UDC 725 . 4 : 669 . 1

Technical Review

History of Steelmaking Infrastructure Technology in Japan and Future Prospects

Shigeo KOBAYASHI*

Abstract

Guided by the philosophy of "building better facilities more economically and rapidly using our own brain power," infrastructure engineers of Japan's steel industry have tackled new technologies to construct infrastructure facilities for steelworks dealing with unique geographic conditions, and thus have contributed to the development of the steel industry and the construction technology of the country. They will continue to build and retrofit state-of-the-art steel manufacturing facilities and play leading roles in their maintenance, exercising the most advanced technology.

1. Introduction

Four million square meters of total road area, 100 km of piers and revetments, 380 km of railways, 13 million square meters of plant buildings and 8.1 billion m^3 of annual water consumption (unless otherwise specified, all units herein are metric): these are the figures describing the infrastructures (civil engineering structures, buildings and water systems) of the steelworks and other manufacturing bases of Nippon Steel & Sumitomo Metal Corporation located in 16 different places across Japan. The main role of the company's civil and building engineers is to construct and maintain all of the above including the foundation structures supporting the production facilities, from which 40 million tons of steel products of the world's highest quality are produced every year.

The history of civil engineering and building construction for Japan's steel industry began with the construction of Kamaishi Iron and Steel Works, then state-owned, which started operation in 1880. Although at the beginning the work was conducted under the technical guidance of specialists from abroad, the engineers of the steelworks began to conduct increasing numbers of land surveys and construction works by themselves in the late 1880s, and then, through the years of the construction of Yawata Iron and Steel Works and the industrial modernization, various technologies still valuable today have been introduced and developed.

Ever since then, through the privatization of the industry and corporate breakups and integrations, the civil engineering and building construction specialists of the company have adhered to the philosophy of "building better facilities more economically and rapidly using our own brain power" and fostered technology periodically as the core of the field.

The technologies for the civil engineering, building construction and water systems for a steelworks include the selection of the works location through land forming and plant construction to their maintenance, and they differ from those for society in general in that the target structures are the foundations and buildings for huge and ultra-heavy steel manufacturing equipment designed to handle large, heavy and high-temperature material in complicated movements accompanied by impacts and vibrations and ancillary facilities related to steel production. Naturally, the facilities in steelworks such as ports, railways, roads, offices and utilities equipment are from the same fields of technology as ordinary types.

This article discusses the civil engineering and building technology unique to steel production facilities as the steelmaking infrastructure technology, outlines its historical development in Japan in the periods of (a) the early days of modern steelmaking, (b) the construction of large integrated steelworks, (c) the rapid economic growth in the 1960s and 70s, (d) the rationalization of the industry and (e) the present day, and attempts to define its future.

2. Steelmaking Infrastructure Technology in the Early Days of Japan's Steel Industry

This section outlines the construction of plant buildings in steelworks focusing on the construction of Kamaishi Works, which began in 1874 as Japan's first ever steelworks to have modern blast furnaces, and that of Yawata Works, which began in 1897. Note here that both the works were state owned when founded, with the former being privatized in 1887 and the latter in 1934.

* General Manager, Head of Div., Doctor of Engineering, Civil Engineering Div., Plant Engineering and Facility Management Center
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511

When the construction of Kamaishi Works[1] started, a German engineer Luis Bianchie was sent to the site accompanying a team of blacksmiths, finishers and casters. Most of the structures built then were made of stone, brick and wood. Traffic facilities that support the materials handling of the works were built at that time: a railway was opened between Kamaishi and Ohashi (mine site) in 1880 as the third railway of the country, and the North Pier of the works built in 1881 (see **Photo 1**).

In the construction of Yawata Works, the first integrated steelworks in Japan, specialists of different technical fields were mobilized from government offices, academic institutes and industries across the country. There are many anecdotes from that period: for the machine foundations for the Thin Sheet Plant in an early construction stage, for instance, Japanese engineers selected concrete structure after intensive studies, but a German superintendent fiercely objected to the idea. They were forced to remove some parts already built and replace them with brick foundations, very much to their chagrin.[2] There were no concrete structures at that time even in western countries; the pursuit of new technology was already evident even in those early days.

Through such experiences, the main material for the foundation changed from bricks to plain concrete, and then, slag bricks, the production of which was commenced on the premises in 1907, were used as an auxiliary material. The use of slag bricks can be viewed as one of the earliest cases of the recycling of byproducts from steel manufacturing.

The use of reinforced concrete began in the 1910s, and it expanded significantly in the late 20s, when reinforcing bars became available at comparatively low prices. Another significant reason for the wider use of reinforced concrete is presumably the increase in heavy structures on soft ground.

Steel frames were used widely for plant buildings in the 1910s, and with the increase in building size, various structural designs were devised in view of the required functions. Then, as structural education became popular, the design and erection technologies for large plant buildings comprising intricately-detailed trusses advanced (see **Photo 2**).[1,2]

The Works was also expanded after it was established. Steel sheet piles, the production of which began in 1930 there, facilitated those expansion works significantly; they were used for temporary earth retaining walls for soil excavation as well as for permanent quay walls and other port structures, and thus, the structural material of port facilities changed from wood to sheet piles (see **Photo 3**).

Due to Kamaishi's location on a deeply indented (ria) coastline, where tsunamis are likely to inflict heavy damage, cases of appalling destruction have been well documented (see **Photo 4**).[1]

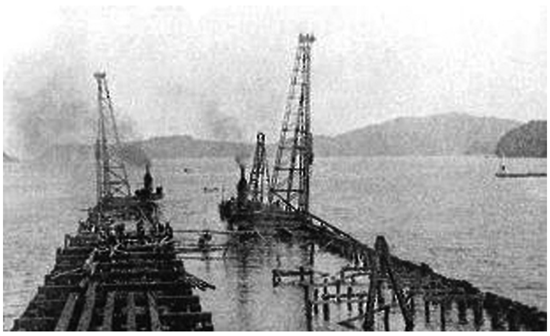

Photo 1 Construction of Kamaishi North Pier

Meanwhile, varieties of road paving technology were developed as an increasing number of automobiles began to be used for the transport of materials. In the beginning, roads inside work premises were paved with crushed slag, but as its shortcomings such as poor car-travelling performance and degradation due to rainwater became apparent, the unique tar paving technique was devised, whereby roads were paved with a mixture of crushed slag and tar by the macadam method.[2]

As stated above, steelmaking infrastructures were built at the start of this period based on the most modern overseas technologies, which were sophisticated through modifications according to the conditions of individual works locations.

