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New Steel-Materials for Bridge Construction

Yutaka SAKATA*[1] Yasumori FUJII*[1]
Akinobu SUZUKI*[1] Masahide TAKAGI*[1]
Kenji NISHIUMI*[2] Takashi KUSUNOKI*[3]
Takeshi TSUZUKI*[4] Akira USAMI*[2]

Abstract

Bridge construction is expected to grow in the future, however, current public works spending conditions make it essential to reduce bridge construction cost. Not only the initial construction cost, but also the increasing maintenance cost necessitated by the growing number of bridges poses a problem. Also, with a decline in the productive population with the arrival of an aging society, labor saving has become increasingly necessary. To meet these requirements, Nippon Steel is developing new technologies relating to bridge materials, designs and construction. With a focus on bridge materials and structural steels, some aspects of the comprehensive approaches of Nippon Steel to bridge construction are introduced in this paper by showing the characteristics and applications of new weathering steel which reduces maintenance cost, longitudinally profiled steel plate which reduces manufacturing cost, box columns made from high fracture toughness steel, and the large-span GRATING slab, steel element for composite pier which reduces the labor required for bridge construction.

1. Introduction

Japan lags behind the US and European countries in road construction. For example, the length of highways completed was about 6,400 km as of the end of fiscal 1997, which amounts to only 56% of the scheduled construction of about 11,500 km. Thus, more road construction plans will be seen in the future. Conventionally, construction of highways concentrated in the coastal plain regions. In the future, however, construction is expected to increase in the inland mountain regions, which will increase the ratio of structures such as bridges and tunnels compared with earthworks. For example, while the current ratio of bridges for the Tomei/Meishin Highways (length about 540 km) is about 16%, the ratio for the Daini Tomei/Meishin Highways (length about 500 km) is 2.5 times larger at about 40%. With the heightened need for reducing public works costs, a reduction in bridge construction costs is also an important factor. Thus, reduced steel girder bridges recently used in bridge construction have been developed to reduce costs. Further, there is a need to reduce not only initial costs but also future maintenance costs, in other words, total cost reduction.

Nippon Steel is taking comprehensive approaches in this area including materials, designing, manufacturing and reduced steel girder bridges. **Table 1** shows new technology classified into steel materials, superstructure and substructure. Of these, focusing on steel materials and construction materials, this paper outlines a work

*[1] Construction & Architectural Materials Development & Engineering Service Division
*[2] Technical Development Bureau
*[3] Plate Sales Division
*[4] Nagoya Works

Table 1 New technology of Nippon Steel related to bridge

Classification	New technology
Steel material	New weathering steel, longitudinally profiled steel plate, box columns made from high fracture toughness steel, high-strength steel, low preheating steel, steel for large heat-input welding, steel with constant yield point, steel with narrow range of yield point variation, vibration-damping steel plate, high-strength steel wire, etc.
Superstructure	Large span GRATING slab (used for reduced steel girder bridge), various composite or hybrid bridges, tubular steel girder bridge, erection method of mountain bridge girders by jacking up and turning
Substructure (pier)	Earthquake-proof technology for steel pier, steel element for composite pier or cast-in-place composite pier, high strength reinforcement bar (SD685) for high pier

method using new weathering steel, longitudinally profiled (LP) steel plates and box columns made from high-fracture toughness steel as steel materials and large span GRATING slabs and steel elements for composite pier as construction materials.

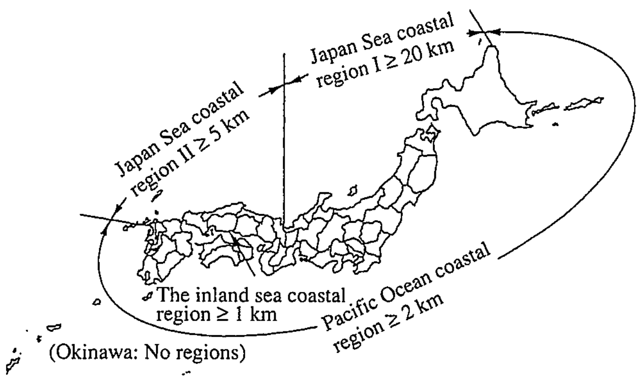
2. Steel Materials for Bridge Construction

2.1 New weathering steel

2.1.1 State of weathering steel

The growing number of bridges has necessitated greater expenses for maintenance such as painting. Attention is now focusing on weathering steel as a steel material for reducing maintenance costs such as re-painting for steel bridges. Weathering steel has a dense rust layer called a stable rust layer formed on the steel plate surface. This dense rust layer protects the steel plate surface and suppresses the progress of corrosion thereafter. However, because of the effect of chloride ions (Cl^-) contained in sea salt particles and deicing salt, layer-like peeled rust may occur without producing any stable rust.

Thus, regions for application must be selected carefully. For this purpose, an application guideline[1] was published by the cooperative research of three organizations, i.e., Public Works Research Institute, Ministry of Construction, Japan Association of Steel Bridge Construction and The Kozai Club. The guideline recommends that for the application range of weathering steel without painting, the amount of air borne salt should be 0.05 mdd (mg/dm^2/day) or lower (see **Fig. 1**). But many of the cities in Japan are located in the plain regions along the coast, and thus the road networks interconnecting the cities have often been set up near coastlines. In cold regions, the amount of deicing salt sprayed in winter has increased since the use of studded tires was prohibited. Also, in these regions, strong requests have been made for development of weathering steel used without being affected by air borne salt and without painting.



1) Air borne salt amount ≤ 0.052 mdd
2) For regions outside of the coastal distance shown in the drawing, measuring of air borne salt amount may be omitted.

