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Specifications for Highway Bridges

—Revised in 2017 by Ministry of Land, Infrastructure, Transport and Tourism—

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Introduction

The Japanese *Specifications for Highway Bridges* (referred to as SHB hereafter) was revised in July 2017 by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and issued to road administrators. SHB is the legally-binding design code for national highways and expressways and the de-facto standard for other roads.

The background of the revision this time arises from MLIT's recent policies of:

✓ Increasing productivity in the construction and preservation of infrastructure
✓ Ensuring the long-term functionality of bridges with lower life-cycle costs and higher reliability

It is key to taking up developments in the industry and academic sectors in a timely manner to achieve these policies, while reliability and quality are assured. Accordingly, SHB has fully restructured its code structure and verification process such that it is capable of providing principles on how to make decisions on the sufficiency of a bridge to the code requirements even when employing various new developments.

Performance-based Specifications

In consideration of diversifying materials and structural types, it is necessary to have a code structure that is capable of verifying the performance in a direct way, not only by means of conformity with the standards. Accordingly, the performance-based code structure in the 2017 revision is comprised of the following five main aspects:

#1. Functional requirements for bridge systems are divided into strength performance, durability performance, and supplemental performance.
#2. The standard bridge service life has been clarified as 100 years.
#3. Both the strength and durability performance requirements are structured in a hierarchical manner from the bridge system level, the subsystem level (superstructure, substructure, and connection between superstructure and substructure), to the element level.
#4. For every single provision, both performance requirements and corresponding standards/deemed-to-satisfy are simultaneously set out as a package.
#5. The bridge strength performance requirement is given using a so-called performance matrix, comprising design situations and bridge state/function requirements, including the required levels of reliability for each combination of design situation and bridge state/function requirement.

Performance Structure

Figure 1 shows the relationship between the performance requirements and Table 1 compares the definitions of strength performance and durability performance.

Bridge strength performance is the primary performance requirement out of the three basic performance requirements and the requirement for the load-carrying functions as a bridge system. A bridge system maintains a state that has a safety margin to the critical state such as collapse and also offers the service level for time-variant load combinations during a design service period, where the safety margin and service level are simultaneously fulfilled with desirable reliability, respectively.

Bridge durability performance is defined as the prerequisite requirement to bridge strength performance. The bridge system needs to continue to mobilize the designed strength performance with a desirable certainty during the given design service period, considering aging and deterioration. SHB requires ensuring reliability for the period for which the physical assumptions that are employed in the verification calculation for bridge

Fig. 1 Performance Requirements

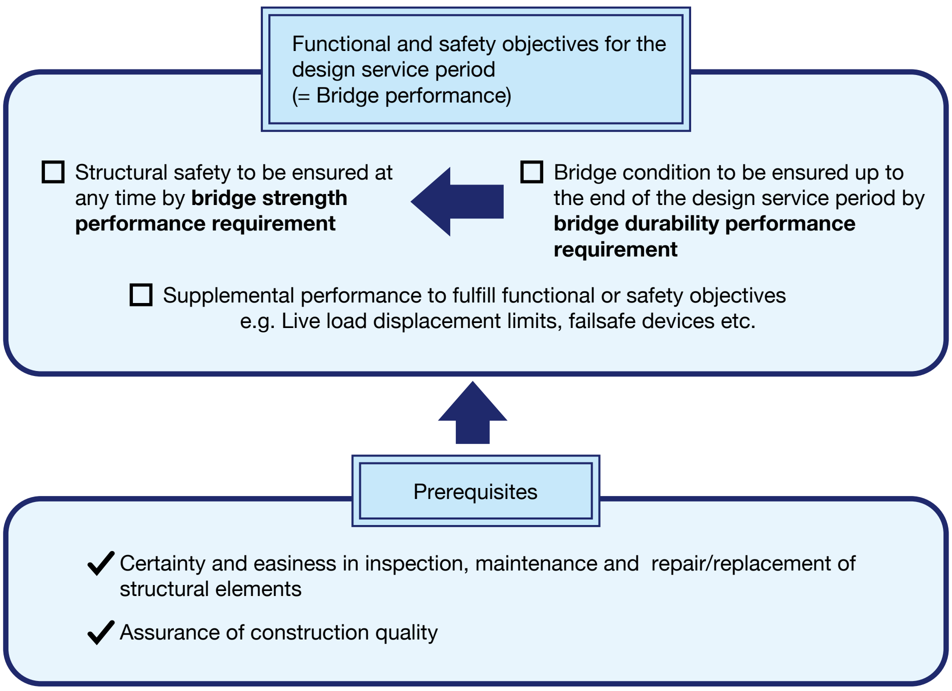

Table 1 Definitions of Performance Requirements Including Reliability

	Bridge strength performance	Bridge durability performance
Action/load requirements	Instantaneous simultaneous actions and loads at any time during the design service life (=100 years)	Accumulation of persistent actions/effects and long-lasting cyclic actions/effects up to the end of design service life (=100 years)
Resistance/durability requirements	The bridge and its components (elements) shall maintain the relevant strength margins for required safety and load-carrying functions, respectively.	It shall be ensured that material deterioration or distress to structural elements will not violate design assumptions to hold the bridge strength performance by the end of the given design service life.
Typical verification index	Strength or displacement on load-displacement curves	Period on the time axis in terms of maintaining strength design assumptions

strength performance will not be violated by material deterioration or distress, where the physical assumptions include the effective cross-sectional area or material strengths of the considered structural elements.

In other words, SHB does not require the prediction of the residual strength of a bridge at the end of the design service period in consideration of aging and deterioration with time, because it is not practical to measure the time-variant reliability in strength or functionality against time-variant load combinations, while simultaneously considering the degradation of element strengths and rigidity with time-dependent deterioration and aging.

The durability performance requirement of a bridge over the design service period is equivalent to examining service life issues and conducting so-called service life design, because it needs to consider the durability period of its elements, components, or subsystems, the probable and worst-case mode and extent of failures, and the associated needs for maintenance, repair, or element replacement. Namely, SHB practically considers that the reliability of bridge durability performance is equivalent to the feasibility of a balance of durability, inspectability, maintainability, and repair or element replacement workability under restrictions over the design bridge service period.

Design Service Period for Bridge Systems

The design bridge service period is newly defined as the period in which the bridge system is expected to provide design function with relevant maintenance. The standard design service period for bridge systems is set at 100 years. In practice, engineers need to refer to the design service period when examining the feasibility levels of planned and worst-case maintenance and remedial work with restrictions in individual projects.

It is worth noting that, in SHB, the standard design service period also considers the reference period to determine a set of load combinations for the verification of bridge strength performance.

Systematic Performance Verification Process

Practically, it is difficult to prove the extent of the achievement of bridge system performance, because a bridge is a very complex system. In the same way, it is also premature to make a universal rule to measure bridge strength performance as a system in a direct way because too many combinations of materials and elements and element arrangements are available as bridge systems to set numerical criteria for verification.

Accordingly, SHB allows that the performance verification of a bridge system can be dissolved into the accumulation of performance verification for all elements for both bridge strength performance and durability performance. In terms of bridge strength performance verification, bridge system performance can be represented by the strength performance of its critical subsystem or element.

The three-tier classifications in the load-carrying state of bridge systems are defined, and this can be translated into a combination of the load-carrying states of superstructures, substructures, and girder-to-column connections, respectively. The three-tier classifications in the load-carrying state are also defined for superstructures, substructures, and girder-to-column connections, respectively. The stability of subsystems with plastic hinges can be theoretically dealt with at this level if needed. In a similar way, the three-tier load-carrying state classifications for structural elements are also defined, so that one can represent each of the three-tier classifications in the load-carrying state of superstructures, substructures, and girder-to-column connections using a relevant combination of element load-carrying states.

In terms of bridge durability performance, a design element durability period is allowed for individual elements, where the design element durability period is the period the mechanical characteristics of materials and the effective cross-section area in the element remain the presumed conditions in evaluating bridge strength performance.

The design element durability period is not necessarily 100 years. Clarifying that not all elements shall function as expected at the design stage for 100 years straight encourages innovations to make durability design more reasonable. A given bridge element can be replaced, allowing the bridge as a system to continue providing bridge strength performance. For example, replaceable decks, bearings, bracing systems and so on may be used or new developments for preserving structural elements may be employed with special cautions for inspectability and repairability even if it still has limited proof data or little experience. Inversely, all elements may be given a design element durability period as long as possible in some cases especially when any preserving work is unfavorable during the design service period of a bridge system due to other limitations or service requirements.

In addition, all provisions package a series of fundamental and mandate performance requirements and corresponding widely-accepted standards/deemed-to-satisfy. Actually this concept was originally introduced in the previous revision held in 2003. This kind of packaging clarifies that given design equations, factored strength or other limit values, structural details etc. are not mandatory and alternatives are allowed to be employed if they meet the mandate performance requirements. In this context, the standards are also expected to work as an exemplification of target performance levels including reliability, such that the performance of an alternative solution can be ascertained by whether the alternative method offers an equivalent or better performance than the standard in terms of reliability.

Bridge Strength Performance and Reliability Concept

Table 2 shows an example of the performance matrices.

Design situations are classified into permanent situations, variable situations, and rare situations, when considering the design service period, modeled with load combinations that account for a given target occurrence probability of load combination for 100 years.

Secondly, for each design situation, the state of the bridge shall maintain the structural safety margin to avoid any fatal failure/collapse as well as achieve the load-carrying function requirement simultaneously, where the required reliabilities differ for the structural safety margin and the functional requirement for a particular design situation.

In this context, the term "performance requirement" in SHB includes accountability for reliability in the given load combinations and resistances, respectively. From the viewpoint of accountability to the public, this description of the performance matrix exemplifies concerns of road users such as "What kinds of situations are considered in design?", "Does the bridge work in the case of an earthquake or hazard?", "How reliable is it?" and so forth.

The present revision has employed a partial factor format for design equations in terms of the verification of strength performance, instead of a single safety factor format (or an allowable stress format). Design load combinations are regarded as the representatives of stochastic simultaneous loading processes to bridges over the bridge service period and are given to meet a target occurrence level.

Load factors and load combination factors are used to define load combinations, and they are to be determined in reference to an intensive probabilistic study, various analyses on the relationship between earlier design load combinations and design results, and trial design examples with new partial factors. For example, although this is one of the references to set out load combinations, an intensive Monte Carlo simulation has been conducted on simultaneous stochastic loading processes for 100 years for as many as 60 bridges at different sites, employing the Ferry-Borges Castanheta probabilistic load combination model of different loads, i.e., live loads, thermal effects, wind loads, seismic effects, and snow loads. The result has indicated that the load combinations for the variable design situation in the revised SHB basically account for 95% non-exceedance probability in the 100-year maximum values of combined loads.

The limit states in resistance are defined as boundaries between two states in Table 2. Resistance factors and several other partial factors are applied to the nominal resistance corresponding to the limit state. Resistance factors are basically estimated to make the factored value of the resistance as a lower 5% fractile value, while other partial factors are further applied to this factored resistance depending on the code requirements.

Remarks

The performance-based specifications are crucial to accept various types and levels of developments from material or element levels to bridge structural systems.

This revision is expected to promote the proactive acceptance of innovative design and construction technology to meet the diverse public demands in a cost and time saving manner, while assuring the reliability and quality of structures. In this context, for example, the 2017 revision of SHB has newly incorporated the characteristic values and partial factors for high-performance steels such as a series of SBHS (steel for bridge high-performance structure) and super high-tension bolts of S14T.

The concept of performance-based specifications is also crucial to developing retrofit or refurbishment design codes for existing structures, because design codes for existing structures have to deal with more diversifying load environments and element condition states than new structures.