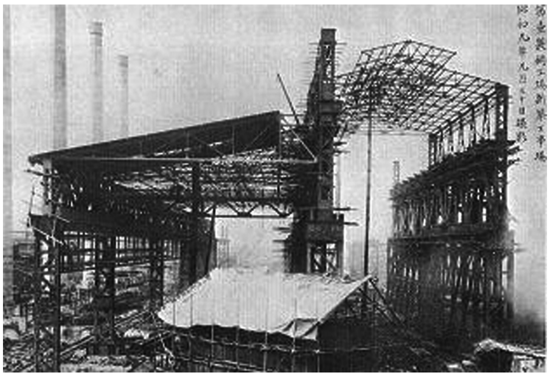

Photo 2 Building construction for Yawata New No. 1 Steelmaking Plant (1934)

Photo 3 Use of steel sheet piles for shore protection (circa 1937 in Kamaishi)

Photo 4 Pier completely destroyed by a tsunami

3. Period of Construction of Large Integrated Steel Works

Large integrated steelworks were constructed in Japan in the second half of the 1950s in parallel with the rapid economic growth of the country; such new works include Tobata (an expansion of Yawata), Wakayama (construction of these two commenced in 1957), Sakai (1959), Tokai (now called Nagoya, 1960), Kimitsu (1961), Kashima (1967) and Oita (1969). These steelworks of Japan were built on soft reclaimed land along the coast. This is characteristic of the country, which is surrounded by the sea and relies on the import of most natural resources; however, this fact has also led to the advances of various infrastructure technologies.

This section focuses on the following: civil engineering technology to enable the building of heavy and tall structures on soft soil; technology to construct port facilities and railways that are the core of the materials handling inside the works; construction technology of plant buildings composed of large steel frames; and water treatment technology, which advanced greatly in response to environmental problems, which aggravated in line with the economic growth. In relation to this, notably the technology of construction works began to form a technical field all of its own at that time, and such works, which had been conducted by the steelmakers themselves, began to be outsourced to outside contractors. As a result, the technologies accumulated through the construction of steelworks were transferred to the outside, and served as a factor for the technical advance of the country's construction industry in general.

3.1 Technology of foundations for blast furnaces [2)]

Here examples of Yawata Works are presented. Since blast furnaces are large and heavy structures, they are built on pilings, and pine piles were used to that end initially.

Then, these were replaced with pedestal piles, or cast-in-place piles of reinforced concrete, that were used up to the late 1930s. When Kukioka (an area of Yawata Works) No. 1 BF was built in 1930, however, there was a thick and tightly packed sand layer in the soil, the pedestal piles were formed down to the sand layer only, and those in the outer two circles of the furnace foundation were formed as composite piles with extensions of pine piles, 20 m in total length each (see **Figs. 1 and 2**); a total of 361 piles driven and cast in this configuration supported the weight of the 9 400 t blast furnace.

As the weights of Kukioka Nos. 3 and 4 BFs were 1.5 times that of No. 1, pedestal piles were insufficient in terms of bearing capacity, and the sunk-well foundation method was adopted, whereby each of the blast furnaces and their bases were supported by four concrete well tubes, 5.5 m in diameter each, sunk into the soil (see **Photo 5**). This foundation method was also used for Tobata (another area of Yawata Works) Nos. 1 and 2 BFs, except Tobata No. 2 BF that was erected on a single sunk well, 20 m in diameter (see **Photo 6**).

Later, for the foundation of Tobata No. 3 BF, H-section piles were used for the first time, due to the ease of pile driving and economy compared with the cast-in-place and the sunk-well methods; a total of 245 H-piles, 300 × 305 × 15/15 mm in size each, were driven. On that occasion, the soft soil of the reclaimed land was improved, for the first time in Japan, by the vibro-floatation method.

Thanks to the introduction of these new civil engineering techniques, the blast furnaces built later during the period of large integrated works had internal volumes of roughly 4 000 m^3, and weighed approximately 10 times those of the initial stage of Yawata Works. The foundations for those large BFs were created mostly using large-diameter steel pipe piles, with which the diameter can be increased easily and directionality is not an issue. At that time, to improve soft ground shortly after reclamation to the desired bearing strength for the construction of raw material yards, railways and other auxiliary facilities, the sand drain method, the sand compaction pile method and similar were employed extensively. The knowledge and findings accumulated through the above were effectively applied later to the land development of coastal regions in

