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Engineering and Construction Capabilities of Kawasaki Steel

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Looking back at the 38-year history of the development of design and construction technology at Kawasaki Steel Corp. (KSC), it can be recognized that there are four major areas of activities which have contributed to the expansion of business for the KSC group of companies, i.e., (1) facility construction section, (2) construction materials section, (3) engineering and construction section, and (4) other related companies. This report discusses the technical results and characteristics of KSC construction technology and makes predictions for the future regarding the following specific techniques, construction management, and overseas project development: soft-ground improvement, foundations for heavy structures, ports and harbors, dredging, reclamation, offshore structures, steel structures, architectural and structural designs, environmental protection, pipeline design and construction, water treatment, railways, roads, bridges, and construction materials.

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1 Introduction

The history of Kawasaki Steel's civil engineering and building construction experience dates back to 1950, when the Repairs and Maintenance Section was established at the Head Office and 1951 when the Civil Engineering and Construction Department was organized at Chiba Works. Today, after 38 years, this special issue of Kawasaki Steel Technical Report on Civil and Architectural Engineering presents the various technological achievements of the company, along with an overview of the future outlook, by looking back on the development of the company's civil engineering and construction capabilities.

The major stream in Kawasaki Steel's civil engineering and construction activities are shown in **Fig. 1**. Historically, there have been four major streams of development. The first was KSC's own facilities construction. This area includes civil and architectural work for all the facilities and plant buildings at Chiba Wroks (East Works and Oihama area), Mizushima Works, and Chiba Works (West Works), which were executed in this sequence by KSC as owner. The works of this sector include not only the Kobe Head Office Building, Nishiyama Memorial Hall, and Chiba and Mizushima General Office Buildings, but also other buildings and facilities such as the Kawatetsu Hospital, company dormitories and housing, resort facilities, gymnasiums and sports fields.

The second stream of development represents the construction materials sector. This sector concerns the development of steel products as construction materials and the related manufacturing processes, technical services, design and execution technology, and marketing.

The third stream of development involved the Engineering Division engaged in construction activities both at home and abroad. These activities were carried out with the aim of cultivating foreign markets, stimulating domestic demand, and participating in regional development, and were based on the innovative techniques developed in the first and second streams. The construction of upstream steelmaking facilities for Brazil's Companhia Siderurgica de Tubarão and the Philippine Sinter Corporation on Mindanao Island may be included in this stream.

The fourth stream of development includes subsidiaries which joined cooperatively the activities and work in the first to third stream. These affiliated companies