We are seeking the enhancement of SHB for the retrofit, repair, and maintenance design, taking advantage of the concept of performance-based specification. ■

Table 2 Performance Matrix for National Expressways and Highways and Other Related Arterial Roads

States / Design situations	States from the viewpoint of load-carrying function		State from the viewpoint of structural safety
	Function State 1: The bridge is intact to carry loads.	Function State 2: While the load-carrying function degrades at parts of elements, the bridge still holds the load-carrying function prescribed for the corresponding situation.	Safety State: The bridge has a relevant safety margin to avoid a critical state.
Prevailing a permanent or variable load	The fulfillment of the state is required with a given reliability which is supposed to be different from that for structural safety.	(Not required)	The fulfillment of the state is required with a given reliability.
Prevailing rare kind or scale of load	(Not required)	The fulfillment of the state is required with a given reliability which is supposed to be different from that for structural safety.	The fulfillment of the state is required with a given reliability.

LS1 LS2 LS3

LS1, LS2, and LS3 = Limit State 1, Limit State 2, and Limit State 3, respectively

Research Committee on Steel Bridges with Higher Resilience and Longer Service Life

by Kazuo Tateishi
Chairman of the Research Committee on Steel Bridges with Higher Resilience and Longer Service Life (Professor, Nagoya University)

Kazuo Tateishi: After finishing the master course at the Tokyo Institute of Technology, he entered East Japan Railway Company in 1988. Then, he served as associate professor at the Tokyo Institute of Technology and The University of Tokyo in 1997. He assumed his current position as professor of the Graduate School of Engineering, Nagoya University in 2003.

Currently in Japan, there is a need to prepare for great earthquakes that are forecasted to occur in the near future like the Tokyo inland earthquake and the Nankai/Tonankai earthquakes. There has also been a call for the provision of structural performance that ensures safety against such great earthquakes, not only for structures to be built in the future but also for the vast number of structures that have already been constructed. At the same time, it has become important to appropriately renew and repair a vast amount of existing social infrastructure under finite financial conditions.

In order to meet these requirements, it will be necessary to promote technological developments that provide greater reductions in terms of the time and cost required to renew and repair infrastructure, while securing its safety. In this regard, in terms of steel structures, it will be necessary to refine the technology that can accurately estimate the performance of various structures. In addition, it will be necessary to promote technological developments conducive to not only the rationalized design of steel structures and the reduction of construction costs but also the efficient maintenance of existing steel structures and their prolonged service life.

To these ends, the two terms "higher resilience" and "longer service life," which plainly express these emerging tasks, have been applied in naming the Research Committee.

Outline of the Research Committee

The Research Committee on Steel Bridges with Higher Resilience and Longer Service Life was established in 2015 within the Japanese Society of Steel Construction (JSSC) as a research project commissioned by the Japan Iron and Steel Federation (JISF). Its road map to attain its respective research tasks is shown in Fig. 1.

Fig. 1 Road Map to Attain Respective Research Tasks of the Committee on Steel Bridges with Higher Resilience and Longer Service Life

Tasks	～FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
① Subtask 1 Working Group on Rationalized Design	Verification of load-carrying capacity of column and un-stiffened plate		Presentation of load and resistance factor for column and stiffened plate and presentation of constitutive law for seismic analysis that can deal with cyclic loading	Revision of *Specifications for Highway Bridges*: Introduction of load and resistance factor design method	Presentation of example of application of SBHS (steel for bridge high-performance structure) member in seismic design	
		Collection of load rating data and its trial analysis		Preparation of load rating manual (draft)	Structuring of design, inspection and rating systems; Organization of manual for bridge assessment	
② Subtask 2 Working Group on Fatigue Strength of Steel Bridges	Expansion of design fatigue class	Effect on fatigue life improvement including that by the use of high-strength steel (experiment, analysis and design method)			Standardization of effect on fatigue life improvement	
	Trial for and arrangement of fatigue life improvement	Collection of information on detective method for fatigue crack, proving of repairing and reinforcing methods for fatigue crack			Preparation of guideline for crack repair and service life prolongation methods	
③ Subtask 3 Working Group on Corrosion and Durability of Steel Bridges	Surveys of task submitted by Ministry of Land, Infrastructure, Transport and Tourism	Assessment of practical bridge data and examination of reliability improvement measure		Guideline for maintenance and corrosion diagnosis data; Maintenance and corrosion diagnosis	Preparation of handbook on design and maintenance and its reflection in standard	
	Survey and assessment of practical example of corrosion of bridge	Examination about steel bridge corrosion diagnosis technology		Preparation of corrosion map and corrosion-protection manual	Technical data on steel bridge having high corrosion resistance	
Interdisciplinary tasks in above-mentioned three subtasks **Steering Conference**		① Interdisciplinary assessment of attainments of each working group→Proposal of attainments to society ② Tackling with the research task that supplements the niche between fields (between subtasks and different fields) ③ Creation of research theme for future				

Many research committees were established based on the commission by JISF and had already started research activities earlier in 1997 (see Table 1). Capitalizing on the long years of research activities, these committees have contributed to solving many emerging issues faced by steel bridge, and these research achievements have been reflected in the preparation of design standards and guidelines. The working groups of the research committees have summarized their research achievements, which are published in the *JSSC Technical Reports* (Japanese).

One primary objective of the current research committee lies in the promotion of research conducive to constructing highly resilient and longer-lasting steel bridges at low cost in order to further expand the application of steel bridges. To achieve this goal, it is necessary to establish a system with the participation of multiple related organizations that support steel bridge development and to reflect research results in future design standards and guidelines.

At the request of JSSC, I assumed the post of committee chairman, and Prof. Yoshiaki Okui of Saitama University and Prof. Jun Murakoshi of Tokyo Metropolitan University assumed the posts of vice committee chairmen respectively. Then, 25 experts working in a wide range of fields from industry, government and academia participated in the research committee.

Table 1 Chronology of Research Committees on Steel Bridges

FY	Research Committee	Working Group
1997-1999	Research Committee on Next-generation Civil Engineering Steel Structures	• Working Group on Design of Rationalized Steel Bridge Girders • Working Group on Seismic Design Method for Steel Bridges • Working Group on Application of High-performance Steel Products for Steel Bridges
2000-2002	Research Committee on the Performance-based Design of Steel Bridges	• Working Group on Safety and Applicability of Steel Bridges • Working Group on Corrosion Protection and LCC for Steel Bridges • Working Group on Seismic Resistance of Steel Bridges • Working Group on Higher Performance of Steel Bridges
2003-2005	Research Committee to Improve Steel Bridge Performance	• Working Group on Rationalized Design Methods • Working Group on Improvement of Steel Bridge Durability • Working Group on Seismic Design Guidelines for Steel Bridges • Working Group on Weathering Steel Bridges
2006-2008	Research Committee to Improve Performance and Reliability of Steel Bridges	• Working Group on Rationalized Structure and Design for Steel Bridges • Working Group on Fatigue Strength of Steel Bridges • Working Group on Seismic Design Guidelines for Steel Bridges • Working Group on Weathering Steel Bridges
2009-2012	Research Committee on Improvement of Structures and Design Method for Steel Bridges	• Working Group on Rationalized Structure and Design for Steel Bridges • Working Group on Fatigue Strength of Steel Bridges • Working Group on Seismic Design Method for Steel Bridges • Working Group on Weathering Steel Bridges
2013-2014	Research Committee on Improvement of Structures and Durability of Steel Bridges	• Working Group on Rationalized Structure and Design for Steel Bridges • Working Group on Fatigue Strength of Steel Bridges • Working Group on Maintenance for Weathering Steel Bridges
2015-2017	Research Committee on Steel Bridges with Higher Resilience and Longer Service Life	• Working Group on Rationalized Design • Working Group on Fatigue Strength of Steel Bridges • Working Group on Corrosion and Durability of Steel Bridges

Three Working Groups to Promote Specific Research

The following three working groups have been set up in the research committee to implement specific surveys and research:

- Working Group on Rationalized Design: Aim to rationalize design methods pertaining to load-carrying capacity and seismic resistance of steel bridges (Chief: Prof. Yoshiaki Okui of Saitama University)
- Working Group on Fatigue Strength of Steel Bridges: Aim to refine fatigue design for steel bridges and technologies to deal with fatigue (Chief: Prof. Kengo Anami of Shibaura Institute of Technology)
- Working Group on Corrosion and Durability of Steel Bridges: Aim to establish corrosion-protection methods for weathering steel and ordinary steel (Chief: Prof. Eiji Iwasaki of Nagaoka University of Technology)

In order to improve the resilience and service life of steel bridges, it is necessary to improve the performance of each of the three areas of structural members: load-carrying capacity, seismic resistance and durability. For that purpose, it is necessary to conduct further studies on the fracture mechanisms and deterioration mechanisms peculiar to steel members. Further, prolonged service life for steel bridges can only be attained assuming that appropriate maintenance is implemented, and thus technologies for inspection, repair and reinforcement in the maintenance of steel bridges are important issues for technological development.

Three working groups have promoted R&D activities based on the wide-ranging issues mentioned above. Taking the opportunity of this three-year milestone from the start of survey and research at the respective working groups in 2015, the results of their surveys and research have been summarized. The three articles that appear on the following pages 6~14 give an outline of these research attainments.

Towards Higher Resilience and Longer Service Life

The performance level required for steel bridges has changed over time, and design methods have also undergone changes in line with this. One typical example is a new design requirement triggered by the Kumamoto Earthquake of 2016. That is, it is now required for bridge structures to withstand multiple large-scale seismic motions. Further, a major revision, the introduction of the load and resistance factor design method, was made in the *Specifications for Highway Bridges* published in 2017, and as a result it is now required that further enhancements be made to the reliability of damage control and the ease of maintenance. Other new issues have emerged: the issue of how to implement effective inspection and countermeasures against damage that is not yet evident along with the start of full bridge inspections.

Given such circumstances, two demands have emerged in the field of steel bridges—the handling of the emerging issues mentioned above and the continued contribution required for the revision of technical standards planned for the future. The contribution towards the revision of technical standards and specifications by accumulating research results will serve as an effective means of realizing enhanced resilience and longer service life for steel bridges. To that end, the Committee on Steel Bridges with Higher Resilience and Longer Service Life was re-established in 2018, and will continue to promote research activities conducive to enhancing resilience and longer service life for steel bridges. ■

Rationalized Design of Steel Bridges and Load Rating for Maintenance

by Yoshiaki Okui
Chief of the Working Group on Rationalized Design, Research Committee on Steel Bridges with Higher Resilience and Longer Service Life (Professor, Saitama University)

Yoshiaki Okui: After graduating from the Graduate School of Science and Engineering, Saitama University, he joined Kawasaki Heavy Industries, Ltd. in 1985. Then he served as associate professor at Saitama University in 1993 and visiting researcher at Delft University of Technology in Netherlands in 1996. He assumed his current position as professor at Saitama University in 2009. His profession covers structural engineering and bridge engineering.

Further attempts are being directed towards the development of the technology not only conducive to building national resilience and regenerating obsolete social infrastructure but also to design steel structures with international competitiveness. In accordance with these attempts, the Working Group on Rationalized Design of the Research Committee on Steel Bridges with Higher Resilience and Longer Service Life has promoted research on steel bridges since 2015 focusing on the following themes:

- Examination of statistical information on the ultimate limit strength and serviceability limit strength of stiffening plates
- Assessment of local-global interaction buckling of columns
- Investigation of rationalized design of composite girders
- Study on rationalized high-tension bolt joints
- Application of advanced analytical approaches in design
- Examination of rationalized seismic design
- Load rating of existing bridges

Outlines of the achievements from research on three themes—first, fourth and seventh—are introduced respectively in the following article.

