Structural Applications of Stainless Steels in Architecture and Civil Engineering toward the Realization of the Stock-type Society

1. Introduction

With the aging of Japanese society, greater importance is being attached to the development and maintenance of stock-type social capital of high quality and high durability. Formerly, when the population was steadily increasing and people's lifestyles were rapidly changing, the primary issue of concern in the construction field was to supply, at low cost and in large quantities, "scrap & build" type houses which met the needs of the times. Today, however, the population is gradually shrinking and social housing needs are changing. More specifically, there are growing expectations for houses that are "safer and more reliable" and that last longer with little maintenance; in other words, "stock-type" houses that retain their social asset value for a long time.

In the civil engineering field too, the major emphasis had been on developing social infrastructure (e.g., roads and bridges) in as short a period as possible for the benefit of the public. Now that the basic infrastructure is highly developed, the need for its maintenance, repair or renewal is increasing rapidly. Accordingly, there is strong demand for the development of new social infrastructure that is highly durable and that does not require extensive maintenance or repair. In addition, an increasing number of existing civil engineering structures is being subjected not to simple repairs, but to reinforcement work to help improve their durability and thereby lighten the future maintenance burden and prolong their service life. The current trend toward the development of the stock-type social capital mentioned above will become more conspicuous in the future, since it contributes much not only to the cutting of life cycle cost (LCC), but also to the reduction of environmental load.

In this paper, we describe the present state of stainless steel application to architectural and civil engineering structures, and explain the present status and future technological development prospects to improve the durability of structures through the use of stainless steel.

2. Present State of Stainless Steel Application to Architectural and Civil Engineering Structures

Stainless steel is generally regarded as a metallic material which is "rustproof" but "expensive." In the architecture and civil engineering fields, it is generally treated as a landscape material which is used for interior and exterior structural members that need the "metallic color" of stainless steel in their design. It is secondary members such as water distribution system components and building hardware that effectively utilize the "excellent corrosion resistance"—the most salient characteristic of stainless steel. It cannot be said that stainless steel is generally recognized as a structural steel material. Actually, however, stainless steels have already been used as highly corrosion-resistant steel materials for welded structures in the fields of chemical plants, transportation equipment and energy-related devices, and the application of stainless steels to increase the durability of structures and lighten the burden of maintenance is increasing, though at a modest rate, in the following fields[1].

(1) River structures (dams, weirs, water gates, etc.)

Since river structures are complex, being continually exposed to a corrosive environment (water) and difficult to inspect and maintain, stainless steels have long been used for them (e.g., gates and water conduits that are difficult to repaint and gate operating components and valves whose corrosion resistance can hardly be maintained by painting). Extensive standards for the application of stainless steels to river structures have also been established[2].

(2) Water supply/water distribution facilities

Since water supply and distribution facilities that use stainless steel are easy to maintain and the influence of stainless steel on water quality is minimal, the application of stainless steel to water supply facilities, including aqueducts, has been increasing. Recently, stainless steel is also being applied to distributing reservoirs, elevated water tanks and emergency water tanks[3].

(3) Bridges

Although there are still few stainless steel bridges in Japan, the application of stainless steel to bridges is increasing, especially in Europe. Many of the existing stainless steel bridges are small, such as pedestrian bridges which are required to have some degree of aesthetic appeal. According to a report, the application of stainless steel is also an effective means of reducing the LCC of bridges. Therefore, stainless steel has come to be used for large bridges which are required to have a long life. For Stonecutter Bridge now under construction in Hong Kong (the world's largest composite cable-stayed bridge consisting of steel and concrete), large volumes of stainless steel are used for the outer covering of the upper part of the main tower and as reinforcing bars for the substructure[4].

(4) Port steel structures

Stainless steel is applied to those parts of steel structures in piers, etc., which are exposed to highly corrosive seawater through tide or seawater droplets. Corrosion prevention using the metal lining made of seawater-resisting stainless steel (NSSC270) affords superior durability and maintainability compared to conventional methods of corrosion prevention, such as painting or electric protection. It has been applied to important port structures (e.g., the jacket-type pier in the new runway construction work at Haneda)[5].

(5) Architectural structures

In the architecture field too, standards for structural design have been developed since the 1980s in order to permit using stainless steels for columns and beams, etc., of buildings to take advantage of their aesthetic appeal, as well as their superior properties[6]. In 2000, stainless steels for architectural structures were defined in JIS and reflected in the notification of the revised Building Law of Japan. As a result, it has become possible to use those stainless steels in general architectural structures. Such stainless steels are also applied to atriums, canopies, swimming pool sheds, outdoor staircases, etc., which are also required to look attractive.