Fig. 1 Guideline on application of non-painted weathering steel

2.1.2 Effect of added elements[2]

Fig. 2 shows the result of a weathering test (5% NaCl salt water spray weathering test: one year) executed in a simulated coastal atmosphere environment by adding phosphor (P), copper (Cu) and nickel (Ni) to a steel material as these alloying elements are expected to be effective for weathering improvements. In the figure, the abscissa represents the amount of each element, and the ordinate

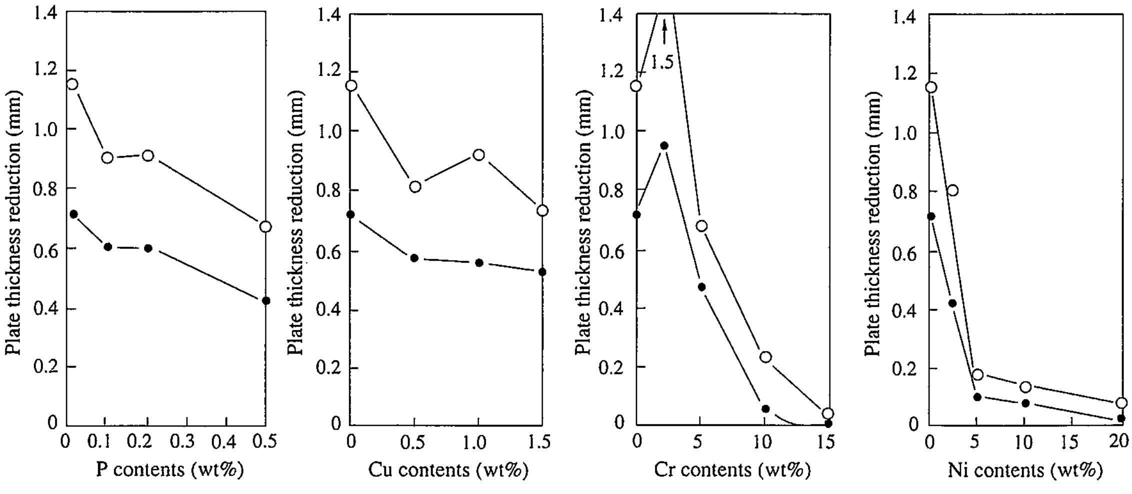


Fig. 2 Effect of adding various alloying elements in simulated coastal atmosphere environment (salt water spray weathering test: one year) (test steel basic component: 0.05C-0.25Si-1.5Mn)

represents the reduction of plate thickness. It can be seen that for P, Cu and Ni, corrosion decreases as the addition of the element increases, the effect is especially large for Ni. On the other hand, Cr was believed to be effective to improve weathering for conventional weathering steel and in the simulated coastal environment, it was found to be effective when contents exceeded 10%. But the amount of corrosion conversely increased when the contents was only 2 to 3%.

2.1.3 Effect of Ni[3,4]

Based on the results of the weathering test, new weathering steel was produced by increasing the amount of Ni contents to the conventional weathering steel as a base without adding any Cr. **Fig. 3** shows the results of a weathering test carried out in Okinawa. Because of its coastal environment where the amount of air born salt is 0.78 mdd, corrosion increases for normal steel materials with time. But with new weathering steel to which 5% Ni was added, the corrosion rate starts to reduce in the third year, and it is estimated that rust has stabilized. **Fig. 4** shows the results of a weathering test carried out by changing the amount of Ni contents. This weathering test was made for six years in the quay (amount of air borne salt was 1.3 mdd) of Nippon Steel Kimitsu Works. The amount of corrosion was greatly reduced by an addition of 3%. Thus, with about a 3% addition of Ni, sufficient resistance to air borne salts may be provided.

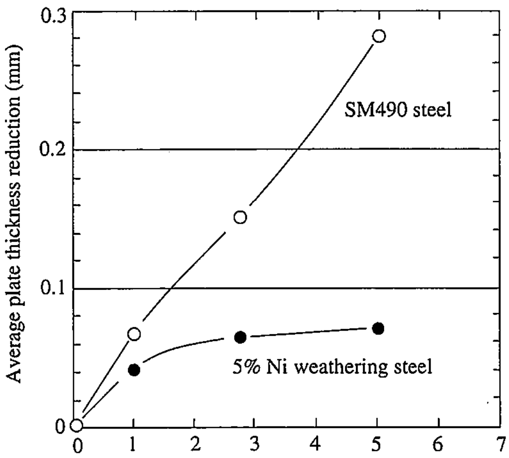


Fig. 3 Coastal atmosphere weathering test in Okinawa (air borne salt: 0.78 mdd)

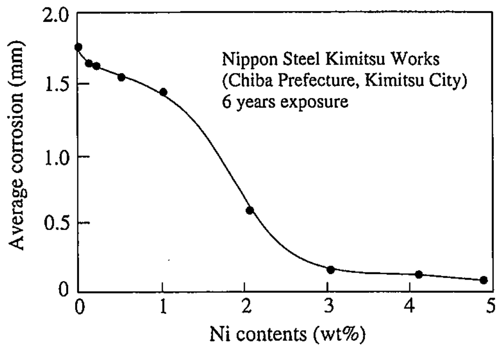


Fig. 4 Effect of Ni addition on coastal weathering (air borne salt: 1.3 mdd)

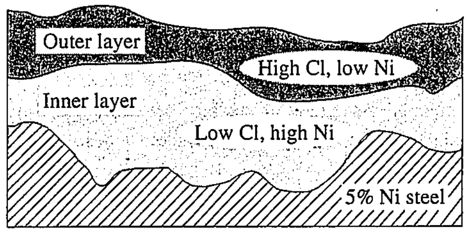


Fig. 5 Schematic illustration of Ni and Cl distribution state in 5% Ni steel rust layer section