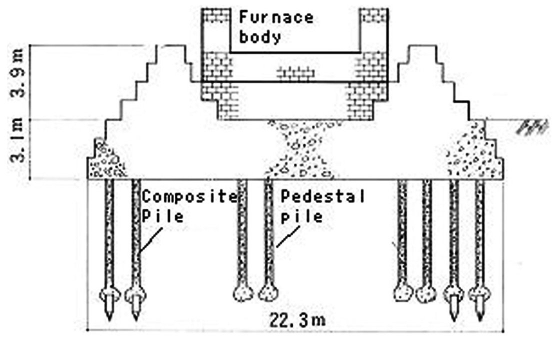

Fig. 1 Sectional view of foundation for Kukioka No. 1 Blast Furnace, Yawata

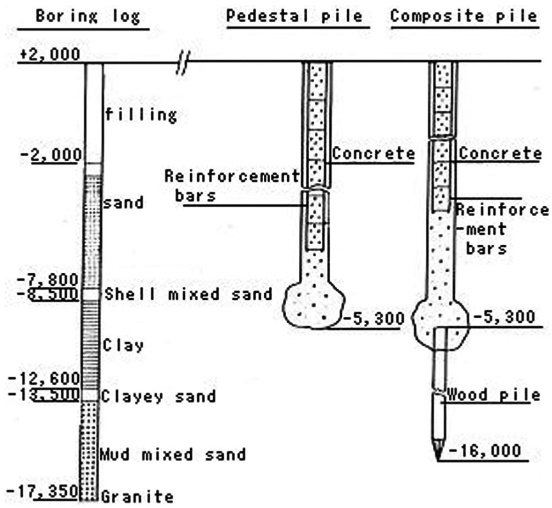

Fig. 2 Foundation piles for Kukioka No. 1 Blast Furnace

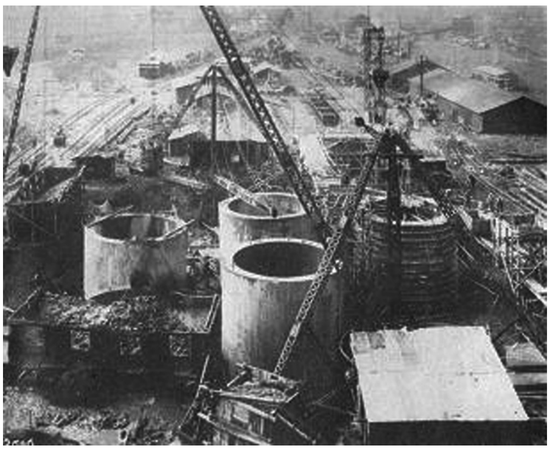

Photo 5 Sunk-well foundation for blast furnace in Kukioka

various parts of the country.

3.2 Port construction technology

The steel sheet piles in the early days had U-shape sections, then from the 1960s, Z-section sheet piles, which have better sectional properties, were used. Cell-type revetments were built for the land reclamation for some steelworks (see **Photo 7** [3)]). Later, shore bridges composed of steel pipe piles and H-section steels, and dolphin-type berths or those with slanted bracing piles were built at many steelworks. Since raw material docks had to have a bottom depth of 10 to 20 m to accommodate huge bulk carriers for ore and coal, various structures were built according to individual local conditions.

The berthing pier of Oita Works (see **Photo 8**), capable of handling 300 000 DWT vessels, stands on the deepest sea floor for berthing facilities in Japan. A sea berth of this size for unloading iron ore and coal from bulk carriers was unprecedented in the country at the time of construction, and tests on reduced models, 3-dimensional structural analysis, loading tests, etc. were conducted to clarify and solve design problems, including the seismic response of a top-heavy pier structure of steel pipe piles, an optimum pile arrangement, repetitive stress imposed by waves and the consequent fatigue of the members. [4)]

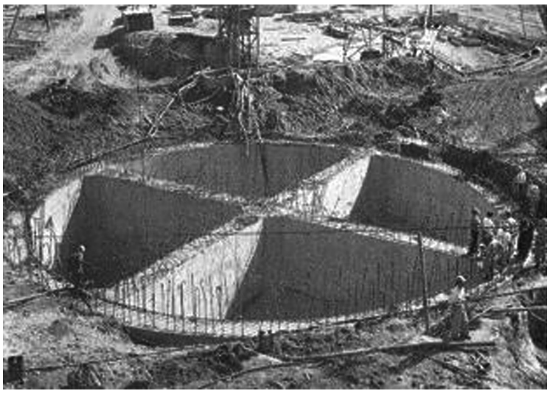

Photo 6 Sunk-well foundation for Tobata No. 2 Blast Furnace, Yawata

Photo 7 Dredging work of Kimitsu Works (colgate cells can be seen in the front, 1967) [3)]

Photo 8 Berthing facility in Oita Works

The steel materials for construction applications used for the steelworks construction projects were evaluated internally in terms of the ease of use, and their basic data accumulated, which later served as effective points of reference for the construction of infrastructure for society in general, greatly contributing to the development of port construction technology.

3.3 Railway construction and maintenance

In the beginning, the technology of railway track structure and its maintenance were introduced from the then Japanese National Railways (hereinafter called JNR, which has been divided into regional railway companies, JRs), and no technologies unique to the railways inside steelworks were newly formed. Regarding track maintenance work, for example, key workers were trained by JNR specialists on basic track maintenance practice, adjustment of turnout points by the string method, etc., and back in the works, they acted as the leaders of track maintenance teams. [2)]

As for the train loads in Yawata Works, whereas the axle load of conventional lines of JNR was 18 t and that of Shinkansen (high-speed rail) 19 t, that of the railways inside works at that time was approximately three times larger. When carriages with such a heavy axle load run along tight curves at low speeds, the track undergoes conditions totally different from those of light carriages running at high speeds, and the railway track maintenance work inside steelworks faces conditions unique to the steel industry.

In fact, the deteriorated conditions of the railway tracks inside steelworks became evident in the mid 1950s, and also because of the newly installed tracks to cope with the rapid production increase, problems in track structure and maintenance increased such as inadequate line layout, poor drainage of track beds and increased axle loads. In view of the special conditions of the tracks, the characteristics of track structure and maintenance problems were listed, and based on these, the company newly established the standards for the structure and maintenance of its own railway tracks.

Meanwhile, Kashima, Kimitsu, Nagoya and Oita Works began to use 60-kg/m rails in the 1960s, even before the operation of Shinkansen, for which they were designed. [5)] In parallel, the methods for improving soft soil by earth replacement, definition of track bed thickness, that of the minimum sleeper intervals for maintenance work, improvement of the two-block-tie sleepers, and steel sleepers with center insulation have been successively developed. Through these experiences, the construction and maintenance technology of ultra-heavy-load tracks has been established (see **Photo 9**). [4, 6)]

3.4 Steel structures for plant buildings

New structural designs and steel materials were introduced for application to steelworks plant buildings in the late 1950s, and as a result, structures were made lighter and design freedom increased to allow diversified building shapes. Such advance in structural design together with rationalized and mechanized fabrication and erection of steel frames brought about shorter construction periods at lower costs.

