

# Eco-friendly Steel Products for Construction Use

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## Abstract

*The construction industry is the largest consumer sector in the Japanese steel market, being responsible for more than 50% of the demand for steel. In relation to increasingly higher environmental performance required for steel products for construction use, this paper outlines Nippon Steel's activities and products that contribute to the construction industry's efforts to reduce environmental loads.*

## 1. Introduction

Steel accounts for roughly 50% of all industrial materials, and nearly as much as 90% of the metal materials consumed in Japan; this is mainly due to its economical price, high strength, good workability, reliability, stable availability in the market and long-accumulated application records. Other advantages of steel include abundance of raw material resources, good recyclability and harmlessness to living organisms because of iron being an element essential for life, and for this reason it is used in a wide variety of fields in direct contact with human body. Despite being used in a wide variety of fields, the area of construction is the largest steel consumer sector in Japan, being responsible for about a half of the domestic steel demands (roughly 30 million metric tons per year). For this reason, it is considered that the steel industry can significantly contribute to the construction industry's efforts to reduce environmental loads by supplying steel products of high functionality. On the other hand, as seen typically with trading of emissions quotas and the RoHS directive, EU countries now place increasing emphasis on environmental protection. The latest trend in the electrical machinery and automotive industries is that the environmental performance of a product is decisive for its market value, and this will soon be the case in the Japanese construction industry.

With this scenario as a background, this paper reports Nippon Steel Corporation's activities related to products for construction use to reduce environmental impact as well as those of the Japan Iron & Steel Federation in which the authors are active as organizers and committee members.

## 2. Approach to Reduction of Environmental Impact Related to Steel Products for Construction Use <sup>1)</sup>

Steel is a production material, and as such, it is related to reduc-

tion of environmental impact in various stages of its life cycle from its production through the fabrication, construction, maintenance, repair and the dismantling of structures to recovery as scrap. Steel products can contribute to reducing environmental impact throughout its natural life cycle in the following two ways.

Firstly, the material properties of steel are directly effective in reducing the impact on the environment. For example, more than 80% of the total impact on our environment throughout the life cycle of an automobile arises from its use. Therefore, the use of high-strength steel reduces car body weight, improves fuel economy and significantly decreases the impact on our natural environment throughout the entire life cycle of the vehicle.

Secondly, measures to alleviate that impact differ depending on whether steel is used as a flow-type or stock-type material. What is essential in flow-type use such as steel cans is how to recycle a great number of pieces with as minimal an impact on the environment as possible, while the important issue in stock-type use, typically such as bridges, high-rise buildings and other social infrastructures, is not to leave a negative heritage to the next generation. Therefore, extending the service life of steel, lowering its maintenance costs while striving to preserve the surrounding natural environment are essential, while alleviating the impact that the production of steel products has on our natural environment. In view of the above, this paper deals with measures to reduce the impact on the environment in consideration of the following facts.

- (1) Construction consumes steel, a recyclable material, in great quantities;
- (2) Steel is often used for structural frames, and thus it is responsible for a significant portion of the overall impact on the environment that structures have;
- (3) Use of steel often assumes a service life of tens, or sometimes as long as hundreds, of years; and

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(4) A steel structure poses a considerable impact on its surrounding environment both during its construction and throughout its use.

**2.1 Recyclability**

The most important advantage of steel in a recycling-oriented society is that a social system for its recovery and reuse has been established. That system effectively alleviates the impact on our environment that steel has as a recyclable material. Fig. 1 shows the recycling loop of iron and steel in Japan<sup>2)</sup>. Annually, about 100 million metric tons of steel is produced domestically, and after being accumulated for use for several weeks to hundreds of years, most of it is recovered for reuse. Judging from past production, quantities imported, exported and the amounts of scrap iron and steel generated in Japan, an estimated volume of iron and steel in Japan is approximately 1.2 billion metric tons.

Recovered iron and steel scrap contains various impurities. It is difficult to remove metal elements such as Cu and Sn from the scrap through refining processes. Therefore, once such impurities make their way into the final steel product, they gradually accumulate in steel scrap through recycling loops. These elements are known as tramp elements. When accumulated in certain quantities, they cause quality problems such as high-temperature cracking of weld joints. The content in steel scrap from origins such as small electric motors and wiring of automobiles and electronic devices is increasing. As a countermeasure, electric arc furnace (EAF) operators define control ranges of these tramp elements for different grades of products. Construction, which consumes roughly 60% of ordinary carbon steel of EAFs produced from steel scrap, is an important sector or use in the cascading system of iron and steel recycling, and it forms urban steel mines, so to speak, accounting for a substantial portion of the accumulation of steel.

The reason that steel is a recyclable material is that it is produced through either the blast furnace and basic oxygen furnace (BF-BOF) route from iron ore or the EAF route from steel scrap in consideration of its final use such as in vehicles or in construction. The two production routes, complementary to each other, form an effective recycling system. For this reason, in order to sustain the capacity for steel to be recycled, it is essential to develop steel refining technolo-

gies to eliminate scrap impurities economically and to control the accumulation of impurities during the entire recycling process. An example in the field of construction is SN steel under the Japanese Industrial Standard (JIS) for building structural use; the contents of alloying elements for SN steel are limited to low ranges while securing suitable material properties. It is important to establish a social system that enables the use of steel materials in any application without having to worry about their adverse effects.

**2.2 Steel weight reduction**

Steel is used for social infrastructures mainly in the form of structural frames. The amount of steel for a structure is determined at the design stage. In the case of a bridge, for example, materials account for about 60% of the CO<sub>2</sub> emission in its life cycle (LCCO<sub>2</sub>), and steel and cement for about 90% of the materials. Thus, in the first place, it is important to study how to reduce their amounts at the design stage. The amount of steel can be reduced by enhancing its material properties such as strength, rigidity and corrosion resistance. For example, use of high-tensile wire-rods for the main cables of a suspension bridge (such as the Akashi Strait Bridge) makes the main towers and their foundations significantly more compact, while the use of high-rigidity steel products such as wide-type sheet piles, diaphragm wall sheet piles, steel sheet pipe piles of higher-strength joints decreases steel weight of a structure, and use of corrosion-resistant steels extends the service life of a structure.

In the second place, when the total amount of steel for a structure is defined, it is important to use in priority those steel materials that have less of an impact on our environment during production in an effort. Since the first oil crisis, the Japanese steel industry decreased unit energy consumption by 20%, and thereafter set voluntary energy saving goals for 2010. As a result, unit energy consumption in Japan has become the lowest among those of the major steel-producing countries (See Fig. 2)<sup>3)</sup>. In addition, as shown in Fig. 3, Japan is the world leader in terms of the number of business units having accreditations for the ISO 14001 family of standards (environmental management). Of 19,584 Japanese business units holding the ISO accreditations, 94 belong to the steel industry, which translates to being nearly all of the domestic steel works.