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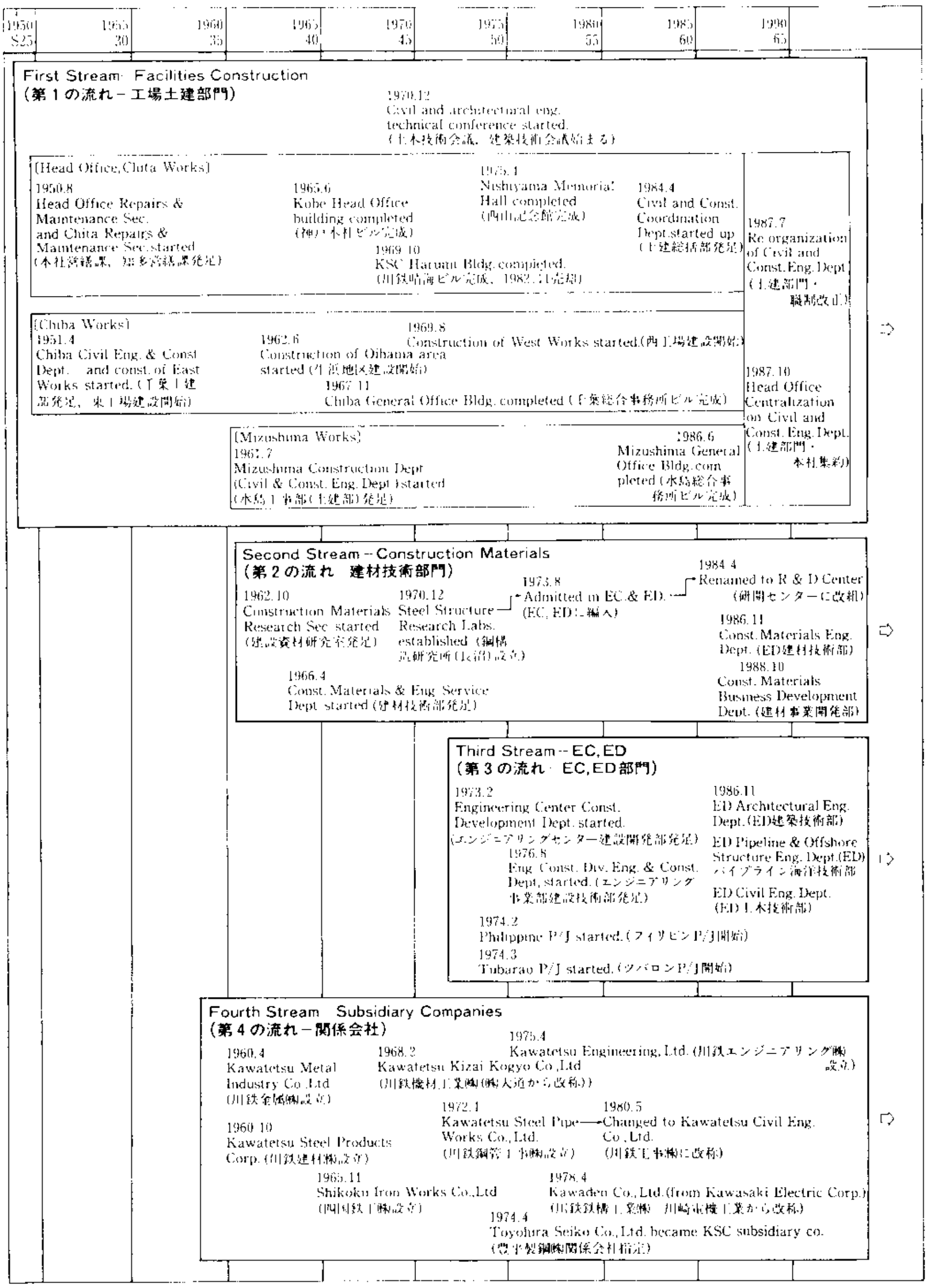

Fig. 1 Four major streams in Kawasaki Steel Corp. civil and construction engineering fields

play coordinated roles in the planning, design, fabrication, execution of work, and maintenance as part of the Kawasaki Steel group.

We can now look back on the process by which various elementary techniques of civil engineering and building construction were developed into more comprehensive techniques and then combined together to produce more sophisticated results while influencing each of the four development streams. Actual examples of recent techniques put into practical use in each of the development streams are also discussed in this special issue. It should be understood that a business creating movement in the construction materials sector represents new stages in which mutual support with the third and fourth streams are to be involved.

The origin of Kawasaki Steel's unique civil and architectural technology and the history of the company's civil engineering and building construction cannot be traced without considering three pioneers during the early history of the company, when the construction of the East Works of Chiba Works began, namely Yataro Nishiyama, the first President, Chozaburo Ueno, the first General Manager of the Civil Engineering and Construction Department, and Hideo Asakawa, Manager of the Architecture Section. The technology and engineering staff which these three persons brought in from the Repairs and Maintenance Department of Kawasaki Heavy Industries, Ltd., Navy Structure Construction Department and the Army Building Construction Department respectively can be considered the origin of the company's present civil engineering and architectural technology. Under President Nishiyama, Ueno developed civil engineering, harbor, and waterfront technology, while Asakawa developed architectural techniques.[1,2] These manpower resources were established during the first development stream.

Since then, the second, third and fourth streams have continued to date. The increase in the total number of civil engineers and architects on the company staff is shown in **Fig. 2. Figure 3** gives a comparison of the

