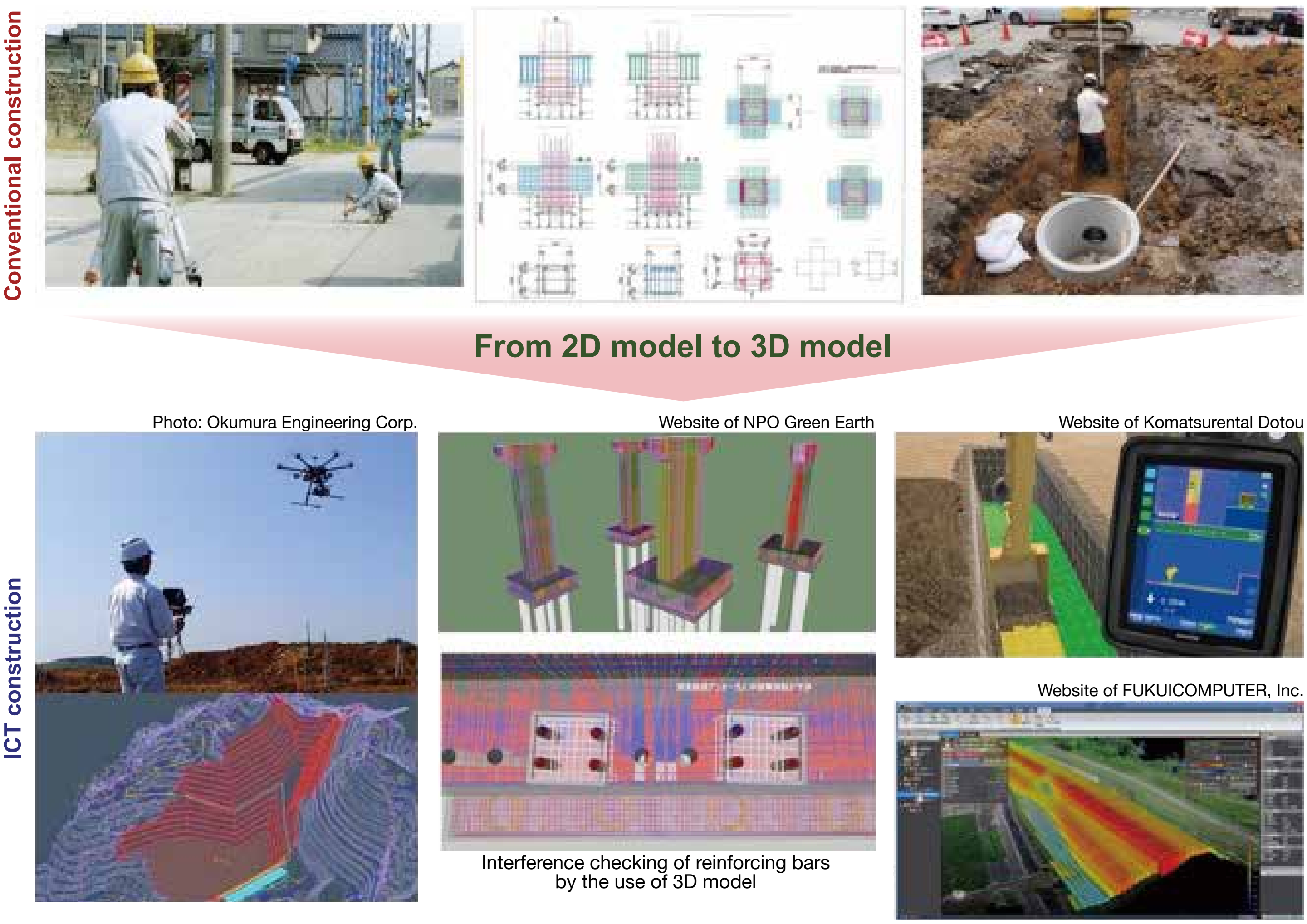
Given such conditions, the Ministry of Land, Infrastructure, Land and Tourism has launched a new strategy called "i-Construction." Its main aim is to reform the construction industry to a renewed one symbolized with three new specified terms—"high wage levels, sufficient holidays and hopeful work" that will be realized through the substantial improvement of productivity.

Specifically, with i-Construction, productivity is improved by capitalizing on diverse approaches centered on three tactics: the aggressive application of ICT in construction operations, which has lagged behind that of the manufacturing industry; the standardization of construction work specifications to improve inefficiencies caused by mono-item and on-site construction operations; and year-round levelled execution of construction operations vs. the order placements that are significantly biased depending on the season, and then "high wage levels, sufficient holidays and hopeful work" can be realized employing these approaches. The final goal is to renew the operating structure of the construction industry by making the most of i-Construction[4]. In order to securely attain the final goal, expectations are high for productivity improvement by, among others, the aggressive application of ICT technology.