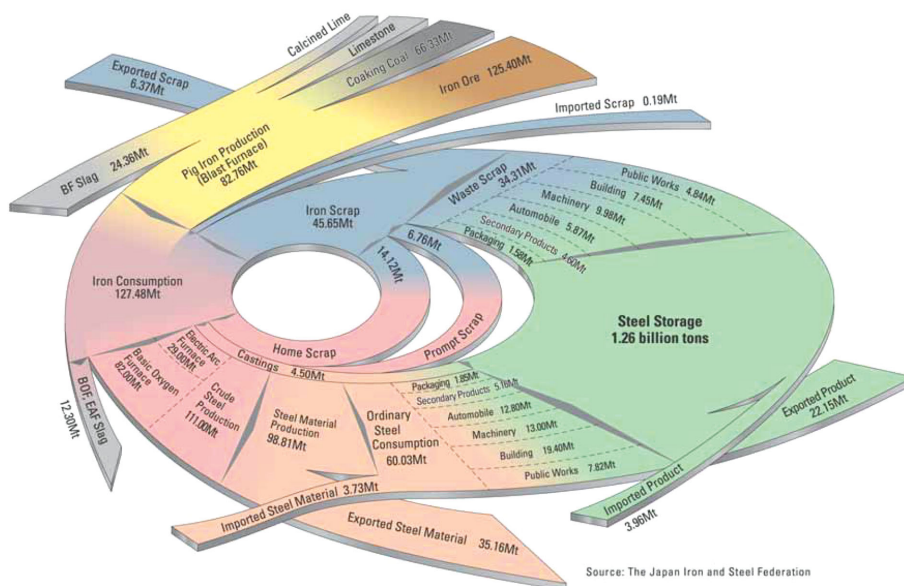


Fig. 1 Iron and steel recycling loop in Japan (Fy 2003)<sup>2)</sup>

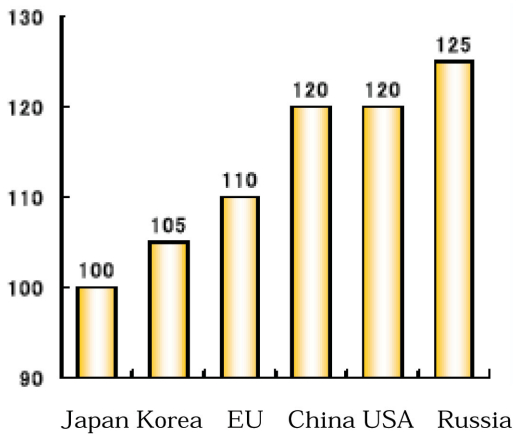


Fig. 2 Comparison of specific energy consumption among major steelmaking nations (indexes with Japan set at 100)<sup>3)</sup>

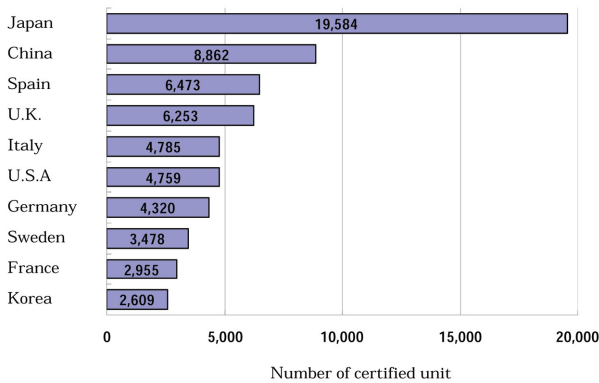


Fig. 3 Number of certified unit of ISO 14001 in major countries

On the other hand, in China, which is at the second position, of nearly 290 large to medium steelmakers existing in March 2003, only 10 steelmakers (Anshan, Dayuan, Hunan, Nanjing, Tangshan, Tianjin, etc.)<sup>4)</sup> were included in the list of the ISO 14001 accreditations. One can presume from these statistical data that Japanese steel materials are produced at the lowest energy consumption in the world under thorough environmental controls. Use of Japanese steel materials in priority, therefore, is considered to have less of an impact on the environment in a global view.

In the third place, in various kinds of social infrastructure construction, some steel materials are left in the soil substantially permanently. These steel materials include things such as anchor rods to prevent caving-in of a tunnel left in the soil even after the tunnel is closed for traffic and steel pipe piles left in the soil for economical reasons after the structure above them is disassembled. The steel left in the soil can be considered as reusable resources (urban mines) for the future as long as they do not adversely affect the surrounding environment. According to an investigation, the rate of social accumulation (amount of social accumulation/amount of input) of steel materials used for domestic civil construction is estimated to be at 40%<sup>5)</sup>. A design method capable of minimizing steel to be left in soil will lead to further material saving. For example, NS Eco Piles®, described below, are driven into the soil by being rotated in a predetermined direction, and thus can be easily recovered from the soil by being rotated in the opposite direction. The product was used for the foundations of the buildings of the Aichi Expo because of its recov-

erability. It should be noted that their application is expanding to include foundations for temporary structures.

**2.3 Durability**

Steel materials for social infrastructures are stock-type goods that can be in service for up to hundreds of years. If the service life of a bridge designed for 100 years of use is extended to 200 years at reasonable expenses for maintenance and repair, the environmental impact caused by its construction divided by the period of use decreases to one half. Replacing ordinary steel with corrosion-resistant steel such as stainless, titanium-coated or weathering steel, for instance, reduces maintenance costs for repainting, renewal of structural members, etc., and is effective in reducing the overall impact on the environment over the entire life cycle of the structure even though the initial investment is increased. Another example of reducing environmental impact caused is steel tunnel segments with watertight joints to suppress water leakage into tunnels and reduce energy consumption for drainage.

In the field of bridge construction, a minimum maintenance bridge easy to maintain and having a service life several times that of conventional ones is being studied. The concept is that factors to shorten bridge service life are identified, and technically and economically viable measures are taken against them to make a bridge substantially permanent. The minimum maintenance bridge makes the most of the material properties of steel in technical fields such as composite floor slabs and effective use of corrosion-resistant steel.

**2.4 Conservation of surroundings**

Social infrastructures are generally extensive, and once constructed, they occupy their sites for long periods of time, and for this reason, it is important to implement environmental conservation measures during their construction and use.

Regarding the construction stage, a comprehensive bid evaluation method was recently adopted for tenders for public projects in Japan, wherein environmental consideration beyond what is legally required is applied as one important point of the evaluation of the bid. In addition, the Construction Waste Recycling Law was enacted in 2000 to reduce the generation of construction waste, which accounts for 20% of industrial waste and 40% of waste finally dumped for landfill. Further, in the same year, the Ministry of Land, Infrastructure and Transport put the Law on Promoting Green Purchasing into effect to promote use of environment-friendly materials for public construction projects. The Law requires the construction industry to solve construction waste problems in an autonomous manner, and defines materials effective in reducing the generation of waste or encouraging recycling of resources as the Eco-Products to be used in priority to others. Nippon Steel had introduced new design of steel pipe piles to reduce earth displacement and generation of construction sludge, and commercialized different types of low-earth-displacement steel pipe piles; three types of them were certified for the Eco Mark (ecological labeling of goods and services controlled by the Japan Environment Association).

At the use stage, in addition to not having any adverse effects on surroundings, it is important for a structure to create a new desirable environment. Landscapes designed to maintain an attractive urban ambience or pleasant countryside atmosphere are actively promoted in Western countries, and that concept is beginning to attract attention in Japan as well. Nippon Steel has commercialized water-permeable steel sheet piles with holes drilled before their being driven into the soil to allow groundwater circulation (see **Photo 1**), and A-type steel slit dams for mudslide control (see **Photo 2**), which catch large boulders and driftwood during floods but allow water and de-



Photo 1 Water-permeable steel sheet pile



Photo 2 Slit dam A type (permeable-type steel dams)

bris to flow through to prevent lowering of river beds and retraction of sea shores, at the same time allowing migration of animals and diffusion of plants in normal conditions. Both products, explained below, have been certified for the Eco Mark.