Photo 9 Torpedo ladle car and heavy loading rail track

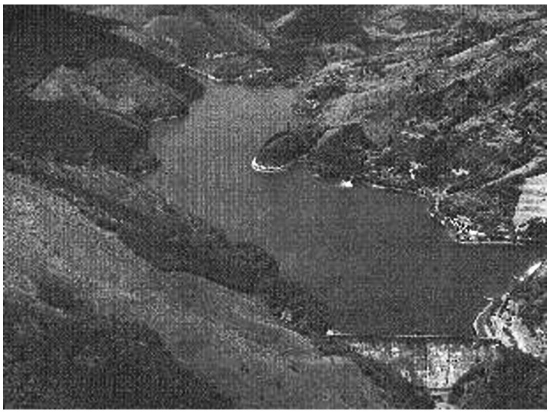

Photo 10 Kawachi-Reservoir (completed in 1927)

The above was due mainly to (1) the introduction and development of welded structure, (2) the development and wide application of high-strength steels for welding use, H-section steels, high-tension bolts, etc., (3) the development and actual use of continuously formed and color-coated steel sheets, and (4) practical application of structural analysis methods thanks to large computers.

With respect to crane girders, for example, (1) welded structure has enabled the reduction of the number of components to less than one half that of conventional riveted structure, and as a result, less labor was required for fabrication, and partial loss of area was eliminated. In addition, since welding allows freer and more economical sectional design, steel weight has been reduced by approximately 15%. During the period of the trial application of welding, welded parts were used for plant buildings for trial purposes, and a large amount of data was collected through stress measurement, vibration tests, etc. [2)]

3.5 Water treatment

An integrated steelworks consumes as much as 180 m^3 of water per ton of steel produced (currently, more than 90% of it is recycled), which means that, in selecting the location for a new steelworks, the abundance of water is more important than a large land area and the access to marine transport. In fact, the pump station of Ongagawa Reservoir and the dam for Kawachi Reservoir (see **Photo 10**) were constructed at the time of the construction of Yawata Works exactly for this reason, and both are still in operation. The former was registered as a world heritage site in 2015, and the latter as a civil engineering monument by the Japan Society of Civil Engineers.

Up to some decades ago, water resource development and utilization of seawater and return water to save the consumption of freshwater constituted important tasks of the water-system engineers of steelworks. As the industrialization of Japan advanced rapidly, environmental issues including problems due to waste water became strongly recognized all over the country, and various corrective measures were developed and put into practice.

Even before the Water Pollution Prevention Law and other environmental regulations were enacted, Nippon Steel & Sumitomo Metal took measures to adequately treat waste liquids; acid treatment facilities were improved (see **Photo 11**), oil and fat treatment units expanded, and ammonia liquor treatment plants installed. At that time, the company firmly established waste liquid control frameworks through close cooperation between relevant organizational units. Consequently, the water quality of the sea areas near the works of the company was improved to meet the environmental standard by the mid 1970s.

Photo 11 Weak acid treatment plant

In addition to the above water treatment technologies, noteworthy advances then achieved in the technology related to water include the use of ductile cast iron pipes, wider use of steel pipes, improvement in pipe joints and acid-resistant lining from the material aspect, and the introduction of the pipeline branching method without flow interruption and underground pipe laying by the jacking method from the construction work aspect. [2)]

4. Periods from Rapid Economic Growth to Industrial Maturation

4.1 Commercial application of technologies born and fostered in steelworks

During the construction period of large integrated steel works, Yawata Iron & Steel Co., Ltd. and Fuji Iron & Steel Co., Ltd., which were separate companies after 1950, merged in 1970 to form the Nippon Steel Corporation. By that time, Japan had achieved the world's highest technical level in steelworks construction, and based on these experiences, new businesses arose such as technical assistance to overseas steelmakers and the engineering businesses based on steel structure technology.

In the field of the former, cooperation and assistance have been well documented; many infrastructure specialists of the company assisted Koreans at POSCO and Brazilians at Usiminas, and a popular novel was written based on the cooperation for the construction of the steelworks of Baoshan Iron & Steel near Shanghai, China, which was later broadcast as a TV drama series.

On the other hand, in the latter, which is a field of business com-

Photo 12 Cable installation for Akashi-Kaikyo Bridge

bining steel materials supply, working and application, the civil engineering and building specialists of Japanese steelmakers were given opportunities to more directly contribute to society through activities such as manufacturing and laying pipe lines, building long bridges, assembling and installing oil drilling jackets, and fabricating and erecting steel frames for commercial buildings and system buildings. The Kawasaki Man-made Island of the Cross-Tokyo Bay Motorway and the cable laying for the Akashi-Kaikyo (strait) Bridge (see **Photo 12**), undertaken by the company, are typical examples of the country's infrastructures.

The Engineering Business Divisions Group was formed in 1972, and the Technical Cooperation Division, Civil Engineering & Marine Construction Division, Steel Structures and Building Construction Division and Plant & Machinery Division were organized under the Group in 1974. These divisions underwent various organizational changes, and at present, they are the Nippon Steel & Sumikin Engineering Co., Ltd., a member of the Nippon Steel & Sumitomo Metal group.

4.2 Development of steel products for construction use and their application technologies

After the construction period of integrated steelworks, the steel industry of Japan entered a period of maturation, and the capital investment began to focus rather on cost reduction, energy saving and replacement of aged facilities with new versions of advanced technology. Consequently, the organizations responsible for the works infrastructure were required to have technologies to enable the construction of increasingly larger and more complicated plant facilities to their designed functions at reduced costs and in a shorter time. Varieties of new steel products for construction use were developed in the course of problem solving, and actually used first inside the works premises.

For example, commercially practicable composite structures such as concrete-filled steel-pipe structures and continuous underground walls of steel were developed to rationalize the construction of top-heavy frameworks and deep underground spaces. In the process of their development, the construction sites inside steelworks were regarded as the fields of trial and error in the pursuit of more rational designs and work practices, where product development engineers and plant construction engineers worked together in the same development team.

The user requirements for steel products became increasingly varied during this period; better corrosion resistance, durability, sound insulation, vibration suppression and fire resistance were required for steel products. In parallel, plastics and ceramics began to be increasingly used as construction materials. In view of the diversification of construction materials, new value-added products were developed and their performance tested at the construction sites inside steelworks; such new products include heavy-coating steel pipe piles and sheet piles, pipe piles resistant to negative friction, epoxy-resin-coated reinforcing bars and other composite materials.