In ICT-applied construction, the high work efficiency and labor saving are realized by making the most of 3D data cross-sectionally in an entire construction process from surveying and design/construction planning to inspection and maintenance, through which the productivity is to be improved (refer to Fig. 6). After six years since the introduction of i-Construction, productivity improvement by means of ICT-applied construction has shown steady achievements, but in the small to medium-scale projects ordered by local governments, the introduction has been delayed due to such obstacles as high hardware/software introduction costs and the nurturing of necessary engineers who can use them.

Given such conditions, under the banner of digital transformation (DX), the society as a whole is undergoing major changes capitalizing on digital technologies. In light of this, it is considered that i-Construction has reached the stage of entering the next phase.

Fig. 6 Promotion of i-Construction — Full Application of ICT



From i-Construction to Infrastructure DX

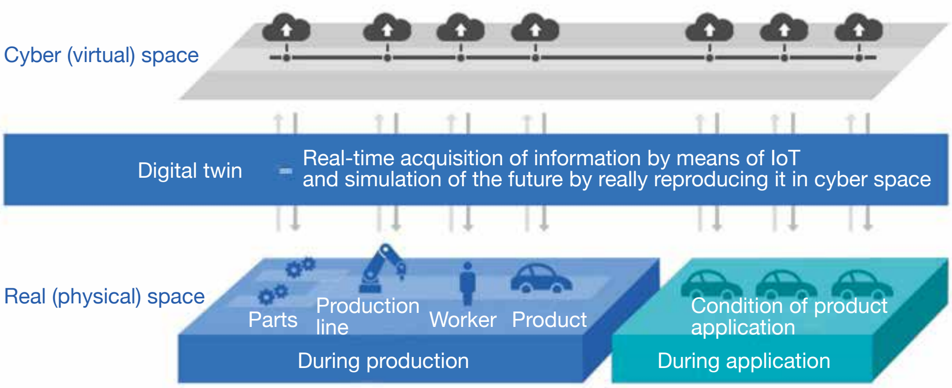
Digital transformation (DX) refers to the concept in which a whole concept of business operations and commercial distribution is reformed by fundamentally transforming existing organizations/mechanisms, procedures and flows of goods and information with the optimum use of high-speed internet, cloud services, AI and other advanced digital technologies and beyond the framework of the improvement of business operations efficiency and the promotion of labor saving.

In this connection, the Ministry of Land, Infrastructure, Transport and Tourism has advocated infrastructure DX and in March 2022 launched an action plan for its achievement[5]. The main aim is to radically transform what infrastructure improvement should be beyond the conventional framework of ICT construction systematized mainly by the use of 3D data and further by capitalizing on not only ICT and other diverse new technologies but also digital twins, automation, AI, virtual and other advanced technologies. (Refer to Fig. 7)

It is the concept of the digital twin, among others, that attracts particular attention. Digital twin is a simulation technology with which data is collected in the real world by making full use of diverse sensors and IoT to connect them and the real world is reproduced as faithfully as possible in the cyber space (virtual space) by the use of this collected data. In the world of the digital twin, simulations are carried out by freely changing the scenarios and input conditions in the cyber space (virtual space) to express real phenomena, and thus simulations can be repeated many times. (Refer to Fig. 8)