### 2.5 Section closing

Environment-friendly steel structures for social infrastructure are developed making the most of the material properties of steel as a recyclable material and the characteristics of stock-type use. Inclusion of such viewpoints in the evaluation of environmental loads in the life cycles of the structures will make life cycle evaluation of structures more objective.

## 3. Environmental Labeling

### 3.1 Certification for Eco Mark

Section 2 described how steel products for construction use could aid in reducing their impact on the environment. However, those products can only demonstrate how they can reduce their impact on the environment when such mechanisms and effects are correctly understood by users and the products are used appropriately. Environmental labeling is a means for expressing environmental information to facilitate user select of environment-friendly goods and services. The ISO classifies labeling into three types according to the general nature of the product (ISO 14024). Of the three, whereas Type II is a self-declaration type labeling not requiring certification, Type I requires certification by a third party, and the Eco Mark is the only one Japanese Type I labeling for products that reduce impact on the environment throughout their life cycles. The Japan Environment Association (JEA) is responsible for the certification for the

Eco Mark since 1989 under guidance of the Ministry of Environment, and the number of certified products as of March 31, 2007, was 5,239 of 47 categories.

Nippon Steel applied for (and eventually obtained) certifications for the Eco Mark because, for infrastructure construction projects, in which different entities, either public or private, having different senses of value are involved, the Type I labeling certified through objective evaluation by an authentic third party would be more suitable than the self-declared assertion of Type II.

### 3.2 Certification criteria for Eco Mark of construction materials

In January 2005, the certification criteria for the Eco Mark of civil construction materials were established, which meant that environmental labeling became an effective reference for selecting construction materials. The criteria require a product to satisfy the following environmental performance items besides the original functionality for civil engineering application:

- (1) The supplier of the product has not infringed the environmental regulations effective in the region where its plant is located for the last five years or more;
- (2) Wood, plastics, glass cullets and fiber used for the product satisfy respective material standards; and
- (3) The supplier provides proof of the product satisfying applicable standards provided for each product kind.

### 3.3 Nippon Steel's products certified for Eco Mark

At the time when the certification criteria for the Eco Mark for civil construction materials were instituted, Nippon Steel was the first in the steel industry to apply for and be awarded the certification in March, 2005. In the certification evaluation, the company's attitudes and activities related to environmental and anti-pollution regulations, measures regarding waste generation from steel production processes, input of new resources, energy consumption and CO<sub>2</sub> emission were examined. Based on the evaluation, six products were evaluated as satisfactory with respect to certification criteria on reducing the impact on the environment during the construction and service of the structure for which they would be applied, and they were granted the right to use the mark shown in **Photo 3**. It is expected that in consideration of the preferential use of Eco-Products under the Law on Promoting Green Purchasing for the construction projects of the national Government, the use of Eco Mark materials for Prefectural and municipal construction projects will be encouraged, thereby bringing about positive effects on the sales of certified products and the reputation of their suppliers.

- (1) Steel pipe piles of low soil displacement

Reduction of waste is an important challenge in the field of construction. Among various kinds of construction waste, sludge is difficult to reuse. Measures to decrease generation of sludge are thus eagerly sought after. By common foundation piling methods, the



Photo 3 Eco Mark

volume of sludge generated is equal to or larger than the total volume of piles driven into the soil; a pile driving method that minimizes soil removal will greatly decrease the generation of construction sludge. What is more, the number of cases is recently increasing where civil construction work comes across soil contaminated with hazardous substances, and as a result, a piling method that does not generate excess soil is in great need. In view of this, JEA certifies steel pipe piles that are suitable for low-vibration, low-noise driving method and generate excess soil up to 30% of the piling volume or less as low-soil-displacement steel pipe piles. The following piling products of Nippon Steel have been certified for the Eco Mark: (i) the steel pipe pile for the TN method (Certification No. 04131008); (ii) Gantetsu Pile® (Certification No. 04131009); and (iii) NS Eco Pile® (Certification No. 04131010). (Note, however, that the amount of soil displacement may fluctuate with (i) or (ii) above depending on the soil condition. It is recommended to confirm expected excess earth generation with Nippon Steel in advance.)

Of these, NS Eco Pile® (see **Photo 4**) is a steel pipe-pile product having a spiral fin at an open lower end for driving by rotation. The earth coming into the inside of the pile from an open lower end while being driven is compacted, and a vacant space of a volume equivalent to the soil compaction forms at the top end. For this reason, NS Eco Pile® is not only free from excess soil generation but of negative excess earth generation, capable of accommodating wastes from other origins of the construction site in the vacant space.

Gantetsu Pile® is a composite pile consisting of soil cement (a mixture of excavated soil and cement milk) and a steel pipe pile with protrusions on the outer surface; generation of excess soil is minimized by effectively utilizing excavated soil. (For further details, please see reference literature 6.)

(2) Water-permeable steel sheet pile (Certification No. 04131011)

Driving of sheet piles may sometimes interfere with flow of groundwater. The water-permeable steel sheet pile has holes to allow water to flow through, and its use maintains groundwater flow and local ecological systems without sacrificing the fundamental revetment functions such as resistance to earthquakes and scouring and durability (see Photo 1).

(3) Steel sheet pile segment dam (Certification No. 04131012)

Excess earth, sand and gravel arising from dam construction are used at other construction sites or dumped for landfill as non-reusable waste. A steel sheet pile segment dam is composed of up- and downstream walls made of steel sheet piles tied to each other with tie rods, and the space between the walls is filled with excess earth and sand arising from the construction work. More than 70% of the



Photo 4 NS ECO-Pile® (less soil excavation steel pipe pile)

dam volume can be used for accommodating excess earth and sand. (4) A-type steel slit dam (Certification No. 04131013)

A dam, when constructed to block river flow, may interfere with the move of soil, sand and life. In contrast, if a dam has an intermittent structure, it catches boulders and driftwood in the case of a flood but does not block river flow in normal conditions, allowing the river to flow carrying soil and sand; this suppresses the lowering of the river beds and retraction of sea shores and allows the migration of local wildlife. The A-type steel slit dam makes this possible by arranging A-shaped steel structures across a river (see Photo 2). (This product, together with the Eco Mark, has been transferred from Nippon Steel Corporation to Nippon Steel & Sumikin Metal Products Co., Ltd. as of April 2007.)

### 3.4 Section closing

The instruction manual of the Eco Mark certification criteria states that a social system for recovery and reuse of steel has been established, showing tangible effects to reduce environmental loads, and that steel does not do any harm to living organisms due to specific chemical substances. The Eco Mark of steel products for civil construction use is meaningful in that it appreciates the environmental functions of the products such as reduction of environmental loads, conservation of local surroundings and formation of new environmental conditions due to the functionality of the products and become apparent when they are used for infrastructure construction.