Table 2 Chemical composition for new weathering steel

Variety symbol	Plate thickness t (mm)	Chemical composition (mass%)							
		C	Si	Mn	P	S	Cu	Ni	Cr
SMA490W-MOD SMA570WQ-MOD	9 ≤ t ≤ 50	0.18 or lower	0.15 – 0.65	1.40 or lower	0.035 or lower	0.035 or lower	0.30 – 0.50	2.50 – 3.50	0.08 or lower

(Reference: JIS weathering steel)

Variety symbol	Plate thickness t (mm)	C	Si	Mn	P	S	Cu	Ni	Cr
SMA400W SMA490W SMA570WQ	9 ≤ t ≤ 50	0.18 or lower	0.15 – 0.65	·1.40 or lower	0.035 or lower	0.035 or lower	0.30 – 0.50	0.05 – 0.30	0.45 – 0.75

Fig. 5 shows typical stable rust structure in new weathering steel obtained by subjecting a weathering test piece to EPMA analysis. There is an Ni concentration in the layer inside the stable rust which may suppress the penetration of chloride ions.

2.1.4 Conclusion

Based on these results, new weathering steel[5,6] was manufactured using the components shown in **Table 2**, and actual steel plates were produced experimentally. Mechanical property tests, e.g., tensile tests and Charpy impact tests, were carried out in these plates. The sample plates were found to meet the specified values. Welding materials essential for structure manufacturing were also developed at the same time, and it was confirmed that there was no weldability problem. New weathering steel may contribute to reduced maintenance costs for steel bridges in the coastal regions where it has conventionally been difficult to apply weathering steel or in the regions where a large amount of deicing salt is sprayed. In the future, the application of weathering steel is expected to grow. New weathering steel (5% Ni steel) was used for a part of the inner girders of the "Shinnittetsu Minami-Ohashi" bridge located in the coastal area of Nippon Steel Nagoya Works, and a follow-up study of changes over time has been conducted.

2.2 LP steel plate

2.2.1 Manufacture of LP steel plate

An LP steel plate, generally called a tapered plate, has a plate thickness which is continuously changed in the rolling direction by changing the roll gap of the rolling machine. LP steel plates with shapes like those shown in **Fig. 6** can be manufactured. **Table 3** shows examples of the dimensions of LP steel plates manufactured at Nippon Steel. Manufacture of LP steel plates is affected by such conditions as the performance of the automatic gauge control (AGC) device, the hardness of the rolling material and the width and length of a plate. Generally, however, LP plates with taper ratios of 4 mm/m and plate thickness changing amounts of 30 to 40 mm can be manufactured.

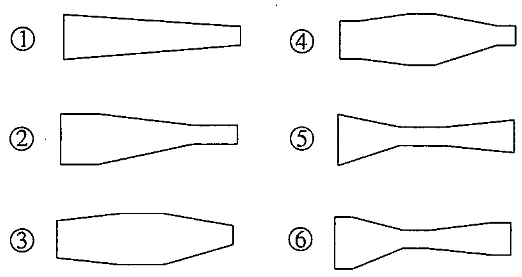


Fig. 6 Variety of shapes for LP steel plates

Table 3 Dimension of LP steel plate to be manufactured

Item	Dimension for manufacture
Maximum plate thickness difference	30-40 mm
Maximum gradient	4 mm/m
Minimum thin part plate thickness	10-15 mm
Maximum thick part plate thickness	100 mm
Steel plate full length	6-25 m
Steel plate width	Over 1.5 m

Dimension for manufacture changes depending on the width and length of steel plate.

2.2.2 Advantage of LP steel plate

In recent years, from the viewpoint of reducing construction cost, steel bridges have been constructed with no sectional changes in members, using the so-called "one member-one section" girder[7]. By using LP steel plates for such a structure, as shown in **Fig. 7**, steel weight can be reduced without plate joining welding. When using one member-one section girder construction, since sectional changes are made in joint positions on-site, taper cutting or filler plates are necessary in the joint positions as shown in **Fig. 8.** However, the use of LP steel plates can eliminate the necessity of such work.

Since the current design standard is a system established based on equal thickness steel plates, the strength properties of LP steel plates with continuously changed plate thickness are not sufficiently reflected. Thus, design has been conservative, using thin plate thickness. On the other hand, research has been underway to develop a practical design method which reflects the strength properties of LP steel plates[8]. It is expected that in the near future, achievements of the research will be reflected in design manuals and costs will be further reduced.

2.2.3 Conclusion

Many examples of using LP steel plates for bridges can be seen in Europe. In Japan, LP steel plates have already been used for several bridges. LP steel plates are effective for steel weight reduction if there is a large difference in plate thickness in one member. But because extra shapes are added for LP steel plates, design must be made such that the advantage of reducing steel weight can overwhelm the extras of LP steel plates. Thus, by combining large gradient LP steel plates with equal thickness steel plates, rather than combining small gradient LP steel plates to make small sectional changes, the advantage of reducing steel weight must be made the best use of. In this regard, in the case of a twin girder bridge using thick sections, since a plate thickness difference is increased in a member, the effect of utilizing LP steel plates may be increased. In the future, it is expected that with the increased construction of twin girder bridges, the amount of LP steel plates used will grow.

2.3 Box columns made from high fracture toughness steel

2.3.1 Application of box columns to bridge construction

Conventionally, the box member used as a chord or a diagonal member for a truss bridge has been manufactured by welding steel plates. Thus, the number of materilas and welds have increased, which has led to cost increases for structures. The number of materials and welds can be reduced by using box columns as fabricated products for such sections, and construction costs can be reduced as well. **Fig. 9** shows a truss bridge using box columns.