Examination of Statistical Information on Ultimate Limit Strength and Serviceability Limit Strength of Stiffening Plates

Steel for bridge high-performance structures (SBHS) was standardized in the Japanese Industrial Standards (JIS) in 2008, and its application was approved in the *Specifications for Highway Bridges*[1] in 2017. While reports of many material test results have already been available for SBHS, there are few reports on the load-carrying capacity of structural members manufactured employing SBHS.

To cope with such a situation, we have conducted a compressive loading test for stiffening plates using SBHS500 (yield strength: 500 N/mm^2) to compare the load-carrying capacities between mild steel SM490Y (yield strength: 355 N/mm^2) and high-performance steel SBHS500. Each of two specimens (slenderness parameter: R_R=0.5, 1.2) were prepared using SBHS500 and SM490Y. The slenderness parameter is defined as:

$$R_R = \frac{b}{t}\sqrt{\frac{\sigma_y}{E}\frac{12(1-\mu^2)}{4n^2\pi^2}}$$

where,

b and t: Entire width and thickness of stiffened plate
σ_y: Yield strength
μ: Poisson's ratio
n: No. of panels to be divided by stiffening plate

As seen in Photo 1 showing a test specimen, a square steel tube column was manufactured that is structured using four stiffening plates, for which an axial compressive loading test was conducted.

Photo 1 Stiffening plate compressive test specimen prepared using SBHS500 (steel for bridge high-performance structures)

Fig. 1 shows the relationship between axial compressive load P and axial compressive displacement U. In the figure, the vertical and horizontal axes are normalized using the yield axial force P_y and the yield displacement U_y, respectively. The test results showed that SBHS steel tube columns has a compressive load-carrying capacity similar or superior to that of mild steel columns.

In order to standardize designs employing SBHS, it is necessary to acquire probabilistic information that shows variations in the load-carrying capacity of structural members. In this regard, examinations have been made employing the Monte Carlo simulations with the nonlinear finite element analysis and response surface method.

Fig. 2 shows an example of examination results—the relationship between the slenderness parameter and the normalized strength of stiffening plates[2]. In this figure, the ultimate limit strength (ULS) and the serviceability limit strength (SLS) obtained from the Monte Carlo simulations are shown, and the round mark indicates the average value of strength, and the error bar above and below the round mark shows 5% and 95% fractile values, respectively.

Fig. 2 also shows the load-carrying capacity of SBHS500 and SM490Y (Exp. SBHS500, Exp. SM490Y) obtained in the axial compressive loading tests mentioned above and the curve of standard load-carrying capacity (JSHB) prescribed in the *Specifications for Highway Bridges*[1] currently in use.

Study on Rationalized High-tension Bolt Joints

The ultimate bending capacity of steel girders with compact sections reaches its full plastic bending moment. Accordingly, in order to design bolt joints for compact sections, it is necessary to define the critical condition that can assure the bending capacity of the bolt joint up to the full plastic bending moment and to examine the design method that can be applied under such a critical condition. In order to develop a design method that can meet these needs, the flexural loading test has been conducted on the I-girder bolt joint (Photo 2).

Fig. 3 shows the relationship between the applied load P divided by the load P_y at the yield bending moment, and the bolt hole deformation δ_b made dimensionless using the bolt axial diameter d. If 5% of a normalized bolt hole deformation δ_b/d is defined as an ultimate strength limit, it

Fig. 1 Comparison of Load-Displacement Curve between SBHS500 and SM490Y in Axial Compressive Loading Test

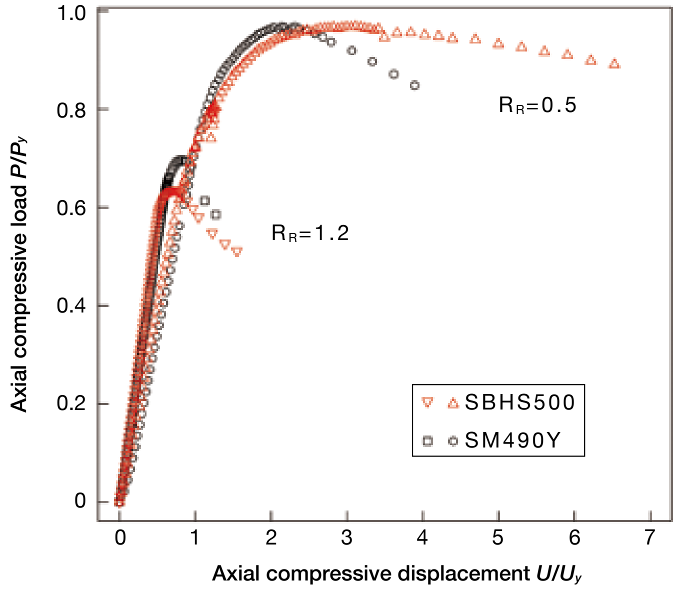

Fig. 2 Ultimate Limit Strength and Serviceability Limit Strength of Stiffening Plates Examined by Means of Monte Carlo Simulations

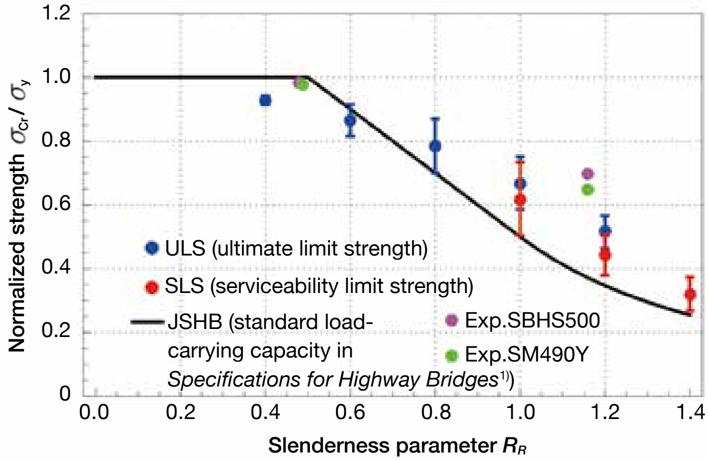

Photo 2 Flexural bending test for I-girder bolt joint

is understood from the figure that a load-carrying capacity 1.3 times or more that of the yield bending moment can be assured for the bolt joint.

Generally, the full plastic bending moment is about 1.3 times the yield bending moment, and thus in cases when the definition of ultimate limit strength mentioned above is applied, it is possible to design a bolt joint for compact section. The Working Group on Rationalized Design will promote research aimed at clarifying the behavior of bolt joints after sliding by means of experiments and analyses. The final goal is to standardize a rational ultimate limit state design method for high-strength friction-joining bolts.

Load Rating of Existing Bridges for Their Maintenance

In many countries, it has become an urgent task to assess the performance of bridges that have been constructed based on old design standards and shown any performance deterioration and damage. Japan is not an exception. In the current research, we have examined load ratings that aim to assessing the performance of existing bridges.

As a target bridge to be adopted for case study, a simply-supported composite I-girder bridge shown in Fig. 4 was chosen. The bridge was constructed in the early part of the 1970s and was designed based on the allowable stress design method by the use of the design live load (L20) of the old design specicfications[3].

Load rating was conducted using as the design load the B live load prescribed in the current *Specification for Highway Bridges*, and the rating factor *RF* was calculated using the following equation:

$$RF = \frac{C - \gamma_d D}{\gamma_l (L + IM)}$$

where,

C: Strength

D and L: Dead and live load effects

IM: Dynamic allowance factor

γ_d and γ_l: Dead and live load factors

Fig. 5 shows the result of calculating the RF values for the bending capacity of I-girder. The RF values were calculated in conformity with four different specifications (old SHB: *Specifications for Highway Bridges*[3]; current SHB: *Specifications for Highway Bridges*[1]; JSCE SSSCS: *Standard Specifications for Steel and Composite Structures*[4]; and AASHTO: AASHTO MBE[5]).

The target bridge was designed in conformity with the old SHB, in which the allowable stress design method with a safety factor of 1.7 was employed. Then, the design live load was changed from TL-20 to B live load, and therefore the RF value currently in use for load rating falls short of 1.0.

However, because the substantial safety factor has been reduced due to the revision to the partial safety factor method in the current SHB, the RF value reaches nearly 1.0. In JSCE SSSCS and AASHTO MBE, because the full plastic bending moment is adopted as the bending capacity, the RF value becomes larger.

As future research subjects, it is important to grasp real site-specific traffic load level and to investigate the safety level of existing bridges taking into account their periodic inspection results. The Working Group on Rationalized Design will strive to tackle these emerging tasks in and after fiscal 2019. ■

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Fig. 3 Relationship between Applied Load P/P_y and Bolt Hole Displacement Amount δ_b/d in Flexural Bending Test for I-girder Bolt Joint

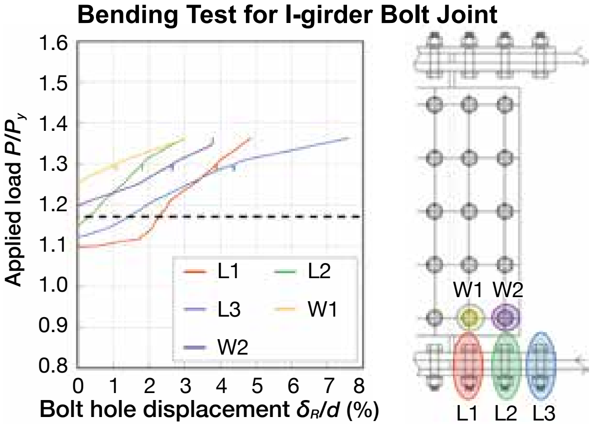


Fig. 4 Sectional Drawing of the Bridge Targeted in Case Study (Simply-supported Composite I-girder; Span: 34.4 m)

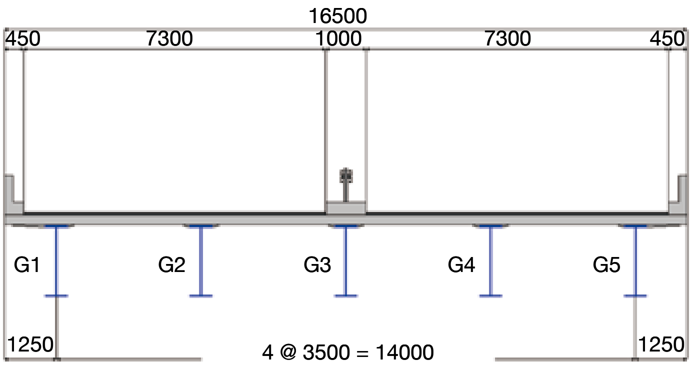
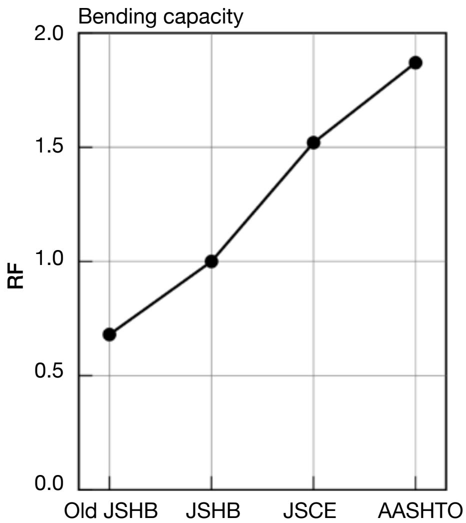


Fig. 5 Results of Calculation of RF Values pertaining to Bending Capacity



Improvement of the Fatigue Strength of Steel Bridges and Assessment of the Effect of Repair and Reinforcement

by Kengo Anami
Chief of the Working Group on Fatigue Strength of Steel Bridges, Research Committee on Steel Bridges with Higher Resilience and Longer Service Life (Professor, Shibaura Institute of Technology)

Kengo Anami: After graduating from the School of Engineering, Tokyo Institute of Technology in 1993, he served as research associate at Lehigh University in the US in 2001 and as associate professor at Shibaura Institute of Technology in 2008. He assumed his current position as professor at the Department of Civil Engineering, Shibaura Institute of Technology in 2014. His profession covers steel structures and their maintenance.