## 4. LCCO<sub>2</sub> Evaluation of Civil Engineering Structures

Life Cycle Assessment Society of Japan (JLCA) advises that, before employing the technique of life cycle assessment, its original purpose and limitations should be well understood<sup>7)</sup>. Emission of CO<sub>2</sub> is only one of many evaluation items of an object's performance in the natural environmental, and various other specific emission indices and recycling evaluation methods are being studied. Thus, it is not easy to evaluate an industrial product's environmental performance based on numerical values; care must be taken especially when comparing a product with another. In consideration of this, to clarify the CO<sub>2</sub> emission of steel structure in comparison with those of other types of structures, the authors conducted, as an internal study of the Committee on Civil Engineering of the Japan Iron & Steel Federation (JISF), a comparative case study using a bridge structure including foundation pilings as a model, applying commonly available data and techniques and taking into consideration the environmental load reducing measures of steel products for construction use described in Section 2. The conditions and results of the study are described in sub-sections below.

### 4.1 Studied structure types and cases

Three bridge superstructure types were studied, two of them being those described in Paragraph 2-6 Bridge Superstructures of the Investigation Report by Working Group for LCA for Civil Construction Industry, Fiscal Year 1996<sup>8)</sup>, prepared by the Committee on Global Environment of the Japan Society of Civil Engineering (JSCE), and the third one being the minimized steel girder bridge. These superstructures were combined with three different types of foundation pilings, namely cast-in-place concrete piles, PHC piles and the screw-in steel pipe piles, making up nine cases in total. The life-cycle CO<sub>2</sub> emission (LCCO<sub>2</sub>) in a service period of 100 years was calculated for the nine cases. **Fig. 4** is a schematic view of the bridge of the study, and **Table 1** shows the combination of the superstructure and foundation types and calculation methods of unit CO<sub>2</sub> emission of steel materials. As seen here, three different methods for cal-

Table 1 Comparison type of trial calculation

Bridge Type 3Cases	Foundation Type 3Cases	Unit CO <sub>2</sub> emission(Steel) 3Cases
Conventional Steel plate girder bridge • L=3@27m=81m • 1 abutment ,3piers • Paint (once per 15years)	Cast in place concrete • Construction sludge • After service life, remnant in grand	JSCE • 2 types unit as BOF and EAF • Recycle credit is calculated
PC pre-tension T-girder bridge • L=2@20m+2@20.5m=81m • 1 abutment ,4piers • No maintenance	SC+PHC pile • Construction sludge • After service life, remnant in grand	LCA Project • 10types unit for steel products • Recycle credit is calculated
Minimized girder bridge • L=3@27m=81m • 1 abutment ,3piers • Weathering Steel (No maintenance)	Screwing-in steel pipe piling • No soil excavation • After service life, steel pipes are drawn	MSR Method • 1type unit • Recycle credit is not calculated

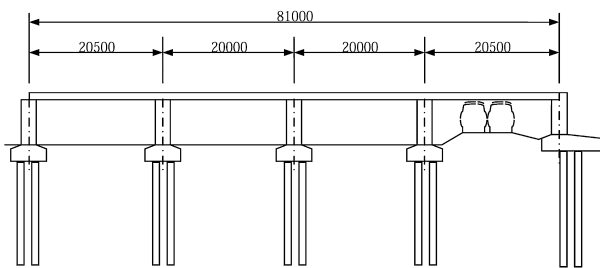


Fig. 4 Outline of sample bridge (PC pre-tension T-girder bridge)

culating unit CO<sub>2</sub> emission described in the following sub-section 4.2 were taken into consideration. Unless otherwise specified, all the numerical data cited hereinafter are those of the Report of the Japan Society of Civil Engineering.

4.2 Unit CO<sub>2</sub> emission of steel materials

(1)Unit CO<sub>2</sub> emission publicized by the LCA project (JLCA)<sup>9)</sup>

The LCA project was organized to compile a common database and establish methods for evaluating materials recycling systems under the auspices of the then Ministry of International Trade & Industry (now the Ministry of Economy, Trade & Industry); it is composed of 22 industrial associations including the JISF. In March 2003, the project publicized a set of unit CO<sub>2</sub> emission figures for various industrial products calculated by the buildup method. This set of figures is one of the most reliable and publicly acknowledged among commonly available ones. Note, however, that those who want to use the data must be individually authorized prior to gaining access to them, and the data require rearrangement according to study object, thus it is recommend to obtain desired data from relevant industrial associations.

(2)Unit CO<sub>2</sub> emission publicized by the Japan Society of Civil Engineering (JSCE)<sup>10)</sup>

There is a closed recycling loop for steel as schematically shown in Fig. 5. The unit CO<sub>2</sub> emission publicized by JSCE presupposes two areas defined by boundary conditions corresponding to two steel production routes in the closed loop: the unit CO<sub>2</sub> emission by the BF-BOF route is calculated at 411 kg-C/t, which is the CO<sub>2</sub> emission within Boundary Condition A, including the CO<sub>2</sub> emitted from the reduction of iron oxide (iron ore), divided by the steel tonnage, and the same of the EAF route at 128 kg-C/t, which is the CO<sub>2</sub> emission

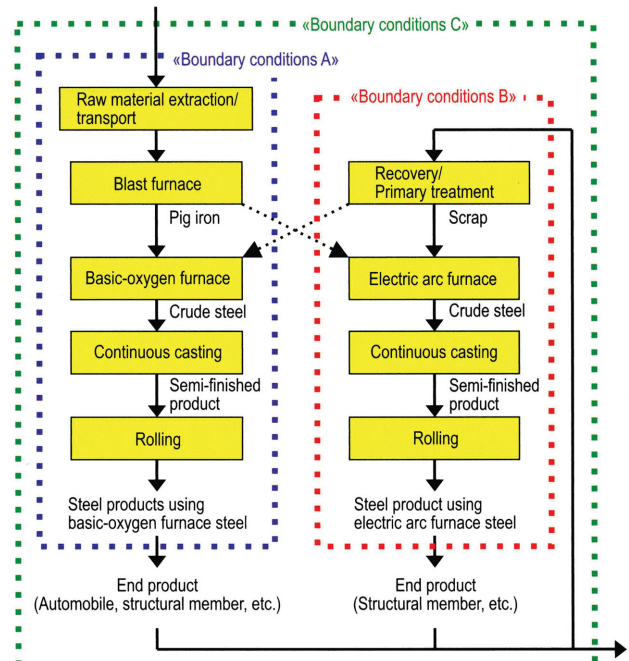


Fig. 5 System flow in the closed loop recycling of steel products

within Boundary Condition B, in which the environmental load of steel scrap is considered to be zero, divided by the steel tonnage.

(3)Unit CO<sub>2</sub> emission in consideration of steel recycling (MSR method)<sup>11)</sup>

While there are still many discussions regarding the definition of the unit CO<sub>2</sub> emission of a recyclable material, it is possible to view the whole recycling loop comprehensively, define a boundary that contains the whole system as Boundary Condition C in Fig. 5, and calculate the unit CO<sub>2</sub> emission as the total CO<sub>2</sub> emitted from the whole system divided by the steel tonnage. Assuming that steel is produced through the BF-BOF route, used, recovered at a recovery rate of  $\alpha$ , and recycled  $n$  times through the EAF route, then the impact on the environment can be expressed as shown in Equation (1) and calculated as shown in Fig. 6.

$$[\text{Unit CO}_2 \text{ emission in whole life cycle}] = (A + B \cdot \alpha^n) / (1 + \alpha^n) \quad (1)$$