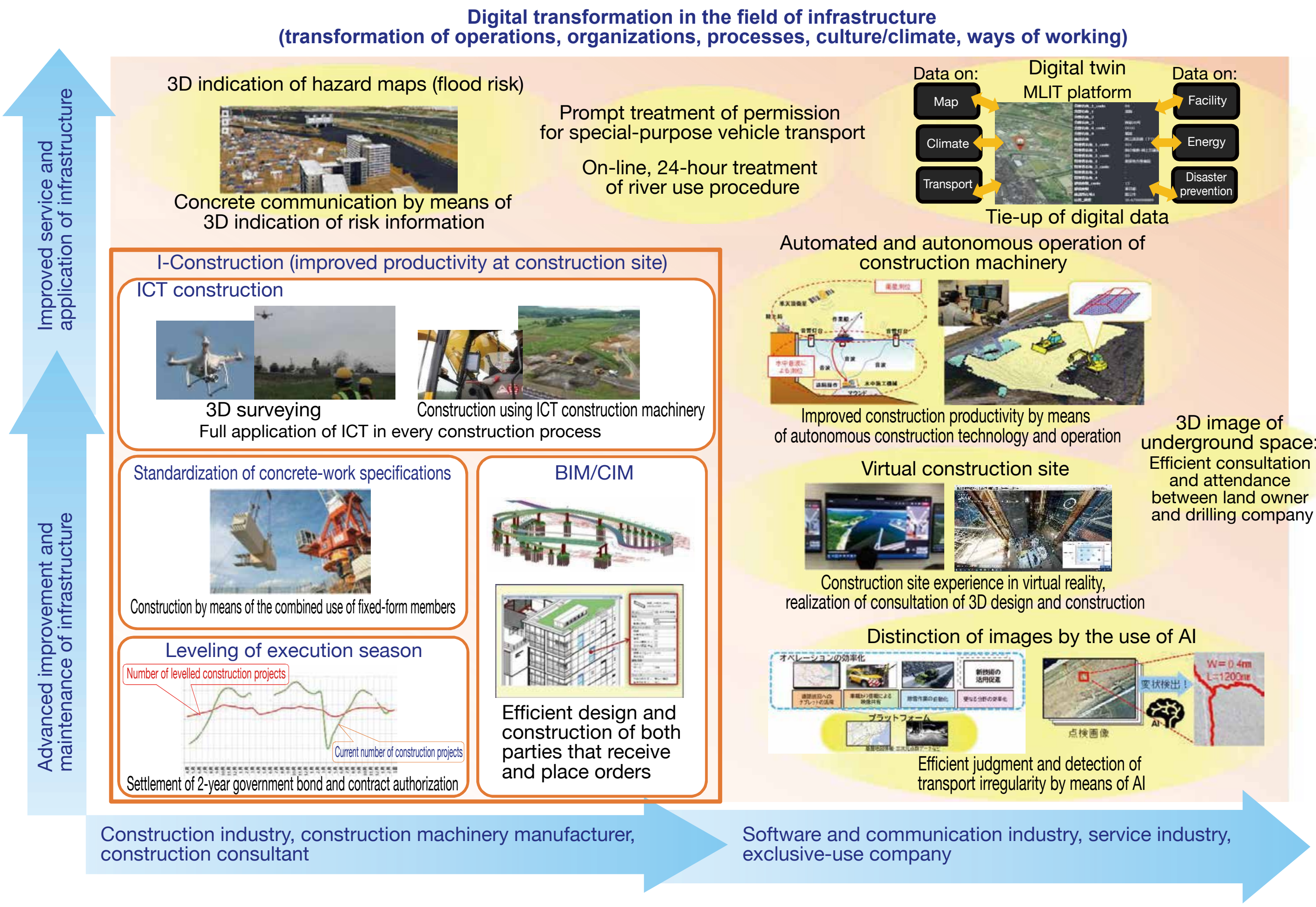
In light of this, for example, the digital twin technology allows for the reproduction of various aspects by means of simulation—the damage assumed when an unexpected disaster occurs, the time and cost required for reconstruction and the impact on nature. This enables extraction of the ideas for the state of an ideal city that minimizes the impact of disasters and incorporation of these ideas into urban planning practice. It also becomes possible to estimate in advance the effects and costs involved in the in-

Fig. 8 Image of Digital Twin



Source of information: SoftBank Business Blog

Fig. 7 DX in the Field of Infrastructure - Action Plans[5]



troduction of new policies and technologies and thus select and implement the most effective methods and tools based on the digital twin. In the future, it is forecast that infrastructure improvements will be based on digital twins and promoted more efficiently.

From now on, the construction industry will reform its operation structure by introducing various kinds of digital technology, but reckless introduction will not always bring about needed effects. To that end, it is required for the industry to make efforts toward the effective introduction of digital technologies. In order to meet such a requirement, lean management is attracting attention.

Introduction of Lean Management

In order to cope with soaring personnel expenses in the bubble economy period in the latter part of the 20th century, Toyota Motor Corporation worked out the "TOYOTA Production System" that systematically extracts operational improvement measures on the production floor and promotes their practical application. The Massachusetts Institute of Technology systematized a new manufacturing system via research on the TOYOTA Production System[6], which was named the "Lean Manufacturing System." Application of the Lean Manufacturing System filtered into not only the manufacturing industry but other general industries, which led to the establishment of lean management.