These high-functionality steel products developed through construction projects inside the works premises are now widely used as essential materials for the construction of social infrastructures.

4.3 Effective use of by-products from steel-production processes

Steel production produces large quantities of slag: 300 kg of blast furnace slag and 100 kg of steelmaking slag, approximately, per ton of steel.

The history of slag utilization can be traced far back: Japanese steelmakers began the studies on slag utilization around 1910, and slag bricks and slag cement were produced and used for constructing steelworks. Various new slag utilization methods were also devised during and after the period of rapid economic growth.

Slag is regarded as waste: slag elution water exhibits high pH values, and some slag is expansive. Despite these drawbacks, it is a good earthwork material with a high shearing resistance angle, and has latent hydraulic setting properties. Thus, it can be used effectively for many types of earthworks. In consideration of these advantages, civil engineering specialists of steelworks studied the quality of slag and the methods of its utilization, and thanks to these efforts, slag cement was included in the JIS system in 1950. Furthermore, various standards of BF slag and steelmaking slag were approved as the material for road beds and concrete aggregate [7–9], and also used for soil improvement such as the packing material for sand compaction.

5. Period of Rationalization and Business Diversification of Steel Industry

5.1 Civil engineering and building technologies during rationalization of business structure

The annual steel production of Japan hit a record 120 million tons in 1974, and then the industry entered a period of rationalization to improve the business structure, wherein sophisticated scrap-and-build practice was required for quick and efficient replacement of aged production facilities with the most advanced versions. One of the new practices introduced during the period is implosion, or structure dismantling with explosives.

Demolition by blasting had been widely practiced overseas, but in Japan, where structures are resiliently designed to withstand earthquakes, it was not considered effective. Another obstacle was the negative reaction of the general public to the vibration and noise. For this reason, the method was rarely practiced in Japan.

In the late 1980s, when many obsolete production facilities were removed, comprehensive studies were conducted on the blasting and collapse design and environmental measures regarding the implosion of several structures of reinforced concrete and steel frames inside the works premises, and implosion was actually applied to some of them. This served at least to elevate the method, which had been an empirical practice, to the level of engineering.

For the implosion of steelworks facilities, the mode of collapse, the blast design and notch cutting to realize an intended collapse mode were studied, and viable and rational implosion plans were proposed. **Figure 3** shows some examples of collapse modes, and **Fig. 4** illustrates an explosive (linear-shaped charge) set inside a structural member.[10] Based on such studies, implosion, which had rarely been applied in Japan owing to difficulties in complicated preparatory work and environmental problems, became successfully employed for dismantling various steelworks facilities (see **Photo 13**).[11]

Meanwhile, laborsaving measures were eagerly pursued to build new production facilities efficiently at low costs. A typical example is the original sat-in pile foundation method of the company, whereby a foundation pile is provided for each building column; it is widely used for the foundations of structural frames as a method not requiring reinforced concrete between the superstructure and piles (see **Fig. 5**).

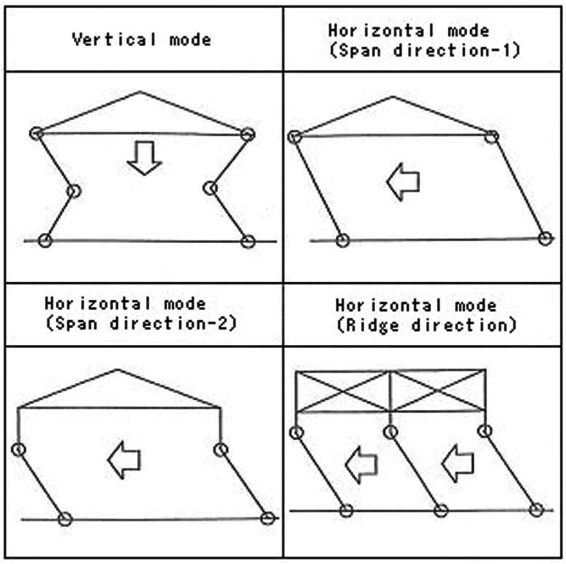

Fig. 3 Various collapse modes

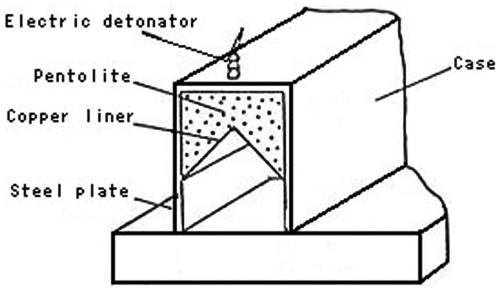

Fig. 4 Schematic illustration of linear-shaped charge

Photo 13 Reinforced concrete structure after blasting demolition

5.2 Infrastructure technologies for business diversification

During the high-yen recession in 1987, the then Nippon Steel Corporation set out a medium- to long-term vision for business diversification, and started various new ventures. One such venture was electronics; the company built a super-clean room for the R&D activities in this field.

The most important key to success in this field at that time was the rapidity in product development, and every player in the field was trying to beat the competition by being the first to come out with a new product. In such a situation, every one of them maintained the strict confidentiality of the technology of the super-clean room, so in terms of development, they were on their own. Ultra-clean air control and ultrafine vibration control constituted the cores of the technology, and the company aimed at developing them by itself.[12]

Ultra-clean air control is performed to create an area of very clean air with class 1 cleanliness under Fed. Std. 209D, USA; it comprises a filter system to shut out dust, air flow control to purge dust and adhesion prevention to avoid dust accumulation. The technology of air current analysis formed an important part in the comprehensive study of the three. **Figure 6** shows an example of the air current analysis results of a clean room.