Recently in Japan, various kinds of fatigue problems have become apparent in steel bridges. In order to prolong their service life, it will be more necessary in the future to upgrade approaches for the improvement of fatigue strength and for effective maintenance including repair and reinforcement.

For that purpose, the Working Group on Fatigue Strength of Steel Bridges, the Research Committee on Steel Bridges with Higher Resilience and Longer Service Life, was established in the Japanese Society of Steel Construction. Aiming at accumulating information conducive to the longer service life of steel bridge from the aspect of fatigue issues, the Working Group has promoted examinations relating to the following three tasks:

- Method to improve fatigue strength by means of weld toe treatment
- Method to enhance fatigue crack inspection efficiency
- Method to assess the effect of repair and reinforcement on fatigue cracks

An outline of the examination and research on the first and third tasks is introduced below:

Examination of Methods for Fatigue Strength Improvement by Means of Weld Toe Treatment

Peening treatment is one of the methods for improving the fatigue strength of weld joints, and its application to steel bridges in Japan, particularly to existing steel bridges, has shown a steady increase. In the current research, experimental examinations pertaining to the effect obtained by means of peening treatment have been made—influences of blast treatment made after peening treatment and prior to painting, and influences of stress fluctuations in the large stress ratio forecasted to occur due to dead load stress.

Fig. 1 shows the out-of-plane gusset fatigue test specimens. The steel products applied to the test were SM490 (rolled steel for welded structures) and SBHS500 (steel for bridge high-performance structures). The peening treatment applied for these examinations covered ultrasonic impact treatment (UIT), hammer peening on base metal (HP) and

Fig. 1 Test Specimens and Fatigue Tests

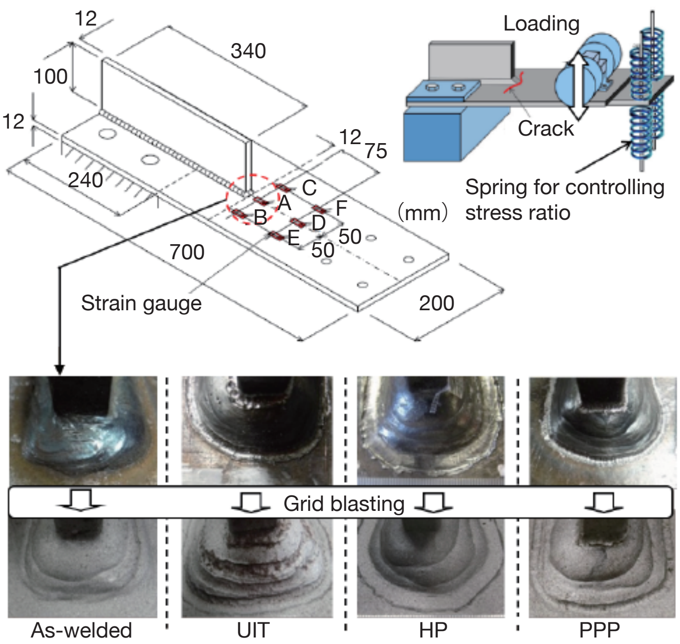
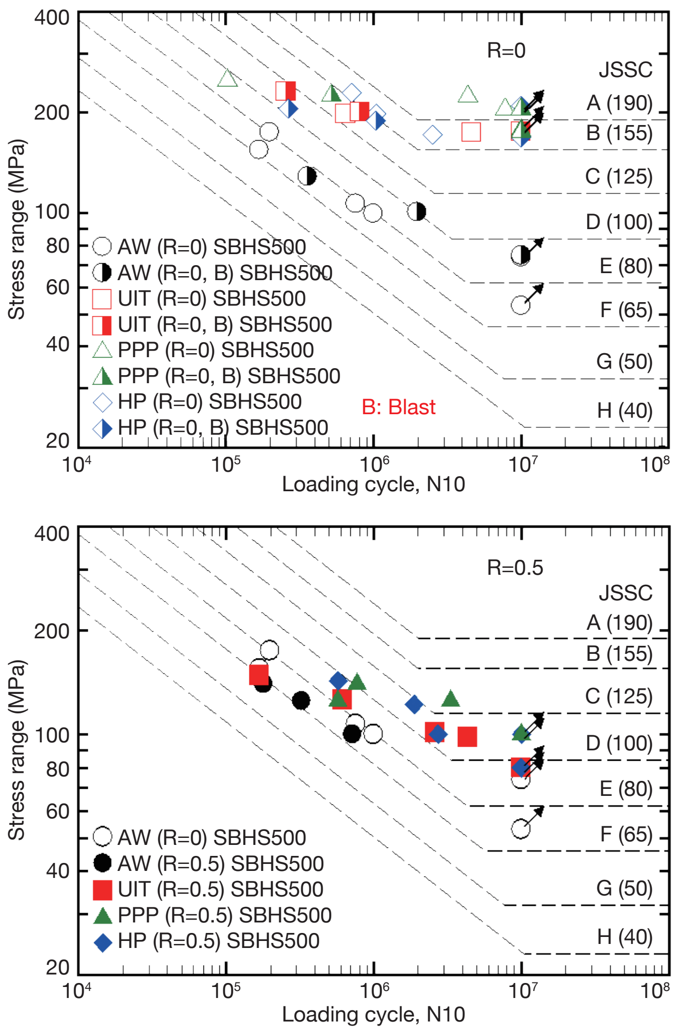


Fig. 2 Fatigue Test Results (SBHS500 Specimen)



air-type needle peening (PPP). Grit blasting was adopted for blasting treatment, which was conducted at the bridge member fabrication plant under commonly applied conditions. A fatigue test was conducted under the conditions of two stress ratios, R=0 and R=0.5, by means of plate bending fatigue testing.

Fig. 2 shows examples of the fatigue test results. Under all testing conditions, no difference in fatigue strength was observed regardless of the type of peening treatments applied.

In the fatigue test conducted at the stress ratio of R=0, both of as-welded and peening-treated test specimens showed no difference in fatigue strength before and after blasting, and considerable effects on fatigue strength improvement were observed from peening treatments. On the other hand, in the test conducted at the stress ratio of R=0.5, while the fatigue limit of the peening-treated specimen was improved over that of the as-welded specimen, the effect of peening treatment on fatigue strength improvement was greatly reduced compared to the case of the test conducted at the stress ratio of R=0.

Currently, the data obtained in the tests and the results of existing fatigue tests are being collected to examine the design S-N curve after peening treatment.

Examination of Methods to Assess the Effect of Repair and Reinforcement on Fatigue Cracks

The stop-hole method and splice plate reinforcement have been applied as representative repair and reinforcement methods for fatigue cracks in steel bridges. In the current research, taking notice of these two methods, we have examined the method to assess the effects obtained by their use.

• Examination of Method to Assess the Effect of the Stop-hole Method

In the stop-hole (SH) method, further propagation of cracks is prevented by providing a round hole to the crack tip. In this regard, few examinations have been made of cracking along the weld toe. In the current research, experiments and analyses have been carried out targeting cracks occurring along the weld toe to examine the applicability of the SH method and the assessment method for fatigue strength after application of the SH method.

Fig. 3 shows fatigue test specimens (non-load-carrying cruciform weld joint specimen: H-type specimen provided only with hole; and SH-type specimen provided with slit and stop hole).

In the current research, because a stop hole is provided for the weld toe, two specimens were prepared in order to avoid the superposition of stress concentrations occurring due to weld geometries and stop hole —specimens in which the stop hole center is located 1 mm and 5 mm respectively apart from the weld toe. The fatigue crack initiation point was at the cross point of the stop hole and the toe in the former specimen, and the stop hole tip or in the toe on the reverse side of the stop hole tip in the latter specimen, and the position in the current research agreed with the maximum stress occurrence position obtained in the FEM analysis in which these two specimens are modeled.

Fig. 4 shows the fatigue test results arranged in terms of the local stress range in the fatigue crack initiation point mentioned above. There are no wide differences in the fatigue test results for respective specimens. Further, these fatigue test results basically agree with those of existing stop-hole specimens in which the crack is assumed to occur from the weld toe and to propagate to the flat plate.

These test results were then evaluated within the local stress range that takes into account the stress concentration on welds and the stress concentration caused by the use of the SH method. As a result, even in the case where the SH method was applied to cracks along the toe, we could show the possibility of assessing the repair effect of the SH method in the same way as in the case of adopting the SH method when the crack tip exists in a conventional flat plate.

• Examination of Method to Assess the Application Effects of Splice Plate Reinforcement

Splice plate reinforcement has widely been applied as a method of reinforcing fatigue cracks. In order to further improve splice plate reinforcement, it has been required to establish a design method for splice plates and an approach to confirm the application effect after reinforcement. In the current research, noting that the stress concentration factor (α_{SH}) of the stop hole located under splice plates has a direct relationship with reinforcement effects, we have examined an estimation equation for α_{SH} and an ap-

Fig. 3 Tension Test Specimens with Stop Holes

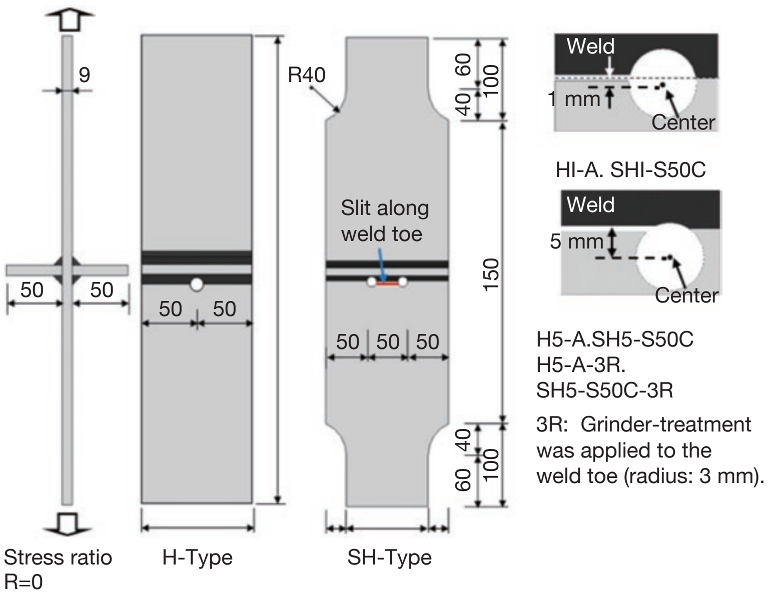
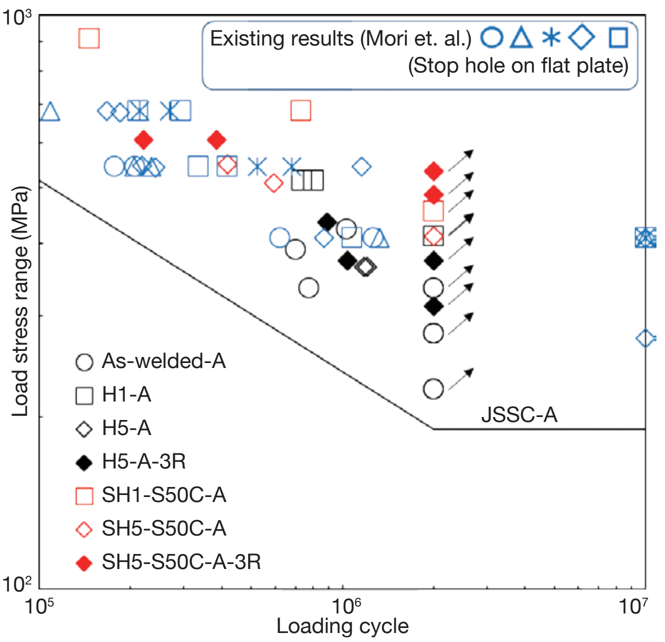


Fig. 4 Fatigue Test Results



proach that estimates the stop-hole stress from strains occurring on the splice plate.