A box column (press column) made by press forming is manufactured by the method shown in **Fig. 10**. A thick plate is molded into a channel shape by pressing, and two channel steel members are joined together by welding. It is known that if subjected to cold work, steel material loses its fracture toughness and, with the passage of time, its plastically worked portion becomes brittle

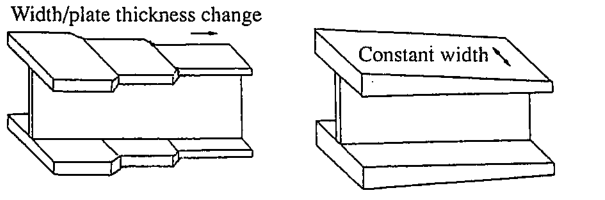


Fig. 7 Application example of LP steel plate

	Equal thickness steel plate	LP steel plat
Bolted joint	Filler plate used	Filler plate unnecessary
Site welding joint	1:5 tapering	Tapering unnecessary

Fig. 8 Effect of LP steel plate in field joint part

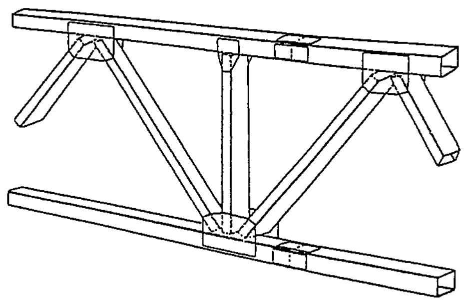


Fig. 9 Application image of box columns made from high fracture toughness steel to truss bridge

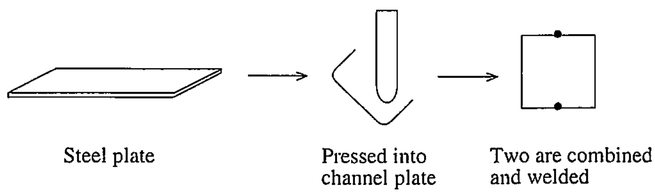


Fig. 10 Manufacture of press forming box column

(strain aging). Thus, in Specifications for Highway Bridges[9)], to secure proper fracture toughness after cold bending, an allowable bending radius for cold bending is set to 5 × t at minimum (t: plate thickness), for example if the content of nitrogen is 0.006% or lower and with $_vE_0 \geq 200$ J.

Box columns are generally used as building members. To effectively utilize their sections, the box columns are subjected to very strict cold bending where the inside bending radius is set to 2.5 × t. When applying box columns to bridge members, consideration must be given to fatigue caused by large fluctuations in deformation or stress by live loads and, even after cold bending, materials capable of proper fracture toughness must be used. For this reason, the box columns as bridge members have been rarely used till lately. In recent years, however, with the capability of manufacturing steel plates with high fracture toughness, examples of investigating application for labor savings by using shape steel have begun to be seen. In "Takishita Bridge of Japan Highway Public Corp."[10)], efforts have been made to construct a truss bridge at reduced cost by using box columns as the main members.

2.3.2 Performance test of box columns

A performance test was carried out on the assumption that box columns were utilized for bridges in cold regions with severe use conditions. Problems were expected with the application as bridge members because the following two portions exceeded the application range of the design criteria:

(1) the corner subjected to strict cold bending of 2.5 × t, and

(2) the seam weld for carrying out large heat input welding of a heat input set to about 150 kJ/cm.

Thus, a steel material property and performance qualification test like that shown in **Fig. 11** was performed, and it was confirmed that box columns have sufficient performance as bridge members even after manufacturing process. Examples of the test results are shown in **Table 4**, **Figs. 12 and 13**. **Table 4** shows the results of a tensile test and Charpy impact test for steel materials which were subjected to 2.5 × t bending and aging treatment (held for 60 min at 250°C).

A TMCP weathering steel material with good base material fracture toughness was used. Thus, even if the strength increase was large in a bent portion, $_vT_{rs}$ was -90°C which is very small, and $_vE_0$ was kept around 280 J. But since this test needs a certain length for the test piece sample, a Charpy test cannot be performed strictly in the uppermost surface position where the strain is largest. For this reason, the test was carried out by extracting a portion

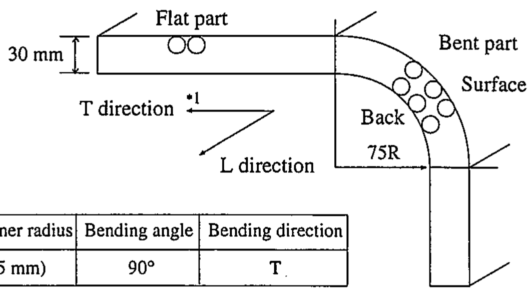
Property evaluation test of box column
- Base material part, bending part evaluation (test steel material: SMA490BW-TMC)
  - Tensile test (base material part, bending part: bending radius 2.5 t)
  - Charpy impact test (base material part, bending part: bending radius 2.5 t)
  - Strain aging test (pre-strain: 5%, 10%)
  - Surface strain evaluation (pre-strain: 17%, Charpy impact test)
- Seam welding part joint test
  (CO$_2$ shielded arc welding: heat input 31 kJ/cm, submerged arc welding (SAW): heat input 147 kJ/cm)
  - Joint Charpy test
  - Joint tensile test
  - Joint side bending test
  - Joint hardness test

Fig. 11 Property evaluation of box column made from high fracture toughness steel

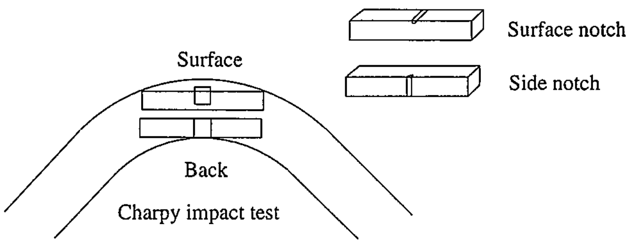
Table 4 Mechanical properties of flat and bent parts