Ultrafine vibration control, on the other hand, is the technology to evaluate the effects of vibrations from inside and outside a building such as those due to traffic, and take adequate insulation measures at the vibration source or transmission routes to meet the strict vibration limits required for machine base surfaces. Here, the calculation used MFLUSH, a dynamic analysis program for FEM of

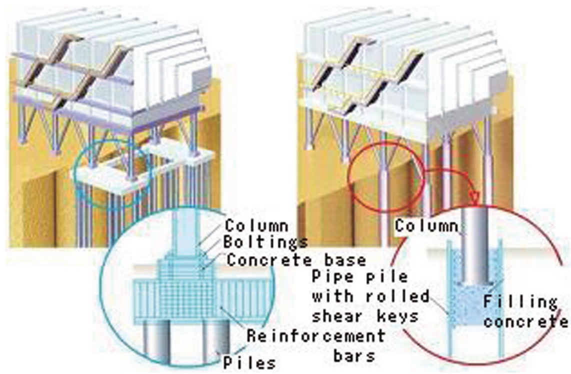

Fig. 5 Sat-in pile foundation

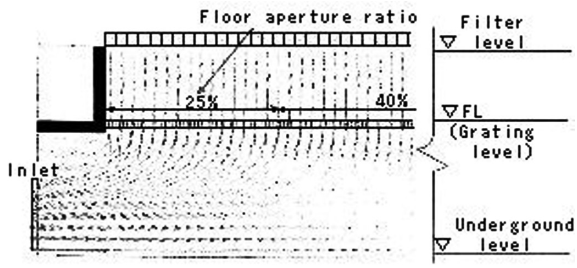

Fig. 6 Example of air current analysis for the bay-area

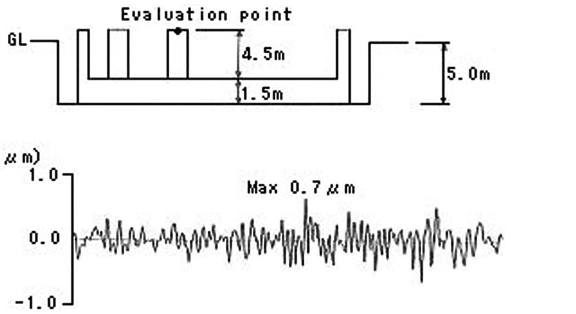

Fig. 7 Machine foundation and maximum amplitude of displacement due to vehicle traffic

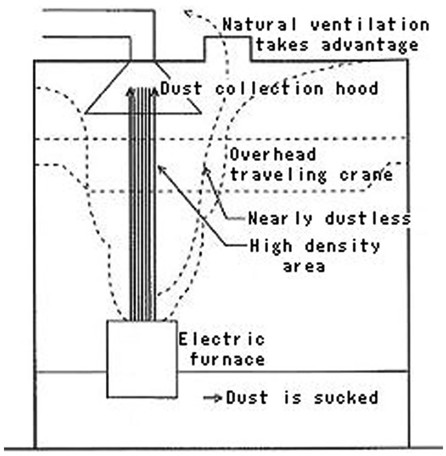

Fig. 8 HV-ventilation system

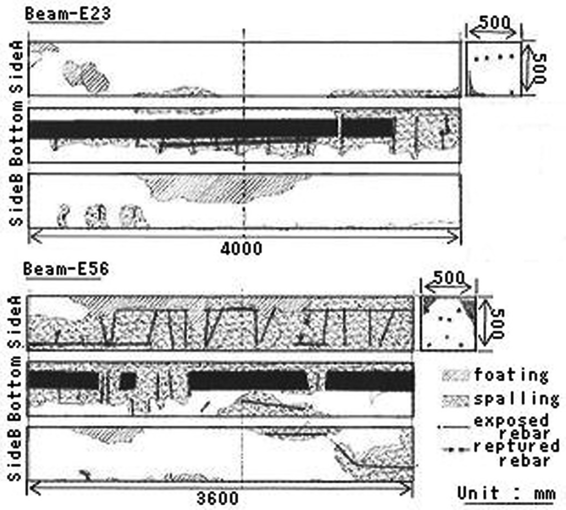

Fig. 9 Sketch of a reinforced concrete beam and its degradation effect

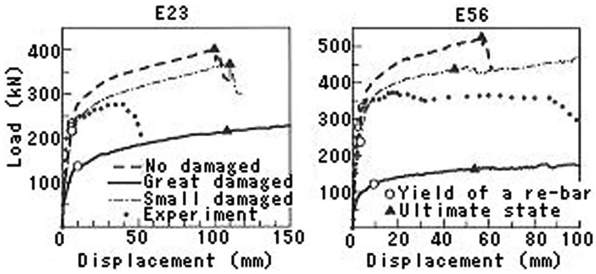

Fig. 10 Example of load-displacement relation

composite systems of ground and structures commonly used for anti-seismic design. Site tests were repeated, and machine foundations satisfying vibration confinement limits to the order of micrometers were constructed through the combined use of vibration proofing slots and damping and isolation measures (see **Fig. 7**).

These measures later served effectively for the construction of steel manufacturing plants that require advanced environmental control and the environment management of work areas of existing plants. For example, the conventional ventilation of plants having high-temperature heat sources was designed to control the temperature by changing the entire atmosphere inside the plant building, but air flow analysis has enabled the formation of an effective air current to create an indoor environment of adequate temperature. In addition to the above, the clean room technology was applied to the control of dust diffusion, and it has become possible to ventilate a plant building without allowing dust to escape outside it by the hybrid ventilation (HV) system (see **Fig. 8**). [13]

6. Enhancement of Competitiveness and Consolidation of Steel Production Capability for Present and Future Challenges

Since the start of 2013, Nippon Steel & Sumitomo Metal has taken measures to sharpen its competitive edges and strengthen its manufacturing capabilities to beat the competition in the global arena. The activities in the field of steelmaking infrastructure technology to support steel manufacturing in this fight are outlined in this section.

6.1 Deterioration evaluation of aged structures and technologies for reinforcement and renewal

The steel industry requires heavy capital investments. Since the end of the rapid economic growth period, when the concept of life cycle costing (LCC) was still unclear, Nippon Steel & Sumitomo Metal has evaluated the degree of deterioration of aged facilities and reinforced them for rehabilitation or replaced them with the most advanced versions, and thus accumulated the know-how of equipment management.