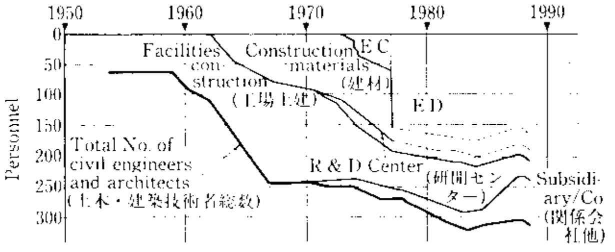

Fig. 2 Increase in the number of civil engineers and architects

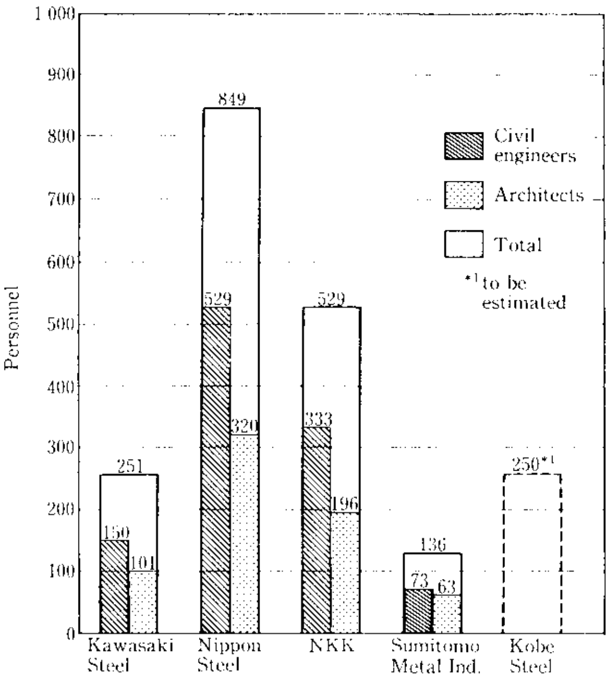

Fig. 3 Comparison of the number of civil engineers and architects among the five major Japanese iron and steel companies (as of Feb. 1988)

number of civil engineers and architects among the five major Japanese steel companies (not including subsidiaries) as of February 1988. How the company's 251 civil engineers and architects will change and expand their activities in the future depend on the history and activities discussed in this special issue.

The features of the company's civil engineering and architectural technology in each field of activity are enumerated and outlined in the following sections.

2 Technology Related to Soft-Ground Stabilization[3]

Typical subsurface soil profiles at the Chiba East, Mizushima and Chiba West districts are shown in **Fig. 4.** With the exception of some of the subsoils below Chiba East district, all upper soil layers are soft. Civil engineers therefore expended great effort in stabilizing the soft ground and tried various techniques to accomplish such improvement.

(1) To ensure that ore loads of 20 to 40 tf/m^2 could be supported in the Mizushima ore storage yard, the gravel compaction pile method and gravel drain method using gravel dredged from the sea bottom at depths of -16 m or more, the preloading method, and well-point dewatering stabilization methods, etc., were employed and over-consolidation (excessive settlement) and slope stability failure were prevented in this manner.[4]

(2) For soil stabilization in the Chiba West district, the sand drain method, Poracon type deep-well-point dewatering method, and clay mixing consolidation (CMC) method, etc., were adopted for the primary soil improvement work in order to accelerate consolidation settlement in the reclaimed land area. In addition, secondary soil improvement work was carried out (mainly using the sand compaction pile method).[5,6]

(3) Since about 1974, blast-furnace slag and converter slag generated at steel plants have been used in place of uniform sand for soil improvement, thus reducing the cost of soil improvement work. The compaction pile method using slag was adopted quite frequently in areas near the foundations of stacks, tanks, gas holders and heavy train tracks as well as those for high-rise and heavy steel structures supported on steel pipe piles. When an earthquake with the seismic epicenter off Chiba occurred on December 17, 1987, damage due to liquefaction took place in areas without soil improvement although none was observed in the areas where soil improvement (stabilization) had been undertaken.

(4) Steel plant foundations, such as those for blast furnaces, oil cellars, scale pits, hot metal pits, and seawater intakes, often require deep excavation. When deep excavation is made in soft subsoils, safe foundation work cannot be executed unless stability