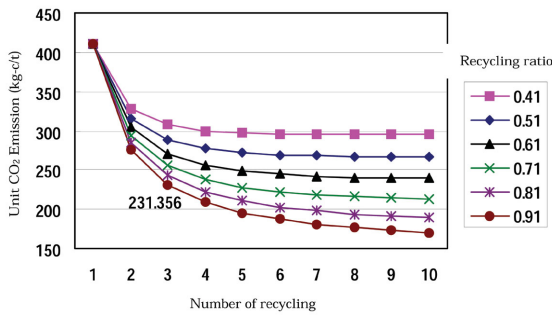


Fig. 6 Assessment example of the unit CO<sub>2</sub> emission calculated by MSR method<sup>11)</sup>

Table 2 Unit CO<sub>2</sub> emission of steel products

Type	Steel products	Unit CO <sub>2</sub> emission (kg-C/t)
Japan Society of Civil Engineers <sup>10)</sup>	BF	411.0
	EAF steel bars and sections	128.0
LCA Project <sup>9)</sup>	Sections	182.2
	Plate	376.4
	Bars	117.5
	Pipe	405.0
	Hot rolled coil	359.7
	Cold rolled coil	390.6
	Hot metal	242.0
MSR Method <sup>11)</sup>	Steel products all	231.4

This calculation method, called the multi-step recycling (MSR) method, is attracting attention lately; the method is based on the understanding that the difference between BF-BOF steel and EAF steel is diluted through many times of recycling, and the life-cycle environmental load of the whole steel material converges to a certain value. For example, letting  $r = 0.91$  and  $n = 3$ , then unit CO<sub>2</sub> emission is 231.4 kg-C/t. This indicates that to reduce environmental loads it is important to increase the recovery rate and the number of cycles of recycling. The values of the unit CO<sub>2</sub> emission used for the study are listed in Table 2.

4.3 Life cycle of steel structure

(1) Life cycle stages and recycle credit<sup>12)</sup>

Here, the life cycle stages of structural materials (steel and cement) are considered, namely production, transportation, construction into a structure, maintenance, repair and demolition of the structure, and finally, recovery and regeneration into recycled materials, final disposal or leaving in the soil. Related to this, when the materials of a structure (A) having completed its service life are regenerated into recycled materials and used for another structure (B), the recycled materials can be considered to have substituted the materials that would have been newly produced for the structure B causing additional CO<sub>2</sub> emission. In this philosophy, it would be appropriate to introduce the concept of recycle credit, that is, the benefit from the saving of CO<sub>2</sub> emission due to material recycling. There are, however, various discussions about how to divide the recycle credit between structures A and B. The authors studied two cases, one where all the recycle credit was attributed to structure A and the other where it was attributed to structure B. With regard to the recycling of con-

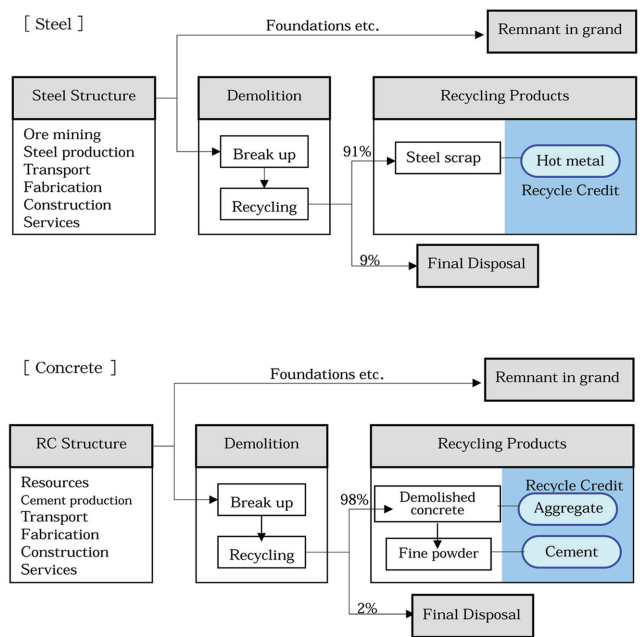


Fig. 7 Life-cycle flow and recycle credit

crete, the most advanced technology to recover high-quality aggregate from waste concrete was taken into consideration. Fig. 7 shows the life-cycle flows of steel and concrete and the recycle credit.

(2) Material transportation, construction, maintenance and repair, demolition and material recovery<sup>13)</sup>

The JSCE report was referred to with respect to materials transportation distances, and also the Journal of Japan Concrete Institute with respect to those of waste concrete. The transportation distances of steel scrap were assumed as follows: 35 km from the demolition site to a scrap processing plant, and 400 km from the scrap plant to an EAF steel works. Here, the environmental impact of the entire round trip by truck was considered. The reports of the JSCE Report were referred to regarding the impact arising from the operation of construction machines, and those of the Japanese Society of Steel Construction (JSSC) regarding the impact arising from pile driving work. Assuming soft-surface ground, the pile length was set at 38 m, the excess soil at the pile driving was supposed to be in the form of sludge and finally disposed of by landfill, except that screw-in steel pipe piles were assumed to generate no excess soil. The environmental loads from the maintenance and repair of the bridge floor slabs and road paving were considered to be the same for all the bridge structures, and therefore, they were excluded from the comparison. Weathering steel was considered not to require maintenance work, and ordinary steel to require repainting of corrosion-resistant paint in every 15 years. The amount of materials to be demolished was the total material input for construction less the amounts of temporary structures and the materials to be left in soil. As for the heavy machines for the demolition work, steel structure was assumed to require the same machines as for the construction, and concrete structure to require heavy breakers and backhoes. Screw-in steel pipe piles were assumed to be recovered, and cast-in-place and PHC piles to be left in soil.

4.4 LCCO<sub>2</sub> calculation results and discussion

Fig. 8 shows the results of calculations using different unit CO<sub>2</sub> emission values, and Fig. 9 the percentage CO<sub>2</sub> emissions of different structural portions to the total CO<sub>2</sub> emission (part a) and those at

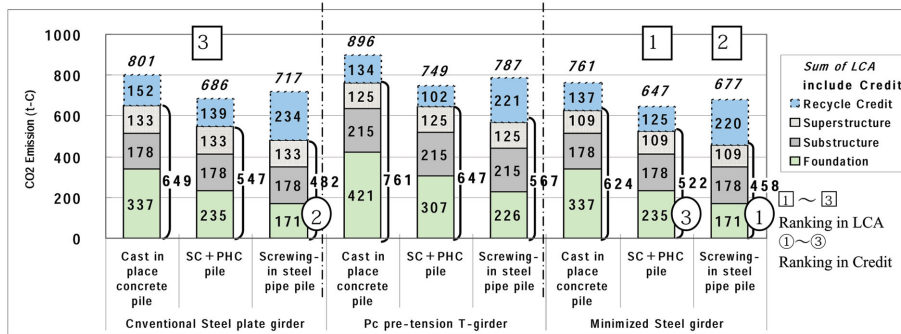
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different life-cycle stages (part b) based on the unit CO<sub>2</sub> emission value of the LCA project. The principal findings of the comparative study were as follows:

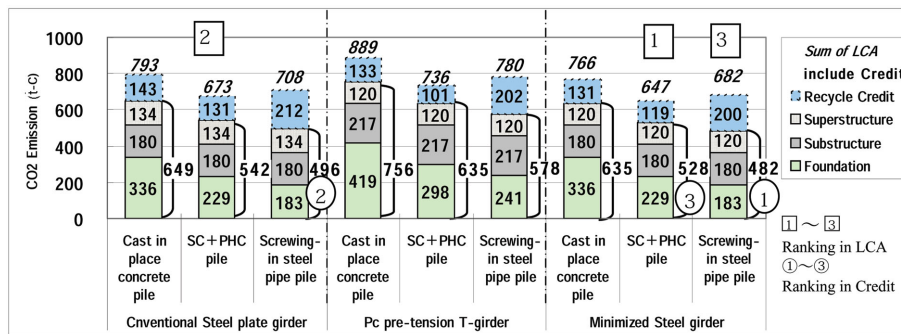
(i) The bridge structure of the least CO<sub>2</sub> emission is that composed of screw-in steel pipe piles and minimized girders; its CO<sub>2</sub> emis-

sion is 60 to 66% of that of the structure of the largest CO<sub>2</sub> emission composed of PC pre-tension concrete T girders and cast-in-place concrete piles.