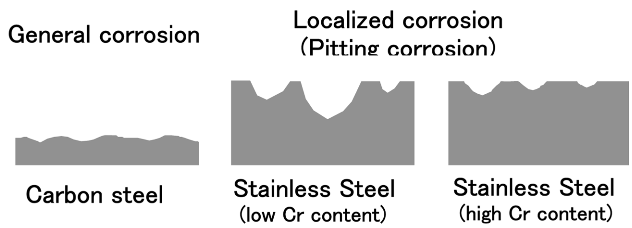
As described above, the application of stainless steels to improve the durability of structures and reduce the maintenance burden is steadily increasing, mainly in the civil engineering field. Although stainless steel costs more in terms of initial work than structural steel subjected to corrosion protection treatment, using stainless steel for those parts which require exceptional corrosion resistance permits enjoying the benefit of LCC in the early stages of its service, rather than depending entirely on conventional corrosion protection techniques. This fact is now better recognized by the market. With the growing awareness of the need for development and maintenance of stock-type social capital, the movement to utilize stainless steel wisely and reduce the LCC of the entire structure is expected to gain momentum in the future.

3. Improved Durability of Structures by Using Stainless Steel

Even in the ordinary natural environment in which architectural and civil engineering structures exist, stainless steel is susceptible to “pitting” in coastal areas where there is a considerable amount of airborne salt. When stainless steel is used as a landscape material with a “metallic color” or when a stainless steel sheet with very little allowance for corrosion is used (for corrosion-protective metal lining of offshore structures, metallic roofs, etc.), a steel grade which hardly rusts in the environment in which it is used is selected and due consideration is given to corrosion protection during the design, construction and maintenance of the structure in which the selected stainless steel is used. Concerning structural stainless steels as well, it is common practice to select and use a steel grade on the assumption that the selected stainless steel does not rust at all or is free from conspicuous rust.

However, with improvements in structural durability as the primary purpose, it is conceivable to permit a certain degree of rust and keep the amount of corrosion within the limit at which the desired performance of the structure can be maintained. For example, a thick stainless steel plate may be considered as a highly durable steel material whose corrosion rate is low, not as a rustproof steel material. To allow for such durability in design, it is necessary to clarify the corrosion behavior under working conditions and accurately grasp the influence of corrosion on the function, or strength, of the stainless steel used as a structural material. With pitting corrosion as shown in **Fig. 1**, the point is how to estimate its influence on the structural strength.

At the initiative of the Stainless Steel Building Association of Japan, a long-time exposure test of structural stainless steels was conducted. Based on the test data, guidelines on durable design were prepared. For the flat parts of structures, the following formula for durable designs based on the exposure test data collected over five



Steels	Coefficient of localized corrosion : K
Type 304	(1.25)
Type 410(L)	1.25
Galvanized steel	1.00
Carbon steel	1.00

Fig. 1 Estimation of the effects on the strength of the various type of steels after atmospheric exposure (differences of corrosion behavior are reflected in term of the coefficient of localized corrosion : K)

Table 1 Classification from environmental factors and recommended steel grades for the structures in civil engineering

Environmental factors			Criterion of grade selection and recommended grades for each division	
Regional division (distance from coastline)	Amount of aerosol chlorides (mdd)	Amount of deposited sea salt (mg/dm^2)	Criteria for preventing from rusting (grade selection of “no rust” steels)	Criteria for keeping structural durability (grade selection of “low corrosion rate” steels)
Severe marine (- 250m)	1.0 -	5 - (on the beach)	Grade A	
		- 5	Grade B - Grade A	Grade D - Grade C
Moderate marine (- 2km)	0.1 - 1.0	- 1.0 (eaves/concentrated)	Grade C - Grade A	
		≒0.1 (roof/cleaned by rainwater)	Grade D - Grade C	
Urban or industrial	0.01 - 0.1	< 0.1	Grade D	Grade E
Rural or mountainous	< 0.01		Grade E - Grade D	

Clssification of steel grades and typical steels for each grades

Grade A (PI≧38)	NSSC270
Grade B (PI≧32)	SUS329J$_4$L, NSSCDX1
Grade C (PI≧25)	SUS316, NSSC190
Grade D (PI≧18)	SUS304, SUS304N2
Grade E (PI≧11)	SUS430, NSSC410W-M