An example of such evaluation technology is the strength evaluation of aged reinforced concrete. [14] The infrastructures inside steelworks such as roads, port facilities, railways and building walls are maintained according to the relevant maintenance management rules of the company. While it is necessary to conduct such activities efficiently according to order of priority within budget limits, structures of reinforced concrete tend to be regarded as virtually permanent and not easily fallible as the deterioration advances, and therefore, they are often left unattended until degradation becomes evident.

However, reinforced concrete is also used for the main members of structures with a low degree of redundancy such as beams for Rahmen (rigid frame) structures, and there has always been a need to evaluate the residual strength of beams of degraded reinforced concrete (such as that shown in **Fig. 9**) relative to sound beams to prevent their failure and falling. At present, it is possible to estimate the residual strength of simple beams with practical accuracy by evaluating the fall of concrete adhesion to the bars due to corrosion and the decrease in sectional area due to flaking as shown in **Fig. 10**, and reflecting the results in the FEM models.

Of the different repair methods, the use of high-fluidity concrete in the repair of the floor slabs of cast houses[15] is explained below. The work area for blast furnace operators, called a cast house, consists of a concrete slab. Since the slab undergoes thermal degradation during prolonged use as the heat of molten pig iron and slag is transferred to it through the runners (troughs), it has to be renewed. As the renewal is very costly and it takes a long time, cast houses were conventionally renewed at the time of blast furnace relining, which is conducted every ten or so years.

A method for repairing cast-house floors was developed in 1996, whereby a damaged portion of the concrete slab is not removed but reinforced with high-fluidity concrete. The slab is about 10 m above the ground, and the size of the block to be repaired is approximately 6 × 6 × 0.3 m. The repair method consists of forming a new floor slab 0.5 m thick under the old one, which will remain there, by pumping high-fluidity concrete from below. After conducting studies on the methods of concrete acceptance inspection at the site and many casting tests, the method proved capable of reinforcing a cast house floor within a period three weeks shorter than before (see **Fig. 11**).

In another case example, to reinforce the foundation of a plant in operation, the most advanced civil engineering technology and large temporary structures were employed.[16]

Aged and deteriorated facilities are repaired mostly during the stoppages for periodical maintenance, but the stoppage period is defined based on the time for the repair of machines, and civil engineering and building work is not considered to define it. Nevertheless, sometimes it is necessary to conduct large-scale repair of foundation structures within the stoppage period.

At the Plate Mill Plant of Kimitsu Works, for example, it became necessary to replace some of the anchor bolts of the very plate rolling mill and drive in some additional piles. To do this during the operation of the mill beneath its foundation, the underpinning method was adopted. To form a dry work space beneath the foundation, which is always under large impact loads, despite the high groundwater level, a pipe roof was constructed and the freezing method was selected (see **Fig. 12**). Thanks to these preparatory measures, 20 anchor bolts, 100 mm in diameter and nearly 4 m in length each, were replaced, and 18 steel pipe piles, 500 mm in diameter and 8 m in length each, were successfully driven into the soil.

Structural members degrade rapidly under the harsh environmental conditions of steelworks, and they have to be repaired adequately within the limits of budget and time. It is therefore necessary to actively introduce the most advanced technologies and upgrade the maintenance and reinforcement activities from equipment inspection to repair.

6.2 Seismic reinforcement

Steel-frame buildings designed based on the old seismic design standard have to be reinforced according to the new standard, and in some of such cases, existing braces of H-section steel have to be strengthened. A common method is to weld steel plates as shown in the upper left corner of **Fig. 13**. In plant buildings, however, there are many cables, pipes, operation panels, etc. and they have to be temporarily removed to avoid possible damage by welding.

As a countermeasure, a fireless brace reinforcing method has been developed, whereby concrete blocks cast in the inside spaces of the H-section steel are pressed with cover plates and tension bars for pre-stressed concrete to form a composite unit, as illustrated.[17] Building reinforcing methods such as the above are important for dealing with new regulations without hindering the operation of the

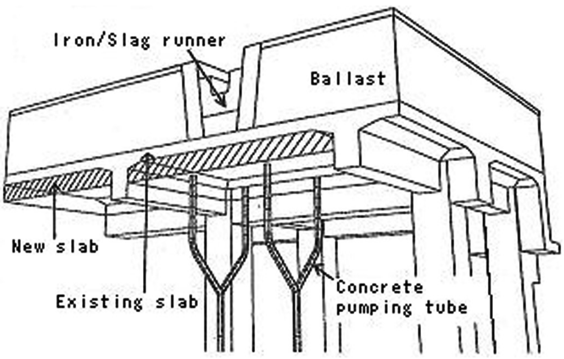

Fig. 11 Cast house floor and reinforcement method by concrete casting from below

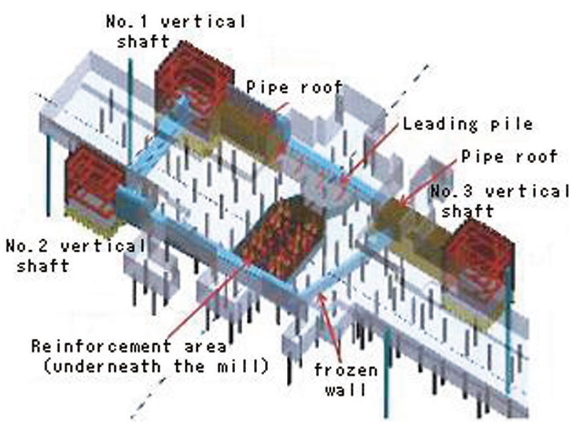

Fig. 12 Foundation repair work by underpinning method for operating equipment / Overall schematic of temporary work