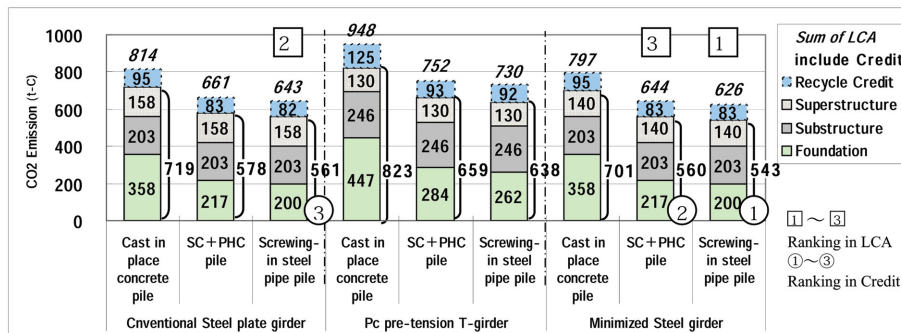
(ii) With respect to different types of super- and substructures, the CO<sub>2</sub> emission increases in the order of minimized girders < steel



(a) Case of the Japanese Society of Civil Engineers

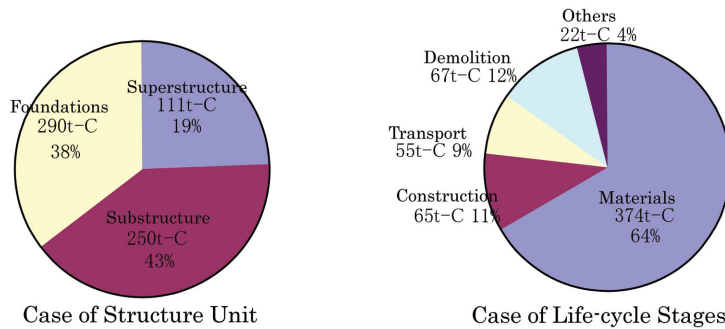


(b) Case of LCA project



(c) Case of MSR method

**Fig. 8 Results of calculation of CO<sub>2</sub> emission**



**Fig. 9 Composition of CO<sub>2</sub> emission (minimized girder bridge+NS ECO-Pile, the case of LCA project)**



plate girders < PC pre-tension concrete T girders. Since the span for the PC pre-tension girders is smaller, more piers are required, leading to larger CO<sub>2</sub> emission for the substructure and foundation.

- (iii) As for the foundation, the CO<sub>2</sub> emission increases in the order of screw-in steel pipe piles < SC + PHC piles < cast-in-place concrete piles. The large CO<sub>2</sub> emission of cast-in-place piles is due to larger material input and excess soil generation.
- (iv) From the viewpoint of structural division, the substructure accounts for 43% of all the CO<sub>2</sub> emission and the foundation for 38%, and the superstructure is responsible only for 19%, less than initially expected. Although many past studies focused only on bridge superstructures, more attention must be paid to the substructure and foundation.
- (v) With regard to life cycle stages, materials account for about 65% of the whole CO<sub>2</sub> emission, and transportation and construction for about 20%; thus about 85% of the total CO<sub>2</sub> emission arises from the stages up to construction completion. Most of the balance, 15%, arises from demolition and recovery.
- (vi) The difference in the calculation results due to the values of unit CO<sub>2</sub> emission used for the study was 11% at the largest (steel plate girders + screw-in steel pipe piles). The CO<sub>2</sub> emission of steel plate girders calculated using the unit emission values of the JSCE was higher than that using the values of the LCA project, but this tendency is reversed with respect to minimized girders; this indicates that the calculation results are not always biased by the unit CO<sub>2</sub> emission values used for the calculation.
- (vii) Taking the recycling credits into consideration, a structure with higher contents of BF-BOF steel and retrievable materials such as the screw-in steel pipe piles is more advantageous environmentally.

**4.5 Section closing**

The LCCO<sub>2</sub> of the super-, substructure and foundation of a bridge was calculated, with and without recycling credit, using different unit CO<sub>2</sub> emission values. Although the calculation results differed depending on the unit emission values used, they did not significantly affect the relative order of the structural types studied in terms of CO<sub>2</sub> emission. As a conclusion, a slender steel structure such as a bridge composed, for example, of minimized girders and screw-in steel pipe piles was found to cause less CO<sub>2</sub> emission in the whole life cycle than a heavier structure such as a bridge of PC pre-tension T girders and cast-in-place concrete piles.

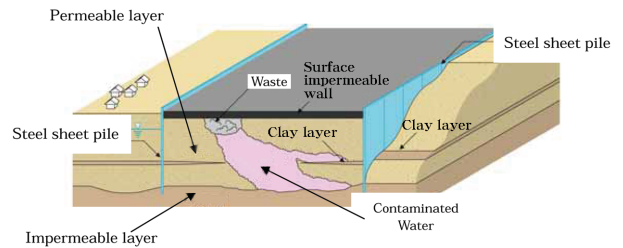
**5. Development of Steel Hydraulic Barriers**

**5.1 New environmental regulations and market trend**

Waste-related problems have become diversified and have caused far-reaching and serious social repercussions. The Japanese Government named the year 2000 the first year of the recycling-oriented era and launched the following new environmental regulations and measures.

- (i) Partial amendments to the ministerial ordinance determining engineering standards pertaining to final disposal site for municipal solid wastes and final disposal site for industrial wastes (June 1998)

Many final waste disposal sites away from coast lines are causes of concern for local residents. Concern often comes on the heels of an incident or suspicion of leakage of seepage water, and thus, it is always difficult to build or expand waste disposal sites. The Amendments envisages application of more stringent standards for the construction and maintenance of waste disposal sites by measures espe-



**Fig. 10 In-situ enclosure**

cially of hydraulic sealing barriers to encourage recovery, service life extension and closure in a controlled state of existing disposal sites.

- (ii) Manual for design, construction and management of revetment for controlled type waste landfill site (November 2000)

In view of increasing difficulty in constructing waste disposal sites on land, new ones are being constructed in seaport areas, where dredged sand and excess soil from construction sites were used for landfill. These sites are equipped with water insulating measures to meet more demanding technical requirements.

- (iii) Soil pollution countermeasures law (February 2003)

In view of increasing cases of soil pollution that are often found on occasions of closure and move of plant facilities, etc., the Law requires appropriate measures against soil pollution that may lead to human health damage.