PI(pitting index) = (Cr%) + 3×(Mo%) +16×(N%)

(The selection from this criteria requires more careful attention for the localized corrosion such as crevice corrosion.)

years has been proposed[7].

$$\Delta t = K (R \cdot t^n) \quad (1)$$

(Δ t: effective thickness decrease ratio, K: local corrosion coefficient, R: corrosion rate coefficient, n: corrosion rate index)

In the above expression, the corrosion rate ($R \cdot t^n$) of stainless steel is extremely low, and the local corrosion coefficient to compensate for pitting corrosion is as small as about 1.25 (ordinary steel: 1.00). Therefore, the extent of any decrease in the effective thickness that influences the strength of stainless steel will be very small, too. Thus, the desired structural durability can be maintained even if rusting of the stainless steel due to airborne salt is unavoidable.

When stainless steel is used as a structural material, selecting the optimum steel grade according to the environment and conditions under which it is used is the most important aspect for the structural engineer. The "Subcommittee to Promote Application of Stainless Steel to Civil Engineering Structures" of the Japan Society of Steel Construction tackled the preparation of a manual to select and use stainless steel grades. **Table 1** shows examples of proposals advanced by the above subcommittee. As shown, two cases are considered. In one case, the rusting itself of stainless steel is to be prevented (criterion used in selecting a steel grade which does not rust from the standpoint of appearance or function). In the other case, a certain degree of rusting is allowed but the corrosion rate is to be minimized (criterion used in maintaining structural durability for a long time). For each of the above cases, a rule of thumb for steel grade selection for each of the environmental categories is given. When the latter criterion is adopted, it is possible to select a steel grade which contains small proportions of alloying elements and hence is more economical. By so doing, the scope of application for stainless steels is expected to expand further.

4. Application of Chrome Stainless Steels to Architectural and Civil Engineering Structures

Austenitic stainless steels have excellent corrosion resistance. In addition, even thick, hot-rolled austenitic stainless steel plates afford excellent toughness and weldability. Because of these characteristics, they are widely used as steel materials for welded structures, mainly in industrial machines and plants. In the architecture and civil engineering fields too, there is no doubt that SUS304—the most typical austenitic stainless steel—will continue to be the most likely candidate for the application of stainless steels, in view of the fact that SUS304 has a good balance of properties, is available in various forms, and has already found many applications. Except in severe environments subject to high concentrations of chlorides, SUS304, when properly used, is free from conspicuous rusting for a long time and displays more than sufficient performance as a structural steel material. In contrast, since SUS304 contains a considerable proportion of nickel (a rare metal), it is much more expensive than general structural steels and structural steels which have been subjected to corrosion-protective treatment (e.g., plated steels). Moreover, the price of SUS304 is susceptible to fluctuations in the costs of raw materials. Even though increasing importance is attached to LCC, the above price structure for SUS304 is an impediment to expanding its application under present domestic conditions that are averse to any increase in initial work cost.

In contrast, ferritic stainless steel sheet (cold-rolled sheet), which does not contain nickel, has seen its applications in automobiles and home appliances, etc., rapidly expanded. Formerly, hot-rolled ferritic stainless steel was considered unsuitable as a structural steel material because of its inferior toughness and weldability. Thanks to technological progress in reducing impurities, etc., in steel manufacturing and application/forming technology, such as welding, hot-rolled ferritic stainless steel containing not more than about 11% chromium now has sufficient properties required of structural steels, and hence can be used in many applications. The characteristics and future prospects of YUS®410W-MS—a hot-rolled ferritic stainless steel developed for architectural structure—are briefly explained below[8].

As shown in **Table 2**, the base of YUS 410W-MS is 11% Cr. Carbon and nitrogen impurities are minimized and the microstructures of the product and heat-affected zones are rendered finer. As shown by the stress-strain curve in **Fig. 2**, the deformation characteristic is similar to that of general structural steels. As the specified strength used in structural design, the same value as that of SS400 carbon steel for structural use can be adopted. YUS 410W-MS has almost eliminated the problem of inferior toughness of welded joints and inferior welding workability (resistance to low-temperature cracking), which are typical drawbacks of ferritic stainless steel. Since the steel contains a comparatively small proportion of chromium, it is subject to pitting corrosion in outdoor environments containing fine particles of sea salt. However, in ordinary outdoor environments, the rate of corrosion growth is extremely low as shown in **Fig. 3**, and hence sufficient structural durability can be secured for prolonged