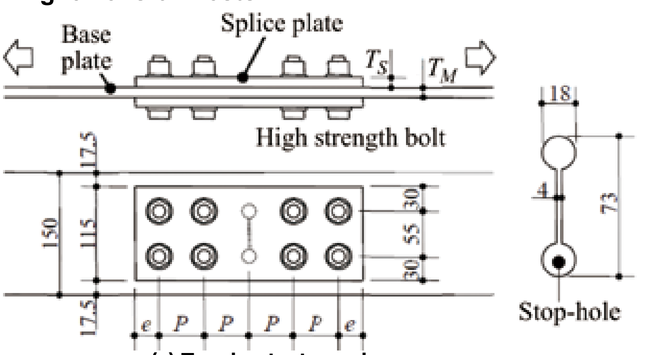
At first, axial tension tests (Fig. 5 (c)) and FEM analyses (Fig. 5 (d)) were conducted employing the test specimen (Fig. 5 (a) and (b)) prepared using as the parameter the dimension of splice plate structure. Fig. 5 (e) shows α_{SH} before the occurrence of slipping of the splice plate. As can be seen in the figure, while the stress concentration factor α_{SH} is greatly reduced by the use of splice plates in every case of specimen parameters, the level of reduction is affected by the splice plate dimensions.

Next, analyses were made of more cases of stress concentrations on stop holes by means of an analytical approach similar to that mentioned above. Based on the analytical results, we have noted the stress reduction effect f_1 brought about by providing the splice plate to the cracked section to increase the effective section and the crack opening suppression effect (bridging effect) f_2 brought about by the use of splice plates, which has led to two proposals: an equation to estimate the relationship between the splice plate dimensions and the stress concentration factor α_{SH} (Fig. 6) and a rationalized design approach for splice plates.

Further we have organized the relationship of stresses between stop holes and splice plates, which has also led to a proposal: a method that estimates the strain occurring in a stop hole from the measured strain values just above the stop hole (Fig. 7). Fig. 6 shows the comparison of stress concentrations on the stop hole and Fig. 7 the comparison of strains at the stop hole respectively in the case of no fastening of bolts on the stop hole.

In the current research, it has become possible to propose a highly accurate α_{SH} estimation equation and an approach to confirm the effect of splice plates on crack reinforcement with the use of the strain at the reference point. It is expected in the future that these proposals will be applied widely to assess the effect of splice plate reinforcement in more complex stress conditions and conditions close to those in practical bridges. ■

Fig. 5 Tension Tests

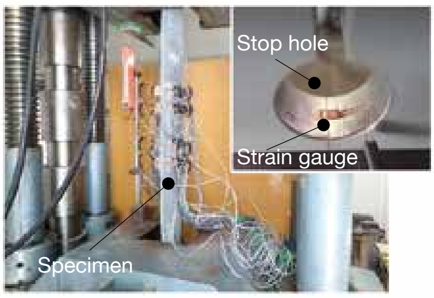


(a) Tension test specimens

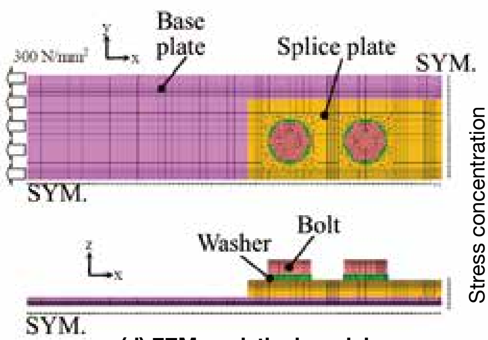
No	t_M	T_S	P	e	*1	
1	12	12	55	30	×	
No. 1: Without splice plate						
2	12	12	55	30	×	Surface conditions: The splice and base plates of all specimens were coated with inorganic zinc-rich paint (thickness: 75 μm), except for specimen No. 3 in which the base plate was grinder-finished.
3	12	12	55	30	×	
4	12	12	55	30	×	
5	6	6	55	30	×	
6	6	12	55	30	×	
7	12	12	40	25	×	
8	12	12	50	30	○	
9	12	12	40	25	○	

o: Application of high-strength bolt to stop hole; ×: No application of high-strength bolt to stop hole

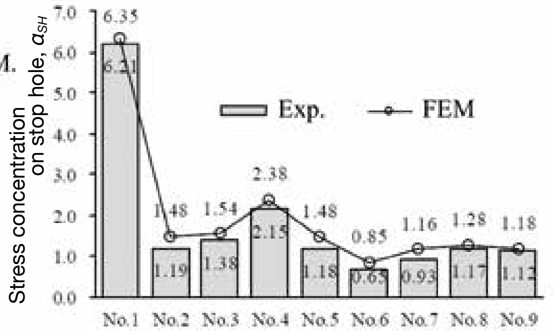
(b) Geometrical parameters of specimens



(c) Tension tests



(d) FEM analytical models



(e) Stress concentration on stop holes

Fig. 6 Comparison of Stress Concentrations on Stop Holes (Eq. 1 and FEM)

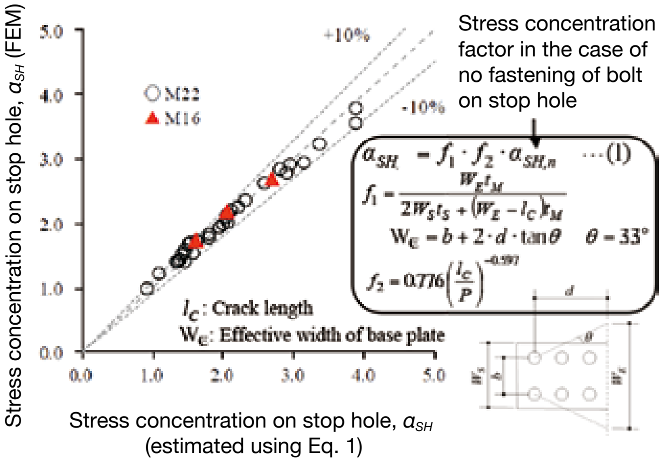
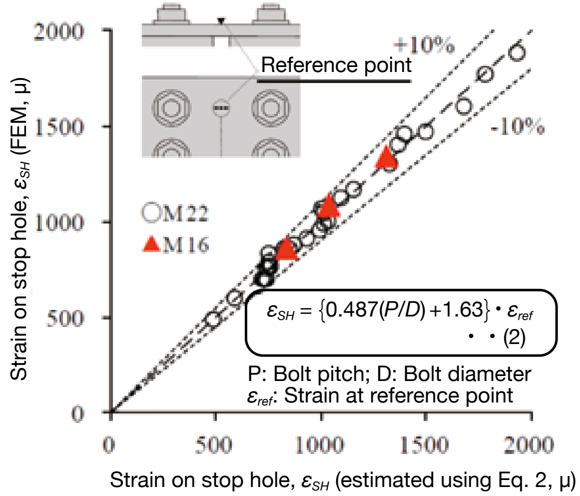


Fig. 7 Comparison of Strains Occurring in Stop Holes (Eq. 2, FEM)



Applicability and Maintenance of Weathering Steel Bridges and Corrosion Repair Methods for Steel Bridges

by Eiji Iwasaki
Chief of the Working Group on Corrosion and Durability of Steel Bridges, Research Committee on Steel Bridges with Higher Resilience and Longer Service Life (Professor, Nagaoka University of Technology)

Eiji Iwasaki: After finishing the doctoral course at the Graduate School, Nagaoka University of Technology in 1990, he served as associate professor of Nagaoka University of Technology. He assumed his current position as professor, Graduate School of Nagaoka University of Technology in 2012. His profession covers structural engineering, steel structure engineering and structural analysis.

For steel bridges, in addition to a proposal for an effective means of combating corrosion that takes into account minimized LCC (lifecycle cost) and other economic rationalities, there is strong demand for a proposal for maintenance technology that effectively prevents the performance deterioration caused by corrosion.

To cope with such a situation, taking notice of the reduction of corrosion-protection costs and the technology to prevent corrosion-induced deterioration and damage, it is urgently required to examine the following tasks: the application to bridge construction of weathering steel that allows the reduction of LCC under appropriate corrosion environments and the technology that maintains weathering steel bridges; and a measure that improves corrosion resistance and durability of steel bridge, a method that applies corrosion-resistant materials, and a measure that retains and recovers the corrosion-protection performance of steel bridges.

Given such a situation, the Working Group on Corrosion and Durability of Steel Bridges of the Research Committee on Steel Bridges with Higher Resilience and Longer Service Life, established in the Japanese Society of Steel Construction, has promoted research on the applicability of weathering steel bridges and technology for their maintenance, as well as countermeasures against the corrosion of steel bridges. Some of the attainments obtained in this research are introduced below:

Application and Maintenance of Weathering Steel Bridges

• Applicability of Weathering Steel Bridges in Deicing Salt-sprayed Areas

In snowfall and cold areas, corrosion damage caused by the leakage of rainwater containing deicing salt is found in many steel bridges. Further, examples of corrosion due to the scattering of deicing salt from the road surface have been reported.

Thus, targeting steel bridges constructed in areas where the amount of airborne salt from the sea is lower, we have surveyed the amount of deicing salt sprayed, the amount of salt flying to the steel bridge girder, and the corrosion loss of plate thickness of steel. For that purpose, the device that accumulates the flying deicing salt and the steel product test pieces subjected to exposure were arranged as seen in Photo 1.