The term "lean" means flab-free, compact or slim. In the lean manufacturing system, the total cost and lead time through an entire production process are reduced by the optimized use of diverse approaches—just-in-time in which necessary materials and parts are accurately secured whenever they are required; maintaining a waste-free manufacturing environment by means of the thorough introduction of five terms—sort, tidy, cleaning, clean and discipline; the early detection of malfunctions; revealing defects by means of visualization; and "*KAIZEN*" (continuous improvement).

Of these approaches, *KAIZEN*, which is accepted as a universal term, is a means to link the improvement measures proposed by those working on the production floor to the enhanced efficiency of an entire production process. It can be said that *KAIZEN* is the most sought-after factor needed in reforming construction operations.

Various kinds of approaches are available in the promotion of lean management. In this connection, how to introduce lean management in the field of construction and how to streamline construction operations by capitalizing on lean management are introduced below:

In the Lean Manufacturing System, on-site works are classified into the following three elements to examine the enhancement of work efficiency and labor saving to be attained by the use of this system:

- Value-added work: Direct addition of added value required for the product; the essential work required to attain the purpose of production
- Accompanying work: Necessary work but auxiliary work that does not add value to the product directly
- Wasted work: Primarily non-applied, unnecessary work

Below, application of these three concepts to earthwork in road construction is examined:

• Value-added work

The aim of road earthwork is to structure the filled-up ground and the roadbed prior to pavement. Accordingly, value-added work covers a series of construction works from the drilling of the natural ground to the transport of drilled earth, the laying and levelling of transported earth and the compaction of the roadbed (refer to Photo 1). In these construction works, because the earth must be treated by the use of construction machinery, comparatively large-scale measures such as the introduction of construction robots are required for enhancing work efficiency and labor saving.

• Accompanying work

Accompanying work in construction include photographing of construction conditions, surveying, document preparation and the measurement of finished shapes. While these works do not fall into the building of filled-up ground and roadbeds, they are necessary in completing the road construction. In general, these works require workforce and time, and thus it can be said that it is easy to improve work efficiency and labor saving by introducing ICT. Enhanced photographing efficiency by the use of electronic blackboards and cell phones and the use of video in place of documents can be cited as appropriate examples (refer to Photos 2 and 3).

Photo 1 Value-added work in road earthwork

Photo 2 Application of small-size electronic blackboard
(Source of information: Okumura Engineering Corporation and KENSETSU SYSTEM Co., Ltd.)

Photo 3 Treatment of measurement data
(Source of information: Okumura Engineering Corporation and KENSETSU SYSTEM Co., Ltd.)

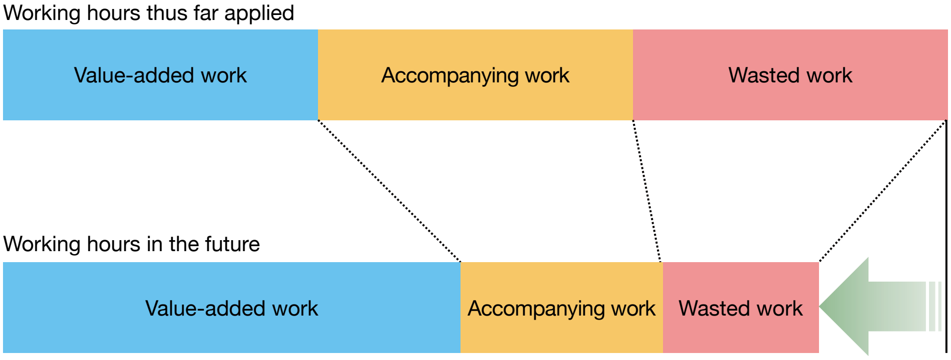
• Wasted work

Wasted work such as the adjustment time between processes and the waiting time required for inspection is a factor that is basically not involved in construction, and it is thus necessary to shorten these times as much as possible. In order to meet such a need, an approach that has recently attracted attention is construction site-attendance technology employing video. Because the time required for accessing remotely-located construction sites can be reduced by means of this technology, it is possible to broadly reduce construction time and also to carry out closer construction site control by increasing the frequency of attendance at construction sites due to its simple applicability[7]. (Refer to Photo 4)

Fig. 9 shows an image of the improvement of working hours for construction engineers brought about by reduced accompanying work and wasted work. Capitalizing on the reduction of accompanying work and wasted work using diverse tools and devices or the construction of lightweight structures, they can perform more activities with higher added value while having temporal allowance.