Table 2 Chemical compositions and mechanical properties of structural ferritic stainless steel for architecture YUS410W-MS

Chemical compositions

	C	Si	Mn	P	S	Cr	Ni	N
Specification	≦0.030	≦1.00	≦1.00	≦0.035	≦0.025	10.75-13.50	≦0.60	≦0.025
Typical value	0.019	0.17	0.9	0.022	0.002	11.01	0.41	0.0147

Mechanical properties

	Thickness (mm)	0.2% proof stress (N/mm^2)	Tensile strength (N/mm^2)	Yield ratio (%)	Elongation (%)	Specified design strength (N/mm^2)
Specification	≦5.0	235-390	≧400	≦80	≧21	235
	> 5.0				≧18	
Typical value	2.3	286	476	60	33	
	6	283	458	62	37	
	9	262	455	58	42	

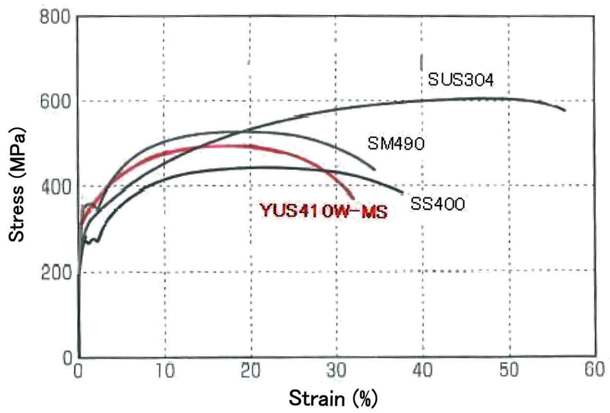


Fig. 2 Stress strain curves of structural stainless steel for architecture YUS410W-MS

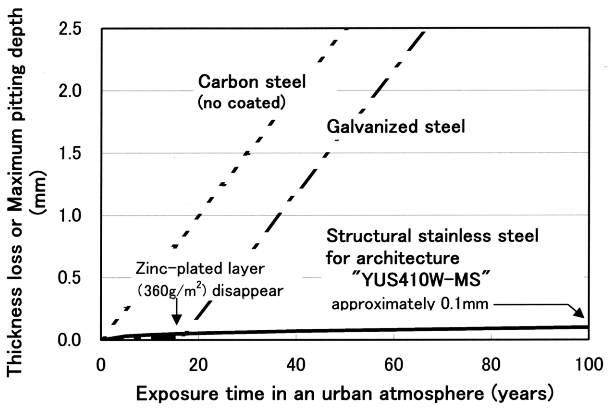


Fig. 3 Comparison of corrosion resistance in an urban atomsphere for various type of structural steels (thickness loss for cabon steel and galvanized steel, maximum pitting depth for stainless steel)

Fig. 4 Application of structural stainless steel for architecture YUS410W-MS (structural frames of the ground floor in a long-life house)

periods. In addition, this steel requires neither consideration for conventional corrosion-protective treatment (e.g., painting or plating) during design/work execution, nor the application of additional corrosion-protective treatment to formed or welded parts.

Fig. 4 shows an example in which YUS 410W-MS was applied as a structural member in a detached house with a steel frame construction. This steel has been approved by the minister as specified under Article 37 of the Building Law, so that it can be used in general buildings. In addition, the steel is a high-durability structural steel which meets the highest level of Class 3 (durability: about 100 years) in the classification of measures against deterioration as defined in the Housing Quality Promotion Act. The steel is expected to find applications in the architecture and civil engineering fields, not only as a material for the body of long-lasting housing, but also as a new type of structural stainless steel that helps reduce the load of corrosion-protective treatment applied during work or maintenance.