Fig. 1 shows the relationship between

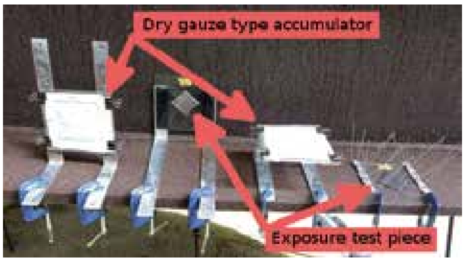


Photo 1 Arrangement of flying salt accumulator and exposed steel product test pieces

Fig. 1 Amount of Deicing Salt Sprayed and Amount Flying onto Girders

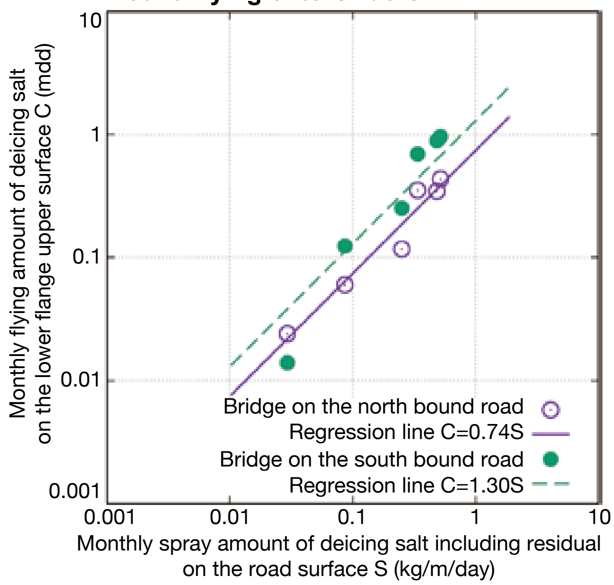
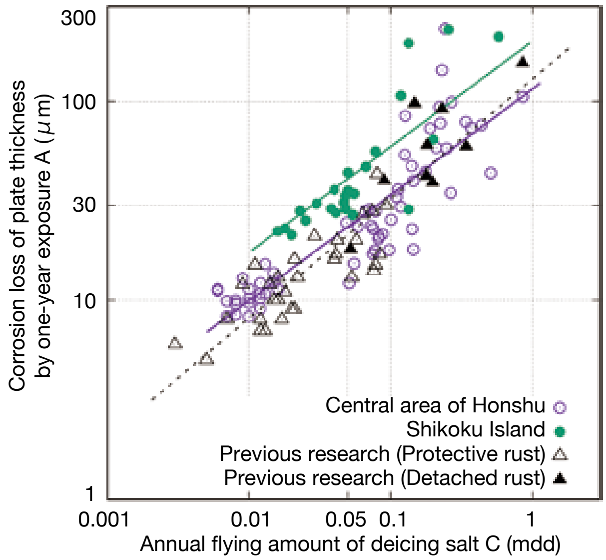


Fig. 2 Amount of Flying Deicing Salts and Corrosion Loss of Plate Thickness



the amount of deicing salt sprayed on the road surface and the amount of salt flying on the upper surface of the girder lower flange. The approximate salt flying amount on the bridge girder can be assumed from the relational equation in the figure. Fig. 2 shows the relationship between the amount of flying deicing salt and the corrosion loss of steel plate thickness caused by 1 year of exposure. The figure also includes the relationship between the amount of airborne salt from the sea and the above-mentioned corrosion loss[1]. While there is a difference in terms of flying substances, that is, the flying salt from the sea (airborne salt) and the flying deicing salt, it is known that an identical relationship pertaining to the amount of flying salt and the corrosion loss can be observed in the figure.

• Case Studies of Surveys of Truss, Arch and Other Special-type Bridges Employing Weathering Steel

Examples of damage and countermeasures for I-girder and box-girder bridges employing weathering steel have already been accumulated. However, information on damage examples for truss and arch bridges as shown in Photo 2 is basically limited. Literature surveys show that highway bridges account for 92% of all weathering steel bridges, railway bridges account for 4% and other bridges 4%, thus indicating a high share for highway bridges. In this regards, it has become clear that special-type bridges account for about 9% of all weathering steel bridges.

Further, surveys have been made of the structural details and corrosion-protection performance of 27 weathering steel bridges constructed in the Pacific coastal area. According to the survey results, while no damage problems were found in bridges constructed in the environmentally sound sites distant from the sea, detachable rust was found in bridges constructed near the sea. In this regard, it will be necessary to confirm the corrosion conditions of the node, anchorage and embedded section of bridges by expanding the survey target to those located near the sea and in deicing salt-sprayed areas.

• Examination of Approaches to Determine the Corrosion Conditions of Weathering Steel by Means of Image Processing

While weathering steel demonstrates corrosion-protection performance that capitalizes on its protective rust, there are cases where the protective rust is not generated depending on the corrosion environment. Therefore, it is necessary to assess the corrosion conditions by means of inspection. Whether or not the protective rust is generated is judged by means of visual inspection of the rust appearance. In the case of applying visual inspections, however, variations occur in the judgement depending on the engineer who undertakes the inspection.

To mitigate such uneven results, we have examined a method that assesses the corrosion conditions by means of image processing of rust extracted using the cellophane tape test. With this method, the corrosion conditions can be judged from the size of the rust particles, but when the numbers of multiple rust particles overlap as seen in Fig. 3, it is impossible to implement accurate judgement. To solve this problem, we have examined the cutting method for overlapped rust particles, and as a result it has become possible to show the diameter of rust particles in which nearly no detachable rust occurs.

Countermeasures against the Corrosion of Steel Bridges

• Preparation and Application of Corrosion Maps by the Use of Three-dimensional Models

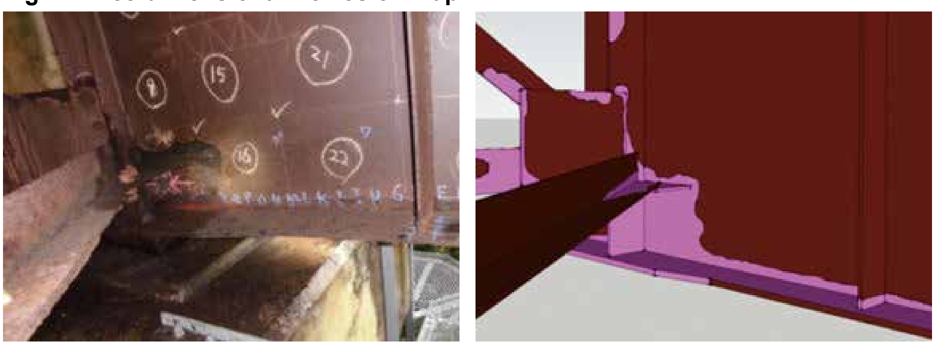
Most of the recording and judgement of corrosion conditions at the stage of inspection are entrusted to the skill of the engineer who undertakes the inspection. Further, because the corrosion map currently in use is prepared using two-dimensional models and photo images, a practical approach has not yet been established that specifically correlates the corrosion conditions with the cause of the corrosion. In order to implement the future maintenance of steel bridges, it will be necessary to examine an effective method to record corrosion conditions during inspection and to control related information.

As one solution to deal with these concerns, we have prepared a three-dimensional corrosion map (Fig. 4). Specifically, we prepared the three-dimensional corrosion map by the use of three-dimensional images to make a corrosion confirmation tool that visually expresses the

Photo 2 Special-type bridges constructed using weathering steel

Fig. 3 Overlapped Rust Particles

Fig. 4 Three-dimensional Corrosion Map



corroded section, which was proposed as an approach that integrates maintenance information and an item that trains inspection engineers.

The three-dimensional mapping of corrosion levels and ranges can serve as a means for specifying the cause of corrosion and can be applied for the examination of the cares required to take in maintenance. Further, this approach can serve as an effective tool for educating inspection engineers who explain cares to be taken by corrosion inspection method and methods of how to apply the three-dimensional corrosion map media.

• Approaches to Assessing the Residual Strength of Corroded Girder Ends and Recovering Their Function

The frequency of the occurrence of corrosion damage is high in girder ends, and practically about 40% of total corrosion damage occurs there. For these corrosion-damaged sections, the residual plate thickness is measured, and the residual strength is assessed based on these measurement results, and then methods for repairing and reinforcing these corroded sections can be examined.

However, there remain some concerns in each of the above-mentioned steps. Then, we have examined the residual plate thickness measurement method that employs eddy current with no need for surface treatments such as rust removal. (Refer to Fig. 5) Further, employing the finite element method based on elasto-plastic finite displacement analysis, we have examined the shear strength assessment method for girder ends where local corrosion occurred. In addition, taking notice of the carbon fiber-applied repair method as an approach that reinforces the reduced strength caused by corrosion loss in girder edges, we have examined the strength improvement mechanism for corroded girder ends.

• Examination of Multi-function Corrosion-protection Decks as a Means to Improve Corrosive Environments

Multi-function corrosion-protection decks have been developed by several teams. These decks not only play a role as scaffolding but also shut out corrosion factors to improve the corrosive environment around bridge girders. (Refer to Fig. 6 and Photo 3)

We have examined the performance required for multi-function corrosion-protection decks. We have also examined the economic advantages in their application by comparing LCCs between two bridges in which the deck was applied and not applied. Further, we have introduced the results of performance verification tests conducted to confirm the corrosion-protection performance of the deck.

As a result of the performance verification tests, many effects brought about by the use of the multi-function corrosion-protection deck have become clear—the shutting out of airborne salt and reduction of wetting time inside the deck. In addition, the result of steel product exposure tests showed high corrosion-protection performance of the deck.

However, decks have not been applied in actual bridges for very long time, and this is a technology that still has few examples of performance verification in practical applications. Accordingly, there remain some tasks in the use of multi-function corrosion-protection decks, and thus it will be necessary to continue to examine their practical applications. ■

Reference

1) Public Works Research Institute of the Ministry of Construction, Kozai Club and Japan Bridge Association: Joint Research Report on Application of Weathering Steel to Bridges XVIII, 2003 (in Japanese)

Fig. 5 Distribution of Residual Plate Thickness in Girder Web Ends

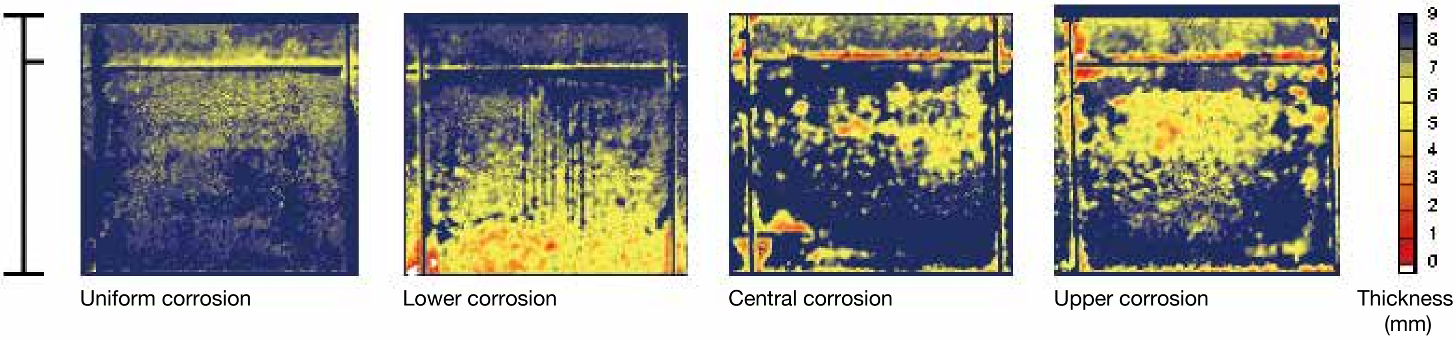


Fig. 6 Multi-function Corrosion-protection Deck

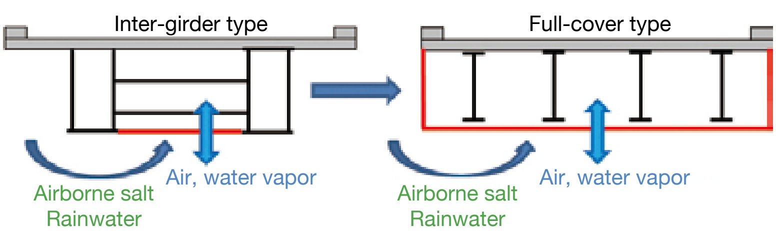


Photo 3 Interior of multi-function corrosion-protection deck

Possibility for Technological Innovation in Construction Employing Statistical Mathematics Approaches

by Tomoyuki Higuchi
The Institute of Statistical Mathematics, Research Organization of Information and Systems

Tomoyuki Higuchi: After finishing the doctoral course at the School of Science, The University of Tokyo, he entered The Institute of Statistical Mathematics in 1989. He is currently engaged in a position as Director of the Research Organization of Information and Systems (Inter-University Research Institute Corporation) and Director-General of The Institute of Statistical Mathematics since 2011. His profession covers Bayesian modeling. He is focusing his research efforts on data assimilation and emulation (simple alternative method for simulation by means of machine learning).