Heat treatment	Position	Tensile test: Thick position	Direction*1	Test piece	Yield strength (N/mm²)	Tensile strength (N/mm²)	Elongation (%)	Charpy impact test: Thick position	Direction	Test piece	Notch position	$_vE_0$ (J)	$_vT_{rs}$ (°C)
Aging (250°C × 60 min)	Flat part	1/4 t	L	No. 4, 10 mmϕ	425 426	528 529	42 39	1/4 t	L	No. 4	Side	303	<–100
									T	No. 4	Side	289	<–100
	Bent part	1/4 t	L	No. 4, 10 mmϕ	605 593 579	634 641 633	26 26 26	0.5 mm 4.5 mm below surface	L	No. 4	Surface	295	–90
									T	No. 4	Surface	274	–
		3/4 t	L	No. 4, 10 mmϕ	547 544 555	603 601 607	25 27 28	0.5 mm below backside	L	No. 4	Backside	285	<–100
									T	No. 4	Backside	262	–
Mill sheet value		Full thickness	T	No. 1A	451	544	25	1/4 t	L	No. 4	Side	311	–
Base material standard value (SMA490BW-TMC)		Full thickness	L or T	No. 1A Minimum Maximum	355	490 610	19	1/4 t	L	No. 4	Side	≥27	–

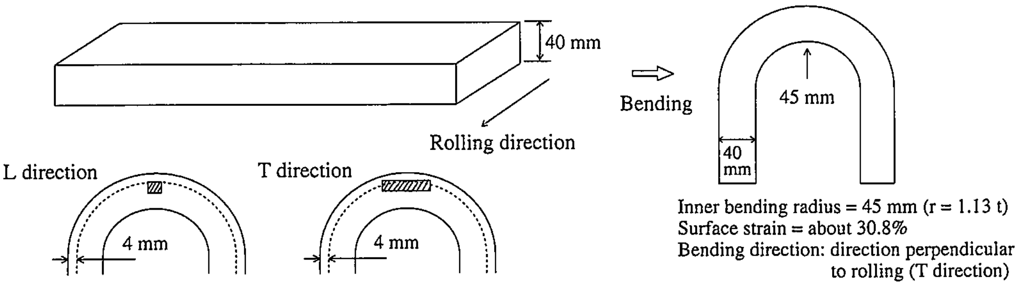
*1 L: Parallel to rolling direction, T: Perpendicular to rolling direction



Bending inner radius	Bending angle	Bending direction
2.5 t (75 mm)	90°	T



(1) Test condition



Charpy impact test piece sampling position (thick position from bent outer surface)	Aging	Test direction	Test temperature
Strain of thick center part (9 mm below bent outer surface) of test piece 4 mm below bent outer surface = 17% / Plate thickness direction / Test piece center part / 4 mm below surface strain: 24.6% / 9 mm below surface strain: 16.9% / 14 mm below surface strain: 9.2%	250°C × 1h	L, T	0, -25, -40, -60, -80°C

(2) Test result

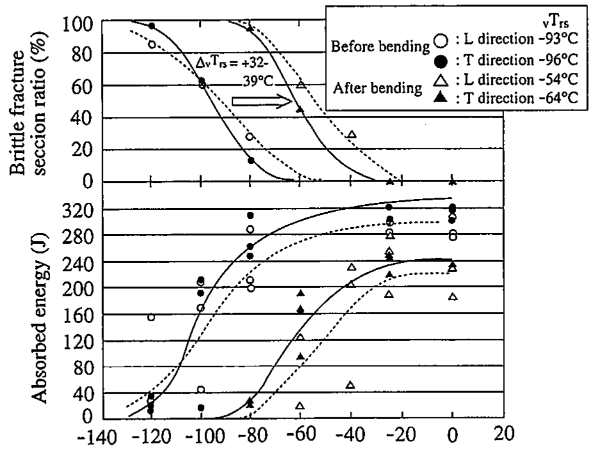


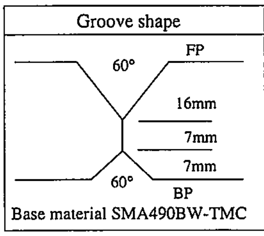
Fig. 12 Surface strain evaluation test for bending corner part

equivalent to the strain (about 17% with a bending radius of 2.5 × t) from the steel material subjected to larger bending as shown in **Fig. 12.** The test results showed that the changing amount of the fracture appearance transition temperature by material bending was 32 to 39°C. For application to bridges in cold regions, fracture toughness can be guaranteed with consideration of such changes in a fracture appearance transition temperature. Further, **Fig. 13** shows the results of joint Charpy impact test for the seam, and the present TMCP weathering steel used in this test has good fracture toughness even in the case of large heat input welding.

2.3.3 Conclusion

A verification test was carried out for application in cold regions using steel materials with high fracture toughness. Performance greatly exceeded the required level even after cold bending. There is room for discussion regarding the performance required of box columns used as bridge members. Nonetheless, the present tests provided basic data for the application of box columns to bridges.