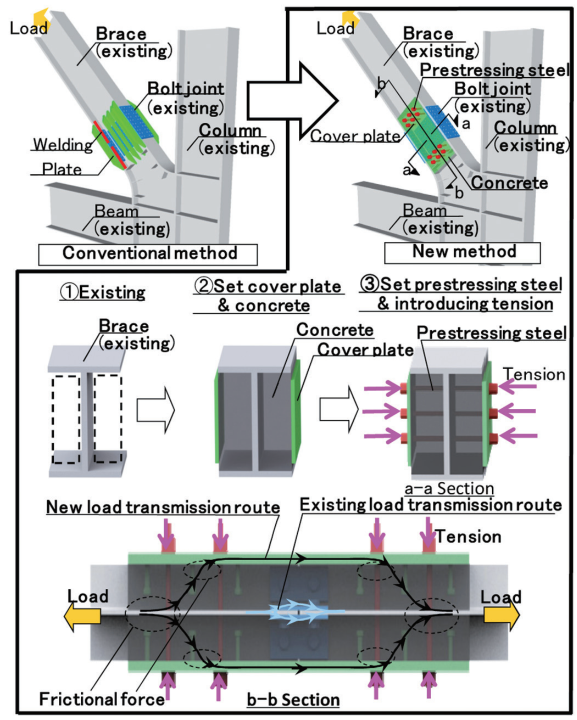

Fig. 13 Reinforcement method by welding and by fireless reinforcement method for H-section bracing joint

plant, especially when there are obstacles to the work. The company will continue to develop effective and efficient reinforcing methods for existing facilities in consideration of obstacles.

6.3 Water treatment for high-quality steel production

The production of high-grade products is essential for Nippon Steel & Sumitomo Metal to beat the competition in the global market. When a manufacturing process is modified for such purpose, the quality of the water discharged from it changes in different ways. Meanwhile, environmental regulations are becoming increasingly strict, those for waste liquids being no exception, and the discharge of liquid not conforming to them is a great risk for the company.

Advancing water treatment technologies to deal with the various types of discharge liquid safely and efficiently and prevent the outflow of illegal-quality water are important tasks of water-system engineers, and they are actually challenging different targets. More specifically, treatment processes have been optimized through tests using real discharge water on subjects such as the biological water treatment methods using iron-oxidizing bacteria [18] or sulfur-oxidizing bacteria [19], the ultra-high-speed coagulation-sedimentation method that allows smaller treatment facilities thanks to fast solid/liquid separation, and the treatment process of fluorine-containing water discharged from the flue-gas desulfurization systems of in-house power plants.

Essential to the water treatment of the steel industry is having to deal with a large amount of discharge liquids with different properties adequately and at high efficiency, and to this end, the pursuit of energy-saving and low-cost treatment methods has to be continued. Meanwhile, existing water systems become aged, and preventive maintenance has to be firmly established for them as a matter of urgency.

7. Closing

The history of the steelmaking infrastructure technology since the beginning of the modern steel industry in Japan has been reviewed, and future challenges in this field presented.

The infrastructure engineers of the industry have continued to develop new technologies to construct and manage facilities that have increased in size and weight to unprecedented levels through cooperation with outside researchers, constructors and consultants under the basic philosophy of "building better facilities more economically and rapidly using our own brain power," and thus contributed to the technical advances of the country's construction industry.

In addition, they are expected to play a leading role in infrastructure maintenance and management. Many of the infrastructures in steelworks are common to those in general society, but because of the severe work conditions such as heavy loads and impacts, heat, acidic gasses, etc., they degrade at rates several times that of those outside steelworks. Thus, the maintenance of steelmaking infrastructures undoubtedly yields technology that can be effectively applied to general social infrastructures.

In view of the above, Nippon Steel & Sumitomo Metal will continue to introduce and practice new technologies of monitoring, inspecting, evaluating, repairing and renewing steel manufacturing plants using IoT, robots, etc., and upgrade equipment maintenance and management systems by appropriately combining advanced methods and technologies.

References

1) Kamaishi Works, Nippon Steel Corporation (then): Hundred Years of Iron and Steel Production. 1986
2) Yawata Works, Nippon Steel Corporation (then): History of Civil Engineering of Yawata Works. 1976
3) Aomi Construction Co., Ltd.: Land Forming Work for Kimitsu Works. 1969
4) Oita Works, Nippon Steel Corporation (then): Building the Future—20-year History of Oita Works. 1992
5) Kimitsu Works, Nippon Steel Corporation (then): New Everyday—20-year History (departmental) of Kimitsu Works. 1985
6) Nagoya Works, Nippon Steel Corporation (then): Strides—20 Years of Integrated Steel Production (departmental history). 1984
7) JIS A 5015: 2013. Iron and Steel Slag for Road Construction
8) JIS A 5011: 2013. Slag Aggregate for Concrete
9) JIS R 5211: 2009. Portland Blast-furnace Slag Cement
10) Kobayashi, S., Kusafuka, M., Ikeda, Y., Nakagawa, K: J. Japan Soc. Civil Engineers. 415 (VI-12), 145 (1990)
11) Kobayashi, S., Sakata, E., Hashidume, K., Nakagawa, K.: J. Japan Soc. Civil Engineers. 498 (VI-24), 67 (1994)
12) Fushimi, M., Kawakami, H., Kobayashi, S., Idezaki, Y.: Shinnittetsu Giho. (344), 55 (1992)
13) Ishii, K., Murahashi, Y., Kawakami, H., Tanaka, K.: Shinnittetsu Giho. (364), 51 (1997)
14) Akashi, Y. et al.: Proc. 64th Annual Meeting of Japan Soc. Civil Engineers. 2009, p. 303
15) Maruyama, N., Kokado, T., Iguchi K., Konishi, H., Fukuda, N.: Proc. Symp. High-fluidity Concrete. 1993, p. 129
16) Hanada, K., Oode, T., Takemura, M.: Proc. 67th Annual Meeting of Japan Soc. Civil Engineers. 2012, p. 231
17) Maesawa, M., Okutani, Y.: Summary Tech. Papers Annual Meeting Architectural Institute of Japan (C-1 Structures III). 2010, p. 1267
18) Miki, O. et al.: J. Japan Soc. Water Environment. 30 (3), 155 (2007)
19) Kamori, H. et al.: Shinnittetsu Giho. (360), 5 (1996)

Shigeo KOBAYASHI
General Manager, Head of Div., Doctor of Engineering
Civil Engineering Div.
Plant Engineering and Facility Management Center
20-1 Shintomi, Futtsu City, Chiba Pref. 293-8511