5. Improved Durability of RC Structures using Chrome Stainless Steel Reinforcing Bars

There are also calls to improve the durability of reinforced concrete (RC) structures. In highly alkaline concrete, the reinforcing bars of ordinary steel remain passive and do not corrode under ordinary conditions. However, they do corrode if chlorides infuse the concrete from the outside and the concrete alkalinity decreases. This is one of the factors in the deterioration of concrete structures. Corrosion of reinforcing bars not only weakens the steel, it also causes the concrete to crack or fall as the reinforcing bars expand due to the rust. This has become an important problem that can lead to a decline in durability of the entire RC structure. To prevent the corrosion of reinforcing bars, improvements have been made to the concrete and consideration for corrosion prevention has been given in both the design and construction. Nevertheless, there is a movement to replace reinforcing bars with those which have better corrosion resistance. For civil engineering structures installed in especially severe salty environments (e.g., offshore structures, bridges in coastal areas, elevated road bridges in cold regions where salt is used to melt snow), the application of epoxy resin coated reinforcing bars and stainless steel reinforcing bars (in foreign countries) is increasing.

Stainless steel reinforcing bars are more expensive per unit price than ordinary steel reinforcing bars. However, they do not need to be used in the entire RC structure. By using them properly and selectively in those parts that are susceptible to deterioration/damage (e.g., reinforcing bars near the surface of concrete where chlorides more easily penetrate), it is possible to dramatically improve the durability of the entire RC structure. Using stainless steel reinforcing bars selectively makes it possible to minimize any increase in construction cost and increase the LCC benefits. In addition, any improvement in reliability of the entire RC structure enhances its asset value. Thus, stainless steel reinforcing bars are considered economically viable.

In the United States and Europe (the United Kingdom in particular) where stainless steel reinforcing bars have already become widespread, technical guidelines and application manuals which are useful in the design and construction of RC structures have been prepared not only by manufacturers of reinforcing bars, but also through the positive efforts of users. Based on those technical guidelines, etc., stainless steel reinforcing bars have been increasingly used in revetments and coastal bridge substructures, etc., which are susceptible to salt damage due to seawater, road facilities in cold regions where anti-freeze is employed, special structures which need to have exceptionally long life, and so forth. For Stonecutter Bridge, the world's largest cable-stayed bridge now under construction in Hong

Kong, as much as 3,000 tons of stainless steel reinforcing bar were used in the piers of the main tower. From the present conditions of application of stainless steel reinforcing bars in the United States and Europe and from examples of damage to RC structures in Japan, the potential domestic demand for stainless steel reinforcing bars is estimated to be tens of thousands of tons per year. Until recently, however, consumption of stainless steel reinforcing bars has been very small and has remained unnoticed by most users of reinforcing bars in Japan.

To establish a technical environment suitable for the application of stainless steel reinforcing bars, the Japan Stainless Steel Association and Stainless Steel Building Association of Japan have, with the help of government subsidies, promoted joint research activities by universities, public research institutes and general contractors in the architecture and civil engineering fields, as well as the manufacturers of stainless steel reinforcing bars. The results of their activities are shown in **Table 3**. These led to standards for deformed stainless steel bars for reinforced concrete being established (JIS G 4322) in March 2008. In September of the same year, the "Guidelines on Design and Construction of Concrete Structures using Stainless Steel Reinforcing Bars (Draft)" was published by the Japan Society of Civil Engineers. Finally, in Japan too, the basic technical infrastructure for the application of stainless steel reinforcing bars has been established.

In the course of the above activity, the excellent corrosion resistance of stainless steel reinforcing bars was brought to the fore. In addition, the critical chloride concentration in concrete for the occurrence of corrosion and other data (see **Table 4**)[9] that can be reflected in the design and quantification of the benefits of high-durability RC structures were obtained. These are among the most important results of the above activity. In Japan, the application of epoxy resin-coated reinforcing bars as high-durability reinforcing bars has already begun. However, there are a number of problems: the need for recoating after forming/cutting of bars, the limitation on and consideration for work execution at the construction site to protect the coating, and a sense of unease about the reliability of work that comes from the difficulty involved in managing the coating quality during construction work at the site. In contrast, stainless steel reinforcing bars are highly durable and can be handled in the same manner as ordinary steel reinforcing bars. Therefore, as high-durability reinforcing bars, stainless steel reinforcing bars are expected to become more widespread in the future.