The terms "mathematical statistics" and "statistical mathematics" are closely similar, often causing confusion. But they differ completely in content and academic orientation. While mathematical statistics is a branch of theoretical statistics, statistical mathematics is the term coined by the persons concerned when the Institute of Statistical Mathematics was established in 1944.

Statistical mathematics is regarded as a system of rational and empirical methodology. It discerns what is crucial among practical issues, formulates it and devises plans for experiment and examination, through which data is obtained, and the analysis of this data and prediction lead to the establishment of action guidelines. Thus, the fields that statistical mathematics covers are substantially vast.

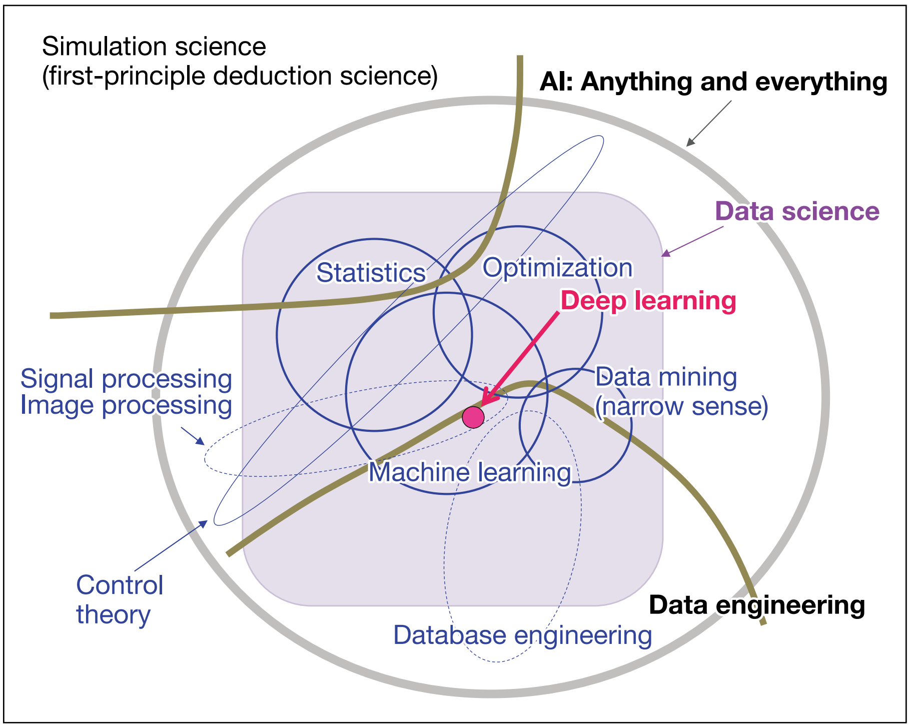
Data Science and Artificial Intelligence

Data science is regarded as an integral system that implies diverse scientific fields involved in statistics, including machine leaning, data mining and data optimization. Fig. 1 shows the concept of data science showing the arrangement of diverse scientific fields from the perspective of mathematics and shows the overlapping of diverse scientific fields. The domain covered by artificial intelligence (AI), the term currently applied, is wider than that of data science. But, the conceptual figure shows rapid changes with time.

When examining AI from the perspective of mathematics, it is the computational technology that combines machine learning, statistics, data mining, optimization and other fields. Machine learning can be defined as a learning system composed of a combination of three elements: an objective, a mathematical model and a learning algorithm.

The objective corresponds to what you want to do by means of the data—the regression, discrimination and classification of data. There are many and diverse mathematical models. In deep learning, an artificial neural network (ANN) is ad-

Fig. 1 Overview of Mathematical Fields Relating to Data



opted as one of these mathematical models. ANN is a nonlinear function that realizes the input-output performance in which links of physiological nerves have greatly been simplified. That is, deep learning is one machine learning approach. Unknown parameters are included in the mathematical model. The method to determine the unknown parameter is called the learning algorithm.

When a combination of these three elements is fixed, the machine learning method makes it possible to program.

Deep Learning

Deep learning is a nonlinear function that is basically identical to the neural networks that were popular in the 1980s (the second AI boom period). The interval between input and output is called the middle (hidden) layer, in which many nodes are included. While the number of middle layers was one or two in the 1980s, the current number properly reaches dozens. There are even cases where the number reaches 100, and in the case of an application example for natural language, it reaches nearly 1,000.

As a result, the number of weight coefficients that connect node with each other becomes enormous. Because the weight coefficient is a parameter, the case frequently occurs in which the unknown numbers reach nearly 1 billion. An issue of over-fitting that certainly occurs when the number of parameter is less than that of the data has been steadily mitigated in the age of big data.

The number of nodes included in the middle layer and how each node connects with each other, that is, the structure of the middle layer should be appropriately selected for the application. As the application target for which deep learning has attained many successful results, the voice, natural language and image are cited as the three main targets.

Diverse types of deep learning structures have been classified according to the type of structures and the application domain, which is schematically shown in Fig. 2.

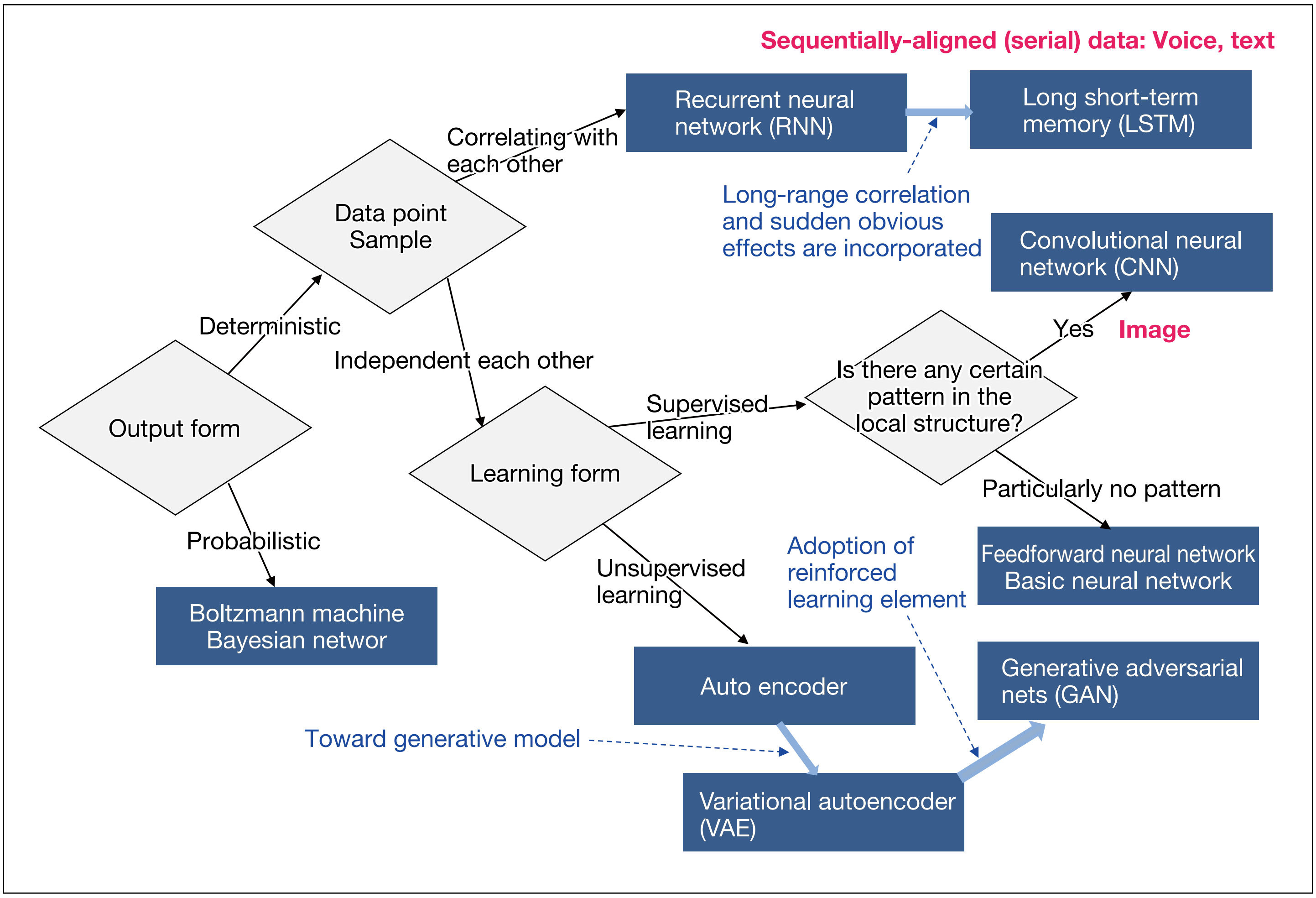
Weaknesses of Artificial Intelligence

Machine learning is an inductive inference in which a rule is established, and decision-making is attained based on the data. In inductive inference, there are several original weaknesses. Accordingly, in order to appropriately apply AI, it is indispensable to correctly understand these weaknesses.

First of all, inductive inference is strong in terms of interpolation but weak in terms of extrapolation. When considering an estimation using inductive inference of an extremely rare phenomenon that has never occurred, this weakness will become obvious. On the other hand, so-called numerical simulations that numerically solve a fundamental formula are strong in extrapolation, but in the case of adopting numerical simulations for interpolation, it is disadvantageous in terms of calculation costs.

Further, it is important to correctly understand the difference between correlation and cause/effect. When machine learning is applied, it is easy to find correlations from among big data. Regarding the difference between correlation and cause/effect, a recommendation on the electronic commerce site says: “If necessary actions are promoted and then if sales increase as a result, that will do.” In other words, the goal in the field of

Fig. 2 Classification of Deep Neural Networks (DNN) in Deep Leaning



commerce is only attained in terms of correlation.

On the other hand, for a problem that directly links with human life, such as the management of the safety of infrastructure, it is essential to identify the cause and the effect, or to understand the relationship between the cause and the effect. Also, on occasions where legal accountability is required as in the sale of financial instruments, it becomes important to adapt the instrument to the consumer's needs and application conditions.

In this way, in the promotion of scientific research and the operation of the manufacturing industry, it is essential to clearly identify the route that connects the cause with the result (in other words, the casual relationship), but there is a limit in identifying the casual relationship only by means of machine learning. In particular, because the artificial neural network (ANN) obtained from machine learning is a black-box, efforts are needed to make its input/output relationship into a "white box."