- (iv) Law concerning special measures for the removal of public nuisance originating from specific industrial wastes (June 2003)

There have been many cases of illegal waste dumping on a large scale; it takes a very long time and a huge amount of money to restore the original conditions of such a site. Left unattended, these dumping sites adversely affect surrounding environments and can lead to significant social and economic damages, but there is almost always a lack of financial capabilities to make restorations. In consideration of that situation, the Japanese Government decided to rectify the problems in a 10-year period up to 2014 with state subsidies.

The above public regulations commonly consider a waste control method called “in-situ enclosure,” whereby polluted water is prevented from seeping out by enclosing the dumped waste with hydraulic barriers made of steel sheet piles or the like (see Fig. 10). In accordance with the public standards and guidelines for controlled-type waste disposal sites, the enclosure must consist of a continuous wall 50 cm or more in thickness, having a hydraulic conductivity of 1 × 10<sup>-6</sup> cm/s or less and reaching a water-impermeable soil layer. The standards and guidelines also require due consideration to local natural conditions and the kind of pollutant. Nippon Steel has developed new products and construction methods for such hydraulic barriers to meet these requirements.

**5.2 Product lineup and characteristics of hydraulic barriers**

A hydraulic barrier made of steel sheet piles requires sealing against water leakage at the joints between piles. In consideration of the water sealing mechanism, the workability and reliability of pile joints, the wall strength and the possibility of incorporating a fail-safe function, and to cope with different conditions of various waste dumping sites, Nippon Steel makes the types of products shown in Table 3 available.

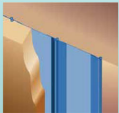
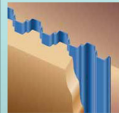
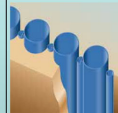
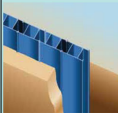
The hydraulic barriers using steel sheet piles, steel sheet pipe piles and NS-BOXes explained below were developed as a result of joint studies with organizations such as the Port and Airport Research Institute<sup>14)</sup> and Japan Association for Steel Pipe Piles, and through

verification tests at a coastal water (Port of Kuré, Hiroshima) for two years from 2003. Through the tests under tough marine conditions, they proved to have excellent workability for easy construction and water-sealing performance clearing legal requirements. As examples of test results, Fig. 11 shows the water-sealing performance of a test well, composed of jointed steel sheet pipe piles fastened to each other with Full-Asphalt Joints®. After one year of construction and even after a 125-mm deformation, the permeability coefficient ( $k_e$ ) of the test well did not decrease significantly, remaining at  $1.0 \times 10^{-8}$  to  $1.0 \times 10^{-7}$  cm/s. These hydraulic barrier products have been commercially applied, and through construction experiences, the know-how for easy water-sealing work and high joint reliability has been accumulated.

(1) Hydraulic barriers of steel sheet piles

At present, U-type, straight web-type and hat-type steel sheet piles

Table 3 Series of steel hydraulic barriers made by Nippon Steel Corp.

Method	Steel liner sheet	Steel sheet pile	Steel sheet pipe pile	NS-BOX
Good point	• Economy • High speed construction	• Popular	• Popular • High rigidity • Seawall	• High rigidity • 2barriers • Seawall
Shape				
Joint Filler	Mortar Asphalt	Water swelling filler	Mortar Asphalt	Asphalt Impermeable filler materials
Installation Depth	30m	30m	60m	35m

are hot rolled commercially. The U-type sheet piles are robust, suitable for repeated use; this type is characterized by the fact that the coupling joints are on the neutral center plane. The joints are of the Larsen type and the effective width (distance between joints) is 400 to 600 mm. The straight web-type sheet piles have a high joint strength and are used for forming the wells of the Steel Sheet Pile Cell method for marine construction, and for walls in combination with steel sections or plates. Hat-type sheet piles having an effective width of as large as 900 mm were developed for application to permanent structures. The coupling joints of all these types of piles have a certain amount of play for the ease of driving, and therefore, their water-sealing performance changes significantly depending on the relative positions of both sides, how the joint inside is clogged with soil and sand, etc.

When it is necessary to secure long-lasting water-sealing performance of pile joints for structures such as hydraulic barriers for a final waste disposal site, the piles are driven after coating the joints with a hygroscopic-swelling water sealant of a durable polyurethane resin and curing it for several hours or more for hardening. This hygroscopic-swelling water sealant is effective in preventing polluted water from seeping to outside the site premises (see Photo 5). Use of such sealant for pile joints became popular from the mid 1980s and the method was applied on a large scale to the projects such as the Offshore Final Waste Disposal Site of Kobe built in 2001.

(2) Hydraulic barriers of jointed steel sheet pipe piles

JIS A 5530 specifies three types of coupling joints for steel sheet pipe piles: an L-T joint is composed of two L sections arranged in parallel and facing each other with a slit in between on one side and a T section on the other; a P-P joint consists of two medium-diameter steel pipes, each having a longitudinal slit so as to interlock with each other and welded to the large-diameter pipe pile proper on each side; and a P-T joint is composed of a medium-diameter steel pipe with a longitudinal slit on one side and a T section on the other. Mortar is often poured into the inside of these joints to make them watertight, but the sealing performance of the so-called mortar jacket method is insufficient especially for application to waste disposal sites. In consideration of this, Nippon Steel developed the following two kinds of water-sealing coupling joints.

(i) Coupling joint with leakage prevention rubber sheet

This structure has been developed to improve the water-sealing performance of P-T joints; a chloroprene rubber sheet is fixed on the flange of the T section, the T section is fitted into the P (joint pipe) by pile driving, and then mortar is poured into the joint. In contrast with grout jackets, the elastic chloroprene rubber is effective in maintaining water-tightness even if the pipe pile joints are deformed by external force. As seen with Photo 6, the sealing rubber sheet is fixed

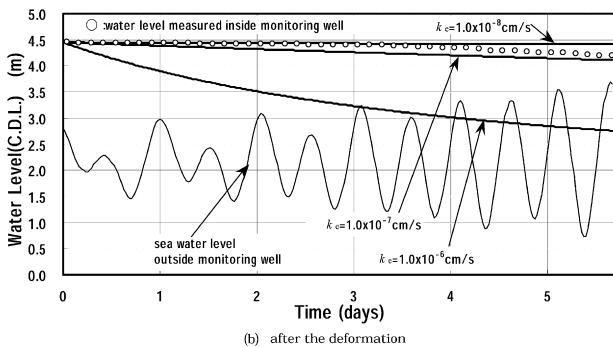
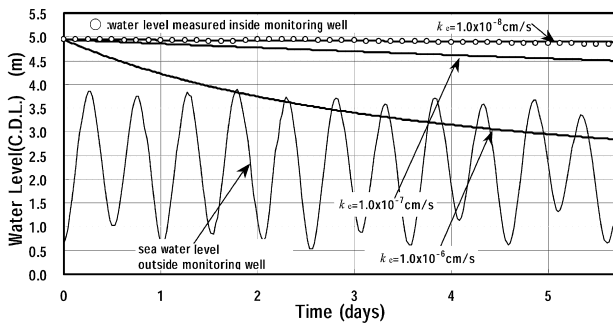


Fig. 11 Cutoff performance of steel sheet pipe pile joint filled with asphalt compound

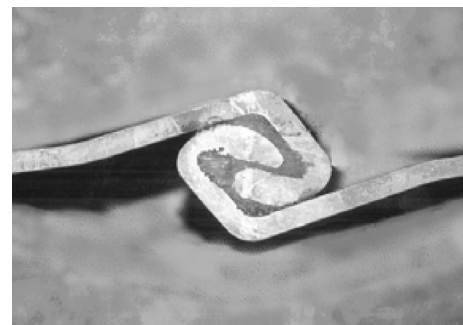


Photo 5 Steel sheet pile joint with water swelling filler material

to the T section with bolts welded to the flange, and to prevent water from passing between the rubber sheet and the steel materials, the boundary surfaces are covered with water-swelling rubber. The Awazu Port Final Waste Disposal Site, Tokushima, Japan, the construction of which began in 2004, has double hydraulic barriers, one made of steel sheet piles and the other of jointed steel sheet pipe piles, and this water-sealing method was used for the latter.