At present, three types of stainless steel reinforcing bars are defined in JIS. They are: SUS410 (12%Cr), SUS304 (18%Cr-8%Ni) and SUS316 (17%Cr-8%Ni-2.5%Mo). The relationship between raw material costs and durability for the individual stainless steel reinforcing bars is as shown in **Fig. 5**. The results of a durability test of various stainless steels in concrete show that reinforcing bars made of SUS410 ferritic stainless steel, which does not contain Ni, can be used widely. Therefore, we are promoting the application of NSSD®410 (the product name of SUS410 manufactured by Nippon Steel & Sumikin Stainless Steel Corporation) as a general-purpose, highly durable reinforcing bar. Examples of the application of NSSD410 are shown in **Fig. 6**. We expect that NSSD410 will be

Table 3 Development of application technology and design standard of stainless steel bars for reinforced concrete in Japan

	Civil engineering	Archtecture
Name	Recommendations for design and construction of concrete structures using stainless steel bars -draft-	Development of high durable reinforced concrete structures for architecture using stainless steel bars
Organization	Japan Society of Civil Engineering	Stainless Steel Building Association of Japan
Date	Published at September, 4 in 2008	2005 - 2007 fiscal years
Type of bars	Type 304, 316, 410 (L)	Type 304, 410 (L)
Outline	On the basis of the experimental data of stainless steel rebars, recommendation for design and construction of concrete structures was published.	The fundamental research required for architectural application had been conducted with subsidy of MLIT Japan.

Table 4 Critical chloride concentration of rust appearance in concrete and allowed concrete crack width, which are recommendated in civil engineering

Bars		Critical chloride concentration of rust appearance in concrete (kg/m^3)	Allowed concrete crack width (mm)
Carbon steel bars		1.2	0.005c*1 (general) 0.0035c (severe)
Epoxy coated bars		(2.0-7.6★)	
Stainless steel bars	Type 410	9.0	Less either 0.005c or 0.5
	Type 304	15.0	0.5
	Type 316	24.0	

★Estimated from the research of the damage in actural structures

*1 c: concrete cover thickness

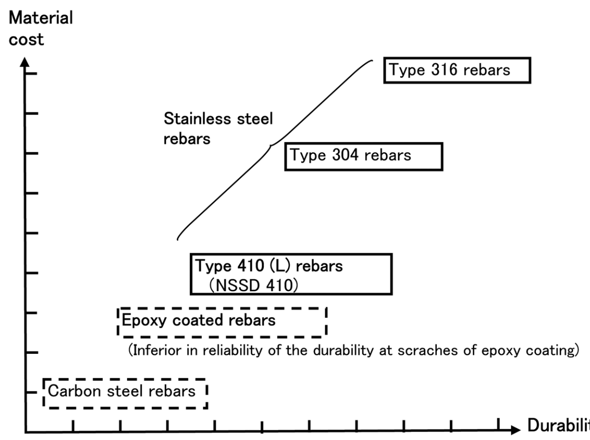
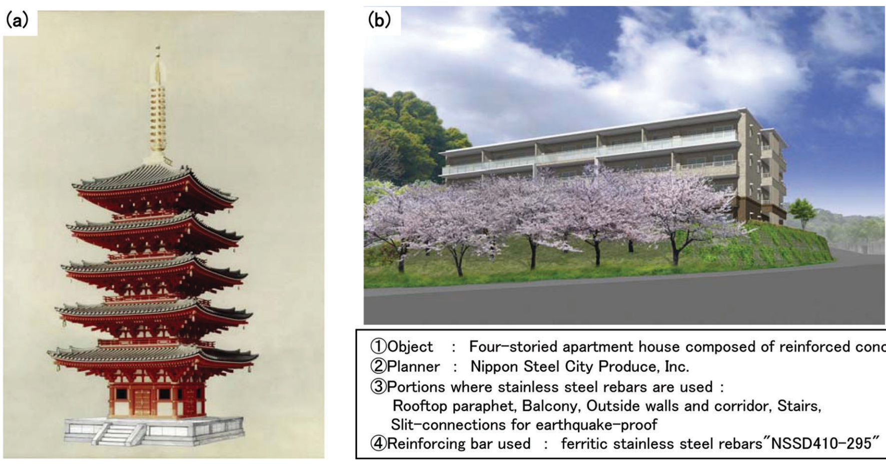


Fig. 5 Concept of the stainless steel reinforcing bars (durability and material cost)

increasingly used in port facilities and bridges in coastal regions, which require high durability in environments in which they are susceptible to salt damage, road facilities in districts where anti-freeze is used, tunnels, and other civil engineering structures.