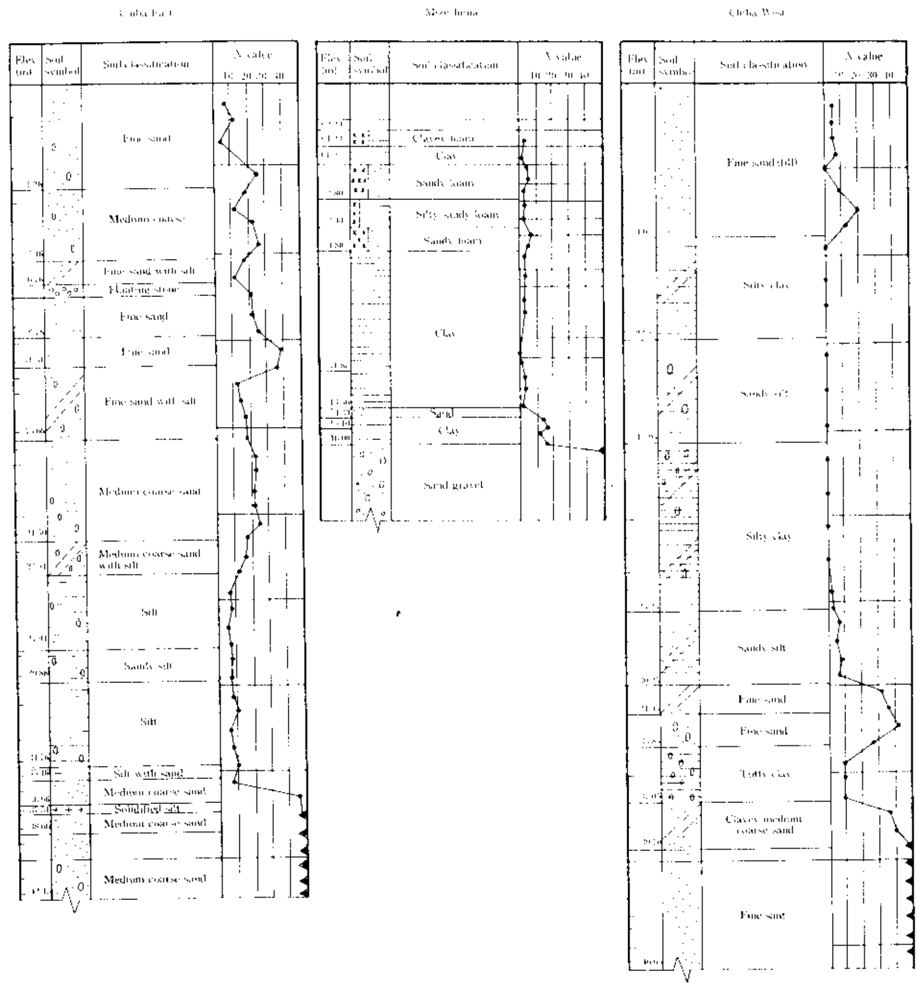

Fig. 4 Soil profiles of three blocks in Kawasaki Steel (Chiba East, Mizushima, Chiba West)

failure and lateral movement are prevented. It is therefore necessary to measure the behavior of the surrounding ground during excavation continuously in the field, and to analyze the data obtained four these measurements rapidly using a computer. This information must then be evaluated in order to determine the conditions which will exist when the next phase of work is carried out. Kawasaki Steel developed a real-time construction control system[7-9] for this purpose, and the company adopted this system for the first time in the field of soil and foundation engineering. This method is one of the well-established civil and architectural engineering techniques of Kawasaki Steel.

(5) When soft ground is placed in an embankment or the area behind a revetment is backfilled, the subsoils always undergo vertical settlement and lateral displacement. A simple method of predicting slope stability failure of an embankment was proposed based on the field measurement of the amount of vertical settlement in the middle of the embankment and the lateral displacement at the toe of the embankment.[10] The height of the ore and coal storage pile can then be controlled using this method.

The decisive factor in technical judgment concerning soft-ground stabilization is a careful and accurate subsoil investigation. One of the important principles of KSC's civil engineering and building construction is to conduct a thorough soil investigation in advance and to consider fully the results of this investigation as related to decision-making in the design and planning stages. Safe and economical construction can be successfully achieved by making field measurements using the real-time construction control method at all times when technically difficult construction is executed.