(1) Welding conditions



Method		Current	Voltage	Speed	Heat input
CO_2		500A	45V	43cm/min	31kJ/cm
SAW	L	1250A	40V	55cm/min	147kJ/cm
	T1	900A	42V		
	T2	850A	55V		
Welding material					
BP side (CO_2)	YM-55W 1.6mmϕ				
FP side (SAW)	Y-CNCW 4.8mmϕ NF-310				

(2) Joint Charpy impact test result (1/4t)

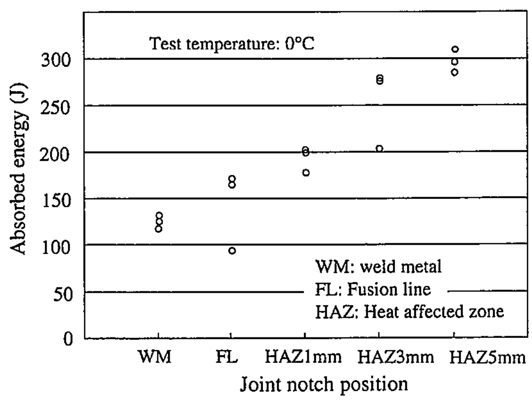


Fig. 13 Seam part joint test result

3. Bridge Construction Materials

In order to meet the need for labor saving to deal with a labor shortage following the progress of aging society, in addition to a reduction in construction costs, Nippon Steel has developed products and methods using shape steel. This section introduces examples of such developments: GRATING slabs for reduced steel girder bridges using special rolled I-beam and a steel element pier method using straight-web steel sheet piles.

3.1 Large span GRATING slab

3.1.1 Slab for GRATING slab

Reduced steel girder bridges with main girders reduced in number and a simplified structure are in focus to reduce steel bridge costs and achieve labor saving. However, since slabs for road bridges are members that directly support vehicle loads, fatigue and damage easily occur. Taking the past cases of fatigue damage of reinforced concrete (RC) slabs into consideration, the damage to slabs was suppressed by designing with increased slab thickness and number of girder reducing slab spans. Thus, highly durable slabs are essential for realizing reduced steel girder bridges.

3.1.2 Structure of GRATING slab

A GRATING slab is a kind of composite slab using special rolled I-beam shown in **Fig. 14**. It is a prefabricated product composed of I-beam having web perforations as a main member, a deformed reinforcing bar set perpendicular to the I-beam and a galvanized steel sheet concrete form when setting the concrete. The shop-fabricated panels are transported to a construction site and installed on the girder and then concrete is placed. The GRATING panel itself serves as scaffolding and forms. Thus, the panel is advantageous in that the lack of a need for form, support and bar setting on site can shorten the work period, and the steel plate in the bottom allows safe execution.

3.1.3 Development of large span GRATING slab

The development of GRATING slabs started from the latter half of the 1960s, and more than 1,000 bridges have already been constructed using them. As prescribed for in the Design Handbook for Highway Steel Bridges[11], the design application range should be below a slab span of 4 m as in the case of RC slabs. For this reason, it had been impossible to directly use GRATING slabs for a reduced steel girder bridge where a slab span exceeded 4 m. The development of large span GRATING slabs used for reduced steel girder bridge required structural investigation to exceed the conventional application range, establishment of a design method and verification of fatigue durability.

As slab span increases, the sectional force generated in the slab also increases. A shortage occurs in the rigidity of conventionally used I-beam. It is necessary to design the slab thickness for fatigue durability. Thus, new I-beam (I-200) with a height of 200 mm was manufactured. **Fig. 15** shows shapes and dimensions of I-beam.

In order to avoid complexity in road bridge slab design, the design bending moment is set by assuming vehicle loads as large as possible. This approach was also taken when investigating the method of designing large span GRATING slabs. The GRATING slab assuming large vehicle loads was formed into the model of an anisotropic plate and subjected to FEM analysis. Based on the results, a design bending moment method applied up to a slab span

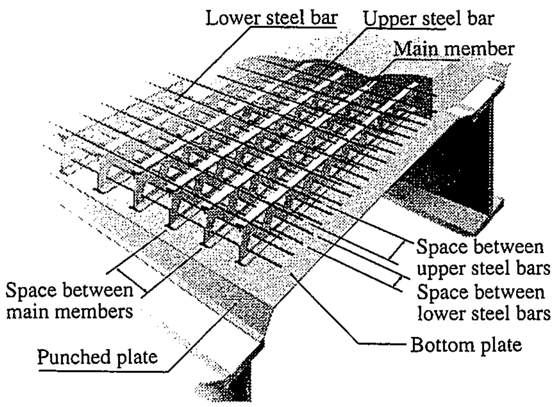
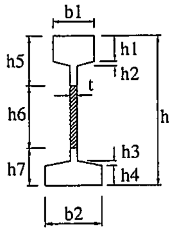


Fig. 14 GRATING slab



(mm)

h	b1	b2	t	h1	h2	h3	h4	h5	h6	h7
105	30	35	4.0	11	2.5	3	7.5	25	50	30
130	30	40	4.5	12	2.0	3	9.0	35	65	30
150	35	50	5.0	10	4.0	3	7.0	55	65	30
200	50	60	6.0	15	8.0	6	12	60	110	30

Fig. 15 Dimension of I-beam

of 8 m was presented. See reference[12] for details on the investigation.

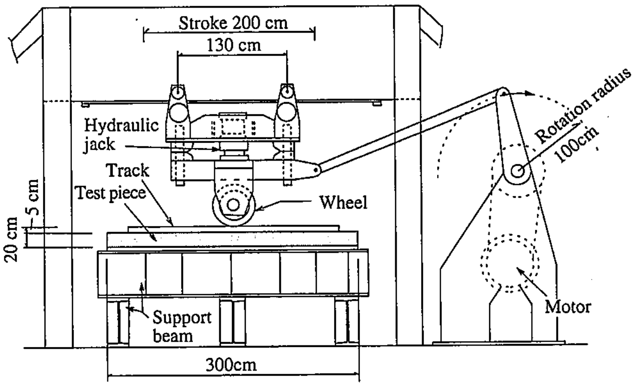
3.1.4 Verification of fatigue durability

To evaluate fatigue durability, durability evaluation of road bridge slabs and a damage mechanism were clarified using a wheel load traveling test capable of simulating traveling wheel loads. Also, for GRATING slabs, a wheel load traveling test was carried out under the conditions shown in **Fig. 16**, and a fatigue damage mechanism was examined[13]. As a result, for fatigue fracture properties, the following characteristics became evident:

(1) Fatigue durability of GRATING slabs depends on the fatigue durability of the I-beam; and

(2) Stress concentration occurs in the corner of a perforation in the web of the I-beam, and this portion becomes a weak point for fatigue strength.