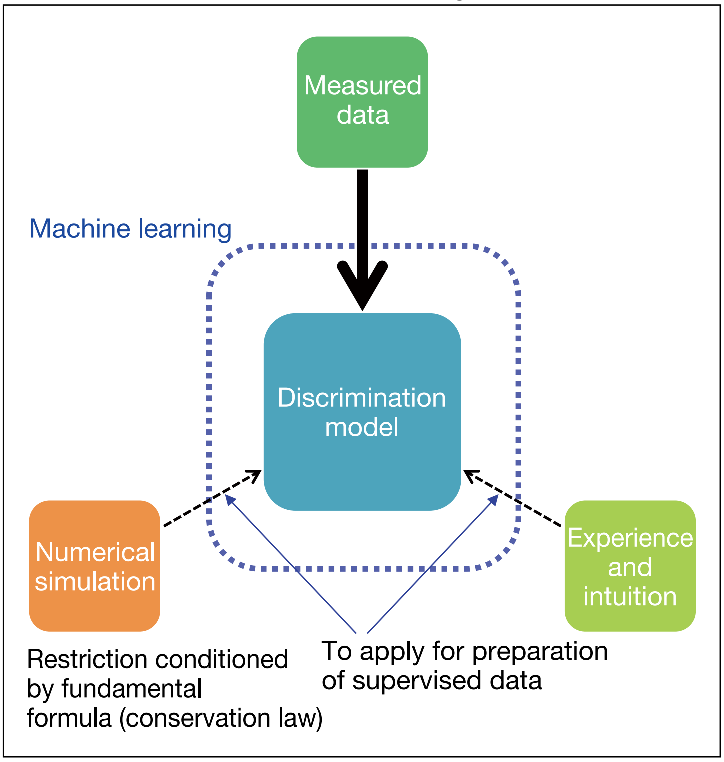
Further, in the inductive method, serious examinations should be made of how to handle, depending on the specified problem, false-positives or false-negatives that cannot essentially be treated as zero. In cancer diagnosis, for example, in order to avoid false-negatives (where the patient has no problem in a cancer diagnosis, but actually does suffer from cancer), false-positives are accepted. Meanwhile in self-diving of cars, because swift steering operation is very dangerous, false alarms generated by the sensor are not incorporated one by one into the operating (control) plan. In other words, a design concept that avoids false-positives is adopted.

In this way, there is a limit in inductive methods in which the rule is established only by the use of data, and thus how to adjust the balance between false-positive and false-negative has become a difficult task in the application of AI in business operations.

Digital Twins

There is no conceptual difference between digital twins and cyber physical systems, and in explaining them, the following three elements—1) measured data, 2) numerical simulations, and 3) experience and intuition—serve as the important players. Noticing to the relationship among these three elements, the leading-edge technologies in the industrial field are outlined below:

Fig. 3 Detection of Abnormal Values such as Outliers, Abnormal Sections and Change Points



When a fundamental formula is unavailable in examining the target phenomena, generative models have conventionally and empirically been prepared using the measured data to control the target phenomena. The scale of the mathematical model to be applied has undergone changes from simple models like multivariable auto-regression models previously applied to large-scale models with deep learning currently applied.

The detection of abnormal values is a most important issue for the entire industry. In the case of examining the detection of abnormal values occurring in industrial operations employing the three major elements mentioned above, discrimination models to detect abnormal values are prepared using numerical simulations and experience/intuition as supervised data and from the measured data obtained through machine learning. Fig. 3 shows the process and structure of the discrimination model employing these three major elements in detection of abnormal values. The opposite is the emulation approach—a technique that uses the measured data as supervised data and prepares a regenerative model for the measured data by means of machine learning, based on the results of numerical simulation.

The numerical simulation usually requires a great deal of calculation time. But in the case of emulation, the structured generative model is an extremely simple model like a linear regression model, and therefore the computation carried out in a design parameter space can be attained at a high speed. Fig. 4 shows the role played in emulation by the three important elements—measured data, numerical simulations, and experience and intuition.

It is the data assimilation that integrates the three sources of information from the measured data, numerical simulation and experience/intuition using Bayes' theorem. Fig. 5 shows the relationship among the three elements in a digital twin. Research on data assimilation has been actively promoted since the mid-1990s, and currently data assimilation is indispensable for forecasting weather conditions. That is, data assimilation is regarded as a technology that is routinely applied.

Utilization of Databases and Linkage Technologies

Research that expresses the experience and intuition using numerical formulas is being promoted at an accelerated pace by constructing generative models for interested targets employing enormous accumulated databases and by means of machine learning. While radically different from the field of civil engineering, this research can be explained with the exam-

Fig. 4 Emulation and Virtual Measurement

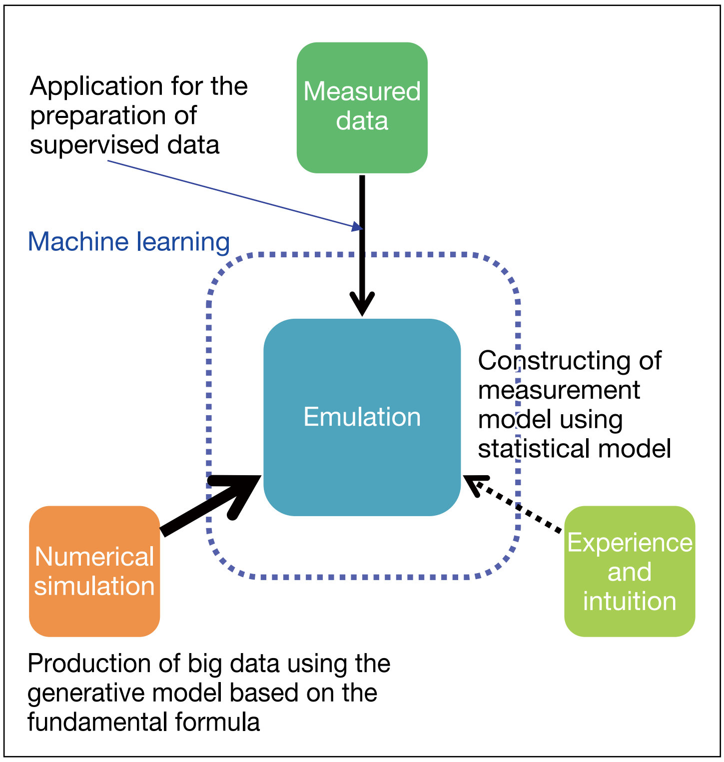
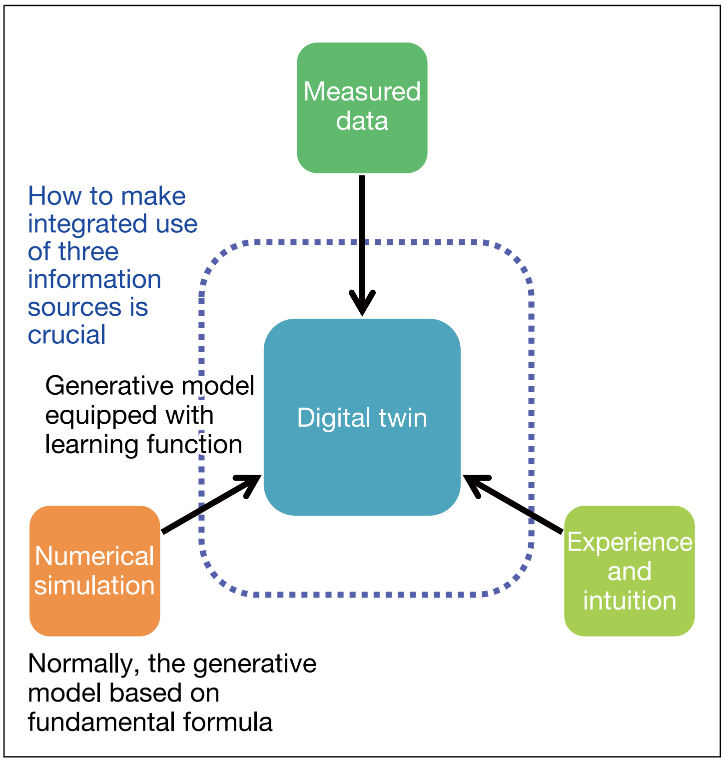


Fig. 5 Relationship among Three Elements in Digital Twins



ple of new medicine development.

When information about the structures of a vast amount of organic compounds accumulated in a database is expressed in graphs, the pattern is completely different from that of the graph that expresses human-to-human links as seen in social network services (SNS). In other words, while there are certain patterns in graphs pertaining to organic compounds, it is difficult for humans to find patterns from the vast amount of databases thus far accumulated. Machine learning has demonstrated high performance in handling such emerging tasks.

Information about molecular structures can be transformed by the use of certain transformation formulas to a string that expresses the chemical formula (that is to say, a chemical structure formula). While the string does not conform to the three-dimensional structure of the original compound on a one-to-one basis, it can fully express the characteristic features of organic compounds. Once the information about molecular structures is transformed to the form of a string as explained above, it becomes possible to apply diverse natural language processing technologies that have recently shown rapid progress.

For example, if a certain chemical formula is given, the subsequent formula can probabilistically be formed by the use of the word predictive function found in a smart phone or other advanced devices. When this function is repeatedly applied, it is possible to produce many virtual molecules that reflect diverse patterns existing in compounds in the database. To these ends, employing the machine learning approach, the tacit knowledge hidden in databases should be positively mathematized as a generative model corresponding to prior information.

It is urgently needed to make evident information hidden in databases and at the same time to introduce linkage technologies that handle related information in an integrated manner. In the case of applying the Internet of Things (IoT) for monitoring social infrastructure, a single data setting is insufficient, and it is inevitably required to integrate diverse kinds of information (data that cannot be obtained on the spot and data stored by other related organizations). In data integration, it becomes necessary to provide diverse devices such as for loss treatment (imputation) and quality guarantee.

For example, in analyzing the data obtained from many position/acceleration sensors arranged on a bridge, video information of passing vehicles using a fixed camera is very useful. In addition to the information thus obtained, meteorological information pertaining to the amount of local solar radiation and the wind velocity should be analyzed. The mathematical foundation of information linkage technology is mainly entrusted to Bayesian' statistics, and thus a considerable amount of calculation time is required to realize rational inferences. To remedy this, many devices to make simple inferences have been put into effect. ■

SEAISI Training Program Held in Japan

The Japan Iron and Steel Federation held the SEAISI Training Program in Japan on 23rd to 27th of October 2017. The program, sponsored by the South East Asia Iron and Steel Institute (SEAISI), is annually held aiming at improving diverse kinds of skills of steel-related persons in the six "ordinary regular member countries" of SEAISI. Japan and the three "supporting regular member countries" of SEAISI—Korea, Taiwan and Australia—have extended cooperation in holding the program on an alternating basis among these four countries. The program was held in Japan for the first time in four years since 2013. It accepted 17 persons working at steelmakers in six ordinary regular member countries.

The 2017 program in Japan was held with the theme of "Japan's High Performance Steel Products (Feature, Key Performance Indicator in Production Process and R&D)," in which three lectures were delivered:

- Application of High-performance Steel Products in Bridge Construction in Japan
- Application of High-performance Steel Products in Building Construction in Japan
- Application and Operation of Japanese Industrial Standards (JIS) in the Field of Iron and Steel Products

The program covered site visits to the Kimitsu Works of Nippon Steel & Sumitomo Metal Corporation, the East Japan Works of JFE Steel Corporation and the Kakogawa Works of Kobe Steel Ltd., where lectures were also delivered explaining key performance indicators in production processes conducive to the management of entire steelworks operations, new ironmaking technologies and methods to reduce CO_2 emissions from medium- and long-term perspectives.

In addition, program participants visited the National Institute for Material Science, where lectures were also delivered pertaining to research being promoted on structural material technologies, material strength and seismic technologies.

Lecture Delivery at the SEAISI Forum

The Japan Iron and Steel Federation (JISF) dispatched Masamichi Sasaki, a member of JISF's Committee on Overseas Market Promotion, to the 2017 ASEAN Iron and Steel Sustainability Forum held by the South East Asia Iron and Steel Institute in Manila, the Philippines, on November 27, 2017. He delivered a lecture titled "Market Development of Steel Structures in Japan—Standardization, Building Codes and Steel Products." The lecture was delivered at the request of the Sub-Committee on Steel Applications in Construction Sector of SEAISI. It was one of lectures delivered by committee members and other related persons. Japan participates in the Sub-Committee as an observer.

In the lecture from Japan, diverse initiatives exerted for the promotion of market development for steel structures in Japan were introduced with a remark—why steel structures have attained remarkable development in Japan is greatly attributable to the systematic preparation of steel structure-related laws and design approaches, technological development, and framing for efficient construction and logistics.

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