3 Technology Related to Heavy Structure Foundations

A typical example of a heavy structure foundation in the steel industry is a blast-furnace foundation. The number of blast furnaces constructed in Japan, including those before World War II, is high at 66. The chronological transition of design loads (vertical and horizontal loads and bending moment) for a blast-furnace foundation is shown in **Fig. 5**. Changes in blast-

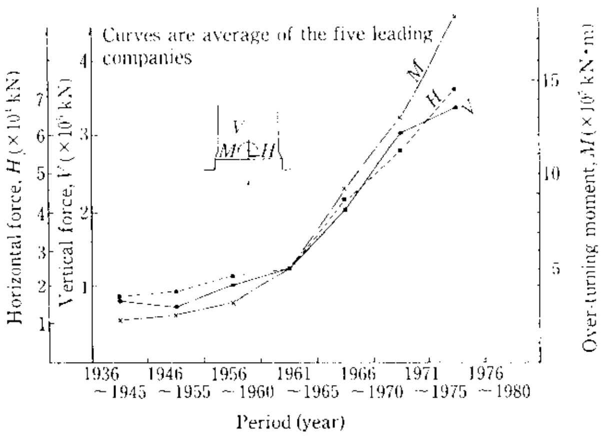

Fig. 5 Changes in design load of blast furnace foundation

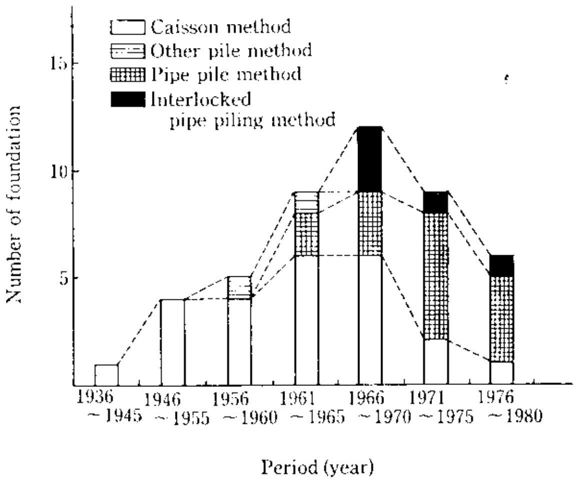

Fig. 6 Changes in blast furnace foundation construction methods

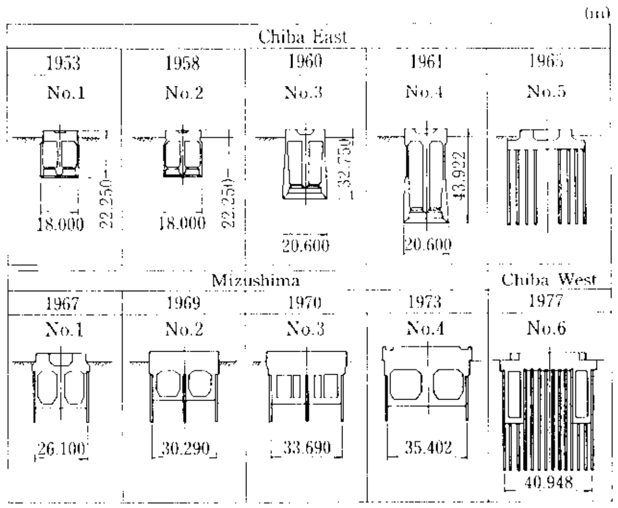

Fig. 7 Development of blast furnace foundation at Kawasaki Steel

furnace foundation construction methods over a period of years are shown in **Fig. 6** for a relatively large number (47) of blast furnaces.[11]

The concrete caisson method and steel pipe pile foundation methods were employed for most blast-furnace foundations. KSC put the interlocked steel pipe pile method into practical use in the development of a new method for heavy structure foundations. This method won the Nishiyama Silver Prize in 1970 and the Nishiyama Gold Prize in 1973 within the company, and afterward contributed to the foundation technology by providing a suitable and cost effective product using steel pipe.

Figure 7 shows in chronological order the blast-furnace foundations constructed at KSC. The open concrete caisson method (well method) was adopted for Chiba East No. 1 to No. 4 blast furnaces. The large-diameter steel pipe piling method (pile group method) was employed for Chiba East No. 5 blast furnace. The interlocked steel pipe pile method was adopted for Mizushima No. 1 to No. 4 blast furnaces. The double interlocked steel pipe pile method was applied to Chiba West No. 6 blast furnace. In the initial stage of construction of Chiba Works east district, the steel pipe piling method had not yet been developed in Japan and timber piles and concrete caissons were used. Reinforced concrete wells (18 m in outside diameter and 15 m in depth) were used for the foundations of Nos. 1 and 2 blast furnaces. Incidentally, the publication by the Japan Society of Civil Engineers in this connection is the earliest paper on the company's civil engineering techniques.[12] The open caisson method using reinforced concrete caissons was adopted between 1953 and about 1961 because soil conditions were relatively favorable. Later, however, as the size of blast furnaces increased, it became impossible to support loads with intermediate bearing strata, and deep caissons were required. For this reason, the limit for open caissons was reached in 1963. Thereafter, progress was made using execution techniques with large-diameter steel pipe piles. The open caisson method therefore gave way to the pile group method.