When manufacturing large span GRATING slabs, stress concentration of the perforation of the I-beam was verified by FEM analysis, and a perforation shape capable of the specified fatigue strength was decided. To verify the fatigue fracture property of actual I-beam, as shown in **Photo 1**, 3 point bending fatigue test was carried out on I-beam with no concrete, and an S-N diagram shown in **Fig. 17** was obtained. **Fig. 17** also shows fatigue design curve of the Fatigue Resistant Design Guide and Commentary by JSSC[14]. It can be understood from **Fig. 17** that the fatigue category of the stress concentration part of the I-beam is B class or higher.



Test conditions

Slab span	: 2.2 m
Slab thickness	: 20 cm
I-beam	: I150@25 cm (SS400)
Arranged bar	: D16@12.5 cm (lower side) @25 cm (upper side)
Concrete	: σ_{ck} = 300 kgf/cm^2
Load	: to 15 tf 500 thousand reciprocations + 18 tf fracture

Fig. 16 Wheel load traveling fatigue test

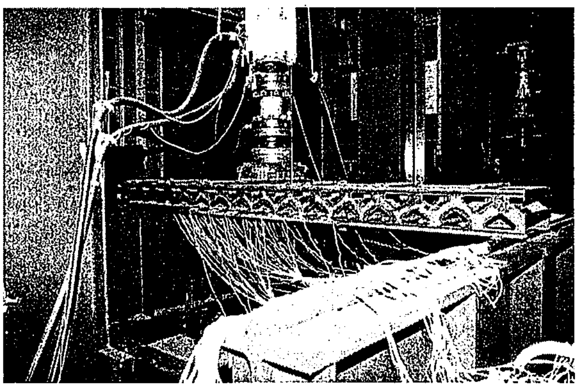


Photo 1 Fatigue test for I-beam (I-200)

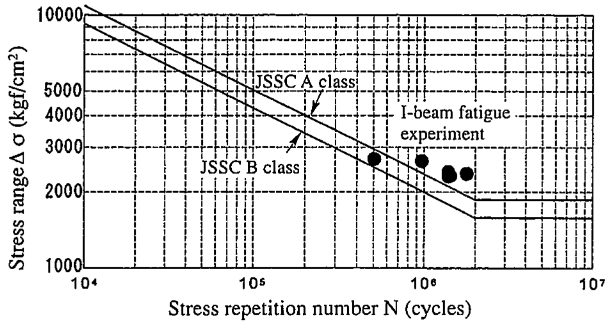


Fig. 17 Single I-200 fatigue test result

A calculation formula for the stress produced in the perforation corner of the I-beam buried in concrete was proposed by Matsui[15]. To evaluate fatigue durability, FEM analysis was performed on GRATING slabs with spans of 6 m and thickness of 26 cm, and the maximum value of bending moment and shearing force applied to the slab sections were calculated. By using these forces applied on the sections, the maximum value of stress produced in the I-beam was evaluated by Matsui's evaluation formula. It was then verified that the value of the produced stress was lower than the allowable stress amplitude (B class of JSSC) and that sufficient fatigue durability was provided.

3.1.5 Conclusion

Large span GRATING slabs were developed for reduced steel girder bridges, various fatigue durability characteristics were investigated and the design method, and it was verified that sufficient fatigue durability can be provided. These large span GRATING slabs fully utilize the characteristics of GRATING slabs such as labor saving, speedy execution and safe execution. The many execution achievements of the past have proved the reliability of the slab structures, and Nippon Steel is convinced that the slabs used for reduced steel girder bridges will further reduce costs and labor saving for bridge construction.

3.2 Steel element pier method

3.2.1 Outline of steel element pier method

A steel element pier method [16] was developed for high bridge leg work in mountain roads (see **Fig. 18**). A steel element is a member manufactured in a factory using a straight-web steel sheet pile with interlocking joints and, when necessary, combining steel materials such as flat steel or shape steel. The steel element pier method was developed to construct bridge piers by connecting such steel elements in cell shapes and adding concrete. The characteristics of the steel element pier method are as follows:

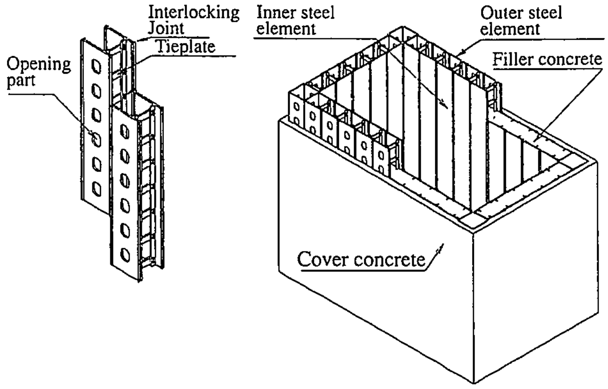


Fig. 18 Steel element pier method

(1) Composite structure of steel and concrete

A steel element bridge pier has a composite structure in which a steel element and concrete function together by a shear connecting function of an opening part. Compared with conventional RC structures, a section of a bridge pier can be made compact and good earthquake-proof performance can be provided.

(2) Labor saving at construction site

A steel element has a structure made by connecting a member manufactured in a factory by a vertical high strength bolt joint direction and a horizontal interlocking joint. Compared with conventional RC structures, labor at the construction site and the period of work can be reduced.