In the architecture field too, the application of NSSD410 is expected to spread from special structures that require durability for an extra long term, such as temples and shrines (**Fig. 7** (a)), the outer walls and foundations of structures constructed in coastal areas, and so forth. In the extra-long-life model project (so-called 200-year housing) that was launched in FY 2008 on the initiative of the Ministry of Land, Infrastructure and Transport, construction of a high-durability house using NSSD410 is planned (Fig. 7 (b)). When the extra-long-life housing of high-durability RC construction is realized, LCC is expected to decrease by 35% and CO_2 emissions to decrease by 45% in 200 years. To promote the application of NSSD410 to general structures, we have obtained the approval of

Fig. 6 Applications of Ferritic stainless steel reinforcing bars NSSD410



①Object : Four-storied apartment house composed of reinforced concrete
②Planner : Nippon Steel City Produce, Inc.
③Portions where stainless steel rebars are used :
Rooftop paraphet, Balcony, Outside walls and corridor, Stairs, Slit-connections for earthquake-proof
④Reinforcing bar used : ferritic stainless steel rebars"NSSD410-295"

①Object : Five-storied pagoda in Toucyouji temple
②Structural designer and constructor : Matsui Kensetsu K.K.
③Portions where stainless steel rebars are used :
Reinforced concrete of the foundation and piles
④Reinforcing bar used : ferritic stainless steel rebars"NSSD410-295"

Fig. 7 Application in planning of using ferritic stainless steel reinforcing bars NSSD410

the Minister of Land, Infrastructure and Transport for SUS410 reinforcing bar in accordance with Item 2 of Article 37 under the Building Law. (Stainless steel reinforcing bars have already been defined in JIS. However, when they are to be applied to general building structures, the supplier is required to obtain prior approval of the Minister as defined in the aforementioned Law.)

It is conceivable that in the future, stainless steel reinforcing bars will be increasingly applied not only to special structures built in an environment in which they are subject to severe salt damage, but also to general RC structures for the development of stock-type social capital. Stainless steel reinforcing bars are shifting from the stage of trial use to the stage of practical use[10].

6. Future Deployment

Thus far, we have explained the present conditions for the application of stainless steels in the architecture and civil engineering field and the possibility of expanding their application as structural members amid the growing demand for the development of stock-type social capital of high quality and greater durability. We have also introduced activities to promote the structural use of ferritic stainless steel, notably as reinforcing bars. To further expand the application of stainless steels in structures in the future, it is important not only to specifically show for each individual structure what type of stainless steel should be used in what part, in what manner, and what merit can be obtained, but also to standardize the application procedures so as to allow for general design of stainless steel structures.

The corrosion resistance and strength of stainless steel differ widely from one grade to another. In particular, the corrosion resistance of a stainless steel is significantly influenced by the environment and conditions under which the stainless steel is used. Therefore, selecting the optimum grade is very important. When a suitable grade is selected and used properly, it contributes much to improving the durability of the entire structure in which it is applied and to reduce the LCC of the structure. If an unsuitable grade is selected, or an otherwise suitable grade is used improperly, it will not produce the desired results and can incur unexpected problems. All engineers engaged in planning, design, construction and maintenance need to fully recognize the advantageous characteristics of stainless steels and matters to be heeded when applying a specific stainless steel. It will become increasingly important to develop techniques to make the most effective use of the characteristics of stainless steels. We hope that stainless steel application technology in the architecture and civil engineering fields will be further developed to allow for the realization of a stock-type society through close cooperation between materials engineers at stainless steel manufacturers and the structural engineers of stainless steel users in the architecture and civil engineering fields.

References

1) Japanese Society of Steel Construction: Subcommittee for Study of Application of Stainless Steels in Civil Engineering Structures, Technical Data
2) Japan Association of Dam & Weir Equipment Engineering: Manual of Engineering Standards for Dams and Weirs (Draft)
3) Japan Association of Water Supply Steel Pipes: WSP068-2004, Guidelines on Design and Construction of Stainless Steel Pipes for Water Supply. February 2004
4) Yamane, K.: Stainless Steel Architecture. No.37, (2009-2)
5) Japanese Society of Steel Construction: Steel Construction Symposium 2008, Material for Lecture Meeting
6) Stainless Steel Building Association of Japan: Stainless Steel Building Structural Design Standards and Explanations. 2nd Edition
7) Mutoh, I.: Stainless Steel Architecture. No.27, (2005-8)
8) Tendo, M.: Stainless Steel Architecture. No.28, (2006-2)
9) Japan Society of Civil Engineers: Guidelines on Design and Construction of Concrete Structures Using Stainless Steel Reinforcing Bars (Draft). 2008-9-4
10) Tendo, M.: Concrete Techno. 27 (11), 2008

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