As the size of blast-furnace structures continued to increase, the focus of construction activities shifted from Chiba East to Mizushima. Since Mizushima had soft soils in the 20-m deep upper layer, the interlocked steel pipe pile method, which is suitable for earthquake-proof construction and can be easily executed, was carried out for the first time in 1965.[13] Afterward this method was used often. However, the double interlocked steel pipe pile method was used for the Chiba West No. 6 blast furnace, the company's newest blast furnace, which was constructed between 1975 and 1977, because the subsoil conditions at the construction site were worse than Mizushima.

The foundations of Mizushima No. 1 blast furnace and Chiba No. 6 blast furnace are described in detail in the following:

(1) Foundation of Mizushima No. 1 Blast Furnace

In 1965, the construction activities of KSC's blast furnaces shifted from Chiba East to Mizushima. The soft reclaimed land at Mizushima provided difficult foundation conditions compared to the uniform sandy soil at Chiba East. Although civil engineers had since 1962 worked hard to solve the problems presented by unfavorable ground conditions at Mizushima, the importance of a thorough review of civil engineering techniques in planning the foundation of larger blast furnaces was realized. The pile group foundation had yielded good results with Chiba No. 5 blast furnace and was counted as one of probable method, but safety problems existed in terms of earthquake-proof design because the soft upper soil layer was quite thick at 20 m. Both the open caisson and pneumatic caisson methods presented difficulties in the execution of work due to the soft subsoil conditions and were therefore considered unfavorable in terms of construction cost. The planning encountered extreme difficulties. The pile group foundation using large-diameter steel pipe piles was initially planned with batter piles serving to resist horizontal loads. This system was not adopted, however, because the effect of the horizontal loads on piles in soft ground had not been sufficiently clarified. As a result of a review of these problems, it was decided to adopt the interlocked steel pipe pile method using steel pipe piles for the foundation of Mizushima No. 1 blast furnace because this method had already shown good results in the execution of work for large wharfs and large underground pits. The progress of development of this method is detailed in "Tetsu" No. 123[14] issued by KSC. (Kazuhiko Hijikuro was awarded the degree of doctor of engineering for his study[15] of this method.) The same method was adopted for No. 2 to No. 4 blast furnaces at Mizushima. Since various problems in the design and execution of the work had been solved by trial and error, this method was used at various locations for the construction of large bridge foundations in addition to blast-furnace foundations. This method also found broad acceptance after it was developed into the temporary cofferdam combined steel pipe piled well methods[16] using steel pipe piles, eliminating the necessity for the construction of pier foundations by temporary cofferdam.

(2) Foundation of Chiba No. 6 Blast Furnace

After the construction of four blast furnaces at Mizushima over a period of about one decade, BF construction resumed at Chiba in 1975. Although the distance from Chiba East, where five blast furnaces had been constructed, is only about 2 km, the subsoil conditions at Chiba West, where No. 6 blast furnace was to be erected, were very bad, with a soft layer persisting to depths of 40 m from the ground surface. Because soil conditions were worse than at Mizushima, it was necessary to continue studies based on experience at Mizushima. Based on earthquake observations carried out with accelerometers installed at the Mizushima blast furnaces, earthquake-proof design methods, in which the response of structures is considered, had made rapid progress.[17] Unlike Mizushima, however, Chiba is in a district where earthquakes are common, and emphasis was placed on earthquake-proof construction in soft subsoils in planning Chiba No. 6 blast furnace. Resistance to earthquake, ease of execution of work, and economy were all considered, and the double interlocked steel pipe pile method was adopted.

Steel pipe piles 273 to 318 mm in outside diameter were used mainly in the foundations for converters and rolling mills in 1960 