(ii) Full-asphalt Joint<sup>15)</sup>

This method has been developed also for P-T joints; before delivery to the construction site, a special asphalt compound is poured into the inside of the joint pipe at a pile fabrication plant. Jointed steel sheet pipe piles are often driven into large soil depths at marine sites through deep water, but coupling joints must be cleaned of sand and earth after pile driving, which is always troublesome, and it is difficult to secure good work quality. Asphalt is water impermeable, but it is not suitable for pouring into a space as tight as the inside of a coupling joint from above the water after pile driving. The Full-asphalt Joint was developed to solve the problem, wherein the slit joint pipe is filled with a special asphalt compound at a fabrication plant, and at the construction site, the male is driven into the female by vibration driving (see **Photo 7**). This joint has the following advantages:

- a) The special asphalt compound is water-impermeable and maintains its fluidity for a long period. Thus, even if an aperture to allow water to leak forms inside a joint, it is closed automatically to maintain its water-tightness for a long period after construction.
- b) The asphalt material readily softens under vibration or impact and thus piles can be easily driven using a vibration or impact hammer. Besides, it is not necessary to clean and refill the joint portion driven into soil, and high reliability of driving work is secured.
- c) Water-impermeability of joints is secured without sacrificing the original functionality of piles proper, and therefore, the advantages of steel sheet pipe piles can be fully exploited in the design



Photo 6 Steel sheet pipe pile joint with leakage prevention rubber sheet



Photo 7 Steel sheet pipe pile joint filled with asphalt compound

of the structure.

(3)Hydraulic barriers of NS-BOXes

NS-BOXes are box-type, jointed steel piles manufactured by combining straight web-type sheet piles with steel plates or square hollow sections; they are used for hydraulic barrier purposes in the form either of jointed H-section pile (BH type) or jointed box-type pile (BX type) as shown in **Fig. 12**. Both the types have double coupling joints, and for water-tight applications, the cells having the joints have to be filled with an earth material, asphalt compound or some other impervious material. Higher water-sealing performance can be obtained by coating the joints with a hygroscopic-swelling water sealant. **Photo 8** shows a hydraulic barrier of NS-BOXes 1 m in width for an offshore waste disposal site in the Niihama Port, Ehime, constructed in 2005; here jointed cells are filled with an asphalt compound.

(4)Hydraulic barriers of steel liner sheets<sup>16)</sup>

When a hydraulic barrier is used for purposes such as countermeasures against soil pollution, a high resistance to horizontal force is not always required. For such low-strength applications, Nippon Steel have commercialized a method for constructing a thin hydraulic barrier (see **Fig. 13**), whereby a continuous water-tight panel is constructed by driving wide steel sheets 2 m or more in width having coupling joints at both edges into soil together with high-rigidity frames, which will be extracted after the driving to leave the jointed sheets in the soil. This method offers the following advantages.

- a) The risk of water leakage through joints is minimized by use of wide steel sheets (up to a maximum width of 2400 mm, the widest of currently available jointed hydraulic-barrier materials);
- b) The net steel weight is minimized because the frame for driving the sheets are extracted and reused many times, and the sheets left in soil are only 6 mm in thickness;
- c) Reliable water-sealing performance of the joints is obtained be-

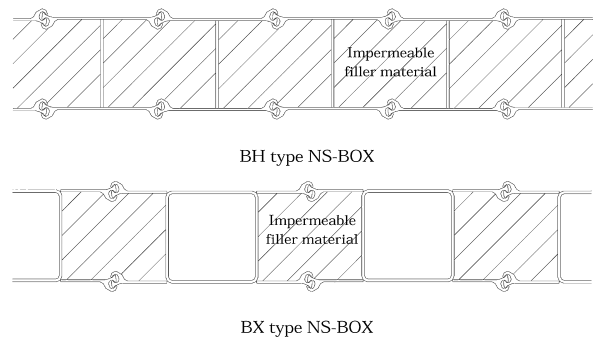


Fig. 12 Steel hydraulic barriers using NS-BOX



Photo 8 Steel hydraulic barriers using NS-BOX

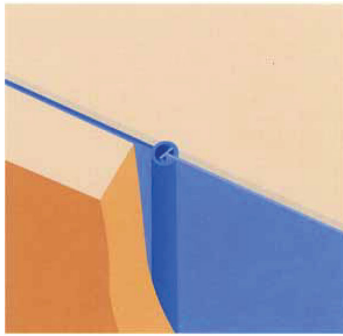


Fig. 13 Steel liner sheet with water cut-off joint



Photo 9 Steel liner sheet with water cut-off joint

cause the insides of P-T joints are filled with a water-impermeable sealant before the driving;

- d) The steel sheet panel can be protected with concrete against water leaching from wastes by filling the space left after extracting the driving frame with cement milk; and
- e) When setting a barrier in a soil cement wall, the sheets can be sunk by their own weight.

This method was first employed in March 2004 to provide an anti-seismic-cracking core for the soil-cement hydraulic barrier of a final waste disposal site in Chiba Prefecture, near Tokyo. Thereafter, it was used for raising the dams of a final disposal site for municipal wastes in the City of Saga, Kyushu, to increase its capacity (see **Photo 9**) in November, 2006 as an enhanced waste control measure to satisfy the structural standards complying with the Amended Technical Standards for Final Waste Disposal Sites. This method was employed for this project for the following technical reasons: (i) the number of P-T joints was small, the sealant could be poured into them before driving the panel sheets, and thus good seismic resistance and watertightness could be obtained; (ii) the small amount of cement and easy construction work were suitable for the construction site near a public waterfront; and (iii) of various types of steel hydraulic barriers, it satisfied relevant legal requirements most economically.

### 5.3 Section closing

The steel hydraulic barriers presented herein above, which are the examples of Nippon Steel products with which the very steel structure directly contributes to environmental conservation, offer a wide variety of alternatives to select in consideration of required performance and local conditions, and as such, have been widely used

for environment-related social infrastructure projects. These types of steel hydraulic barriers will be further improved to meet increasingly stringent requirements.

## 6. Closing

Many people call the 21st Century the age of environment awareness. Aware of the social responsibility to create an amenable global environment for the century, Nippon Steel has defined environmental protection as a core of its corporate philosophy. In view of the latest trend where increasingly higher environmental performance is required for construction materials and work methods, this paper described how steel products for construction use can contribute to efforts to reduce negative impact on our natural environment, and presented several typical examples of such steel products. Since the activities to develop new steel products for civil engineering applications are not confined only to one company but often involve outside organizations, the present paper referred also to the activities in the frameworks of the Japan Iron & Steel Federation, Japanese Society of Steel Construction, Japan Association for Steel Pipe Piles and Port and Airport Research Institute. The authors would like to express their sincere gratitude to the people related to these organizations.

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