Photo 4 Remote attendance and remote witnessed inspection using camera
(Source of information: Kankyo Fuudo Techno, HORIGUCHI CORPORATION Co., Ltd. and IKEE Group)

Fig. 9 Image of Improvement of Working Hours



Towards a Construction Industry in the DX Age

The construction industry is definitely moving towards transformation. The industry has gained a great opportunity to establish an operating structure that can overcome diverse problems forecast to surely visit in the future. While society is moving into an emerging trend of digital transformation (DX), the construction industry is currently in the midst of an age in which it can capitalize on this trend and thus promote its transformation.

In light of this, new transformation efforts will be made in the industry. It should be realized, however, that they will not always be successful. Some efforts may end in failure. Of great importance in this case is not to criticize such failures, but to foster a culture of appreciating new challenges. It is also recommended that efforts should start with small initiatives for improvement, rather than embarking on massive efforts from scratch. If a small-scale attempt produces good results, the scope of the effort should be expanded. Conversely, if the attempt produces little effect, an effective way to proceed would be a commitment to new alternatives by drawing reasonable lessons from previous experiences.

Expectations are high for the construction industry to transform into a vibrant industry through such efforts.

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Conclusion of a Memorandum of Understanding with Thailand on the Use of JIS Copyright and the FY2022 Japan-Thailand Steel Cooperation Program

The Japan Iron and Steel Federation (JISF) implemented technical cooperation program in the steel sector for Thailand from 2008 to 2016 based on the intergovernmental agreement of the Japan-Thailand Economic Partnership Agreement (JTEPA). Since 2017, JISF has been providing the technical cooperation to the Thai steel industry as a cooperation program between JISF and the Iron and Steel Institute of Thailand (ISIT) on an annual basis. The program mainly involves the standardization of steel product in Thailand, including formulation of steel product standards in Thailand and technical guidance to strengthen a quality inspection system of the testing laboratory owned by ISIT.

While the majority of the Thai Industrial Standards (TIS) for steel products are based on the Japanese Industrial Standards (JIS), also by the trust fostered through these cooperation program, JISF has received a request from the Thai Industrial Standards Institute (TISI) to contact agreement to use the copyright of JIS steel standards which are held by the JISF's Standardization Center. As a result, a Memorandum of Understanding on the use of JIS copyrights was signed between JISF, TISI and ISIT in July 2022. The conclusion of the MoU is expected to increase the compatibility between TIS and JIS standards for steel products and improve market access for Japanese steel products in Thailand. As the MoU includes ISIT publishing an English translation of the TIS steel standards based on JISF's request, it is also expected to facilitate the business activities of Japanese steel companies in Thailand.

Under the steel technical cooperation program in FY2022, JISF conducted a technical guidance and seminar by the Japanese experts to the ISIT Testing Laboratory which covered analysis of coating layer, appropriate use of the testing equipment and management system in Bangkok in January 2023 together with a seminar on JIS steel standards such as Steel Sheets and Strips, Steel Pipes, Steel Bars, Steel Sheet Piles and mechanical testing for Metallic Materials for TISI officials and ISIT member companies by the experts of JISF's Standardization Center.

Lecture on "Seismic Evaluation of Steel Frames Using High-Performance Steel" at SEAISI Event

At the SEAISI Steel Mega Event & Expo held in Kuala Lumpur, Malaysia on November 17, 2022, Dr. Muslinang Moestopo of the Indonesian Society of Steel Construction delivered a lecture titled "Seismic Evaluation of Steel Frames Using High-Performance Steel." The lecture was given as an achievement of the joint research by the Japan Iron and Steel Federation, the Japanese Society of Steel Construction and the Indonesian Society of Steel Construction.

In this joint research, trial design was performed on general-purpose buildings to be constructed in earthquake-prone Indonesia employing the local standard and SN steel product, a typical high seismic-performance steel from Japan, for which seismic evaluation was made. Specifically from the aspect of the risk assessment of buildings in the event of earthquakes, it was understood from the evaluation results that building performance close to the design performance required for local buildings could be secured by applying SN steel with less deviations in yield points and that building performance to protect human lives and social assets could be improved by capitalizing on high-performance steel.

After the lecture, there was a Q&A session with the participants, which suggested growing interest in high performance steel emerging in Southeast Asia.

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The Japan Iron and Steel Federation
3-2-10, Nihonbashi Kayabacho, Chuo-ku, Tokyo 103-0025, Japan
Phone: 81-3-3669-4815 Fax: 81-3-3667-0245
URL https://www.jisf.or.jp/en/index.html

Japanese Society of Steel Construction
3F Aminosan Kaikan Building, 3-15-8 Nihonbashi, Chuo-ku, Tokyo 103-0027, Japan
Phone: 81-3-3516-2151 Fax: 81-3-3516-2152
URL http://www.jssc.or.jp/english/index.html

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