(3) Easy execution of form and scaffold

A steel element itself is highly rigid. Thus, by utilizing this property, installing the form and scaffold can be facilitated. For hollow sections, the inner form can be omitted.

3.2.2 Improvement of aseismic performance

The steel element pier method provides a composite structure composed of a steel element and concrete. But since the steel frame and concrete together resist external forces, the design is carried out in accordance with an RC structure design method. After the Kobe earthquake disaster, bridge pier earthquake-proof design standards were rectified, and the regulation for steel element pier method was set for RC bridge piers. For conventional RC bridge piers, the ultimate concrete strain was set at 0.35%. For concrete with lateral reinforcing bars, the ultimate concrete strain can be improved by the confinement effects, and this will result in greater ductility for a bridge pier structure.

In addition, the steel element pier method provides a structure where the inner and outer steel sheet piles are connected together by tieplates to suppress steel element buckling. Thus, the concrete inside the steel element is confined by the steel element. Confinement effects can improve the ultimate concrete strain. **Fig. 19** shows the result of a short column compression test using a volume ratio of confinement tieplate (ρ_s) as a parameter to evaluation of the concrete confinement effects of a steel element.

It was verified that with the increase of ρ_s, the maximum stress of the concrete increased, reduction in stress after the maximum stress was slow and ultimate concrete strain increased. Further, the result of a cyclic loading test[17] carried out on hollow section bridge

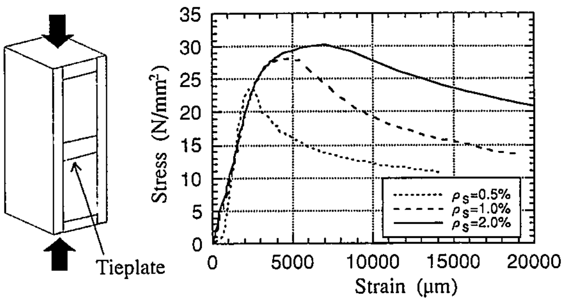


Fig. 19 Concrete confinement effect

piers showed that a steel element bridge pier has a slow deterioration gradient after the maximum load and has better deformation performance than an RC bridge pier (see **Fig. 20**). **Fig. 21** shows the result of calculating an allowable plasticity rate by a ductility design method of a bridge pier having a height (H) of 25 m and 65 m against the earthquake vibration of a type II, which was based on a design method having a tieplate confinement effects introduced. The result showed that with the increase of ρ_s, the allowable plasticity rate increased and it exceeded 4.0 by arranging 2% of a volume ratio of confinement tieplate.

3.2.3 Example

Wamisawa Bridge is a 5 span continuous PC box section rigid-frame bridge with a length of 352.0 m constructed in Shimonita Town of Gunma Prefecture through which Joshinetsu Highway passes. The steel element pier method was employed for four piers with heights of 25.0 to 65.0 m (see **Photo 2**). Cross sections of the piers are rectangular hollow sections of 4.0 × 6.0 m. Only the P4 pier has a lower height and concentration of a horizontal force occurs, and thus it has a rectangular hollow section of 6.0 × 6.0 m. Wall thickness is 1.0 m for all the piers. The steel element pier method was also employed for the Tokai Hokuriku Highway, and it was verified that pier construction labor can be reduced and the work period can be shortened.

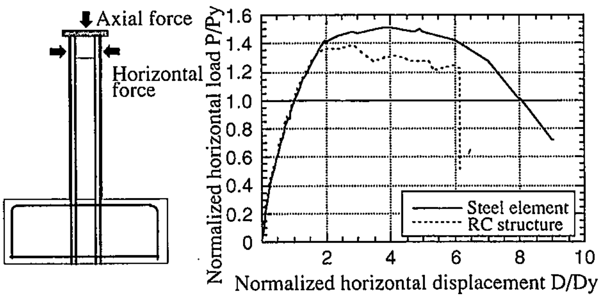


Fig. 20 Pier cyclic loading test

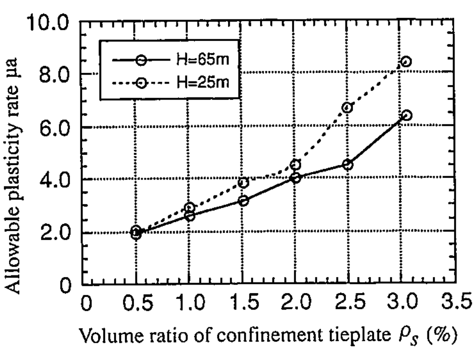


Fig. 21 Allowable plasticity rate

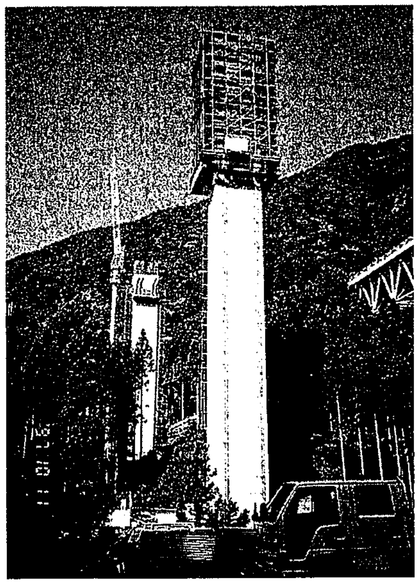


Photo 2 Erection state of Wamisawa Bridge P2, P3 pier

4. Conclusion

This paper presents an outline of research and developments in bridge construction with an emphasis on steel materials and construction materials. The descriptions here were limited by space, and many other new technologies have not been mentioned.

Nippon Steel intends to continue its development of new steel materials and construction materials described in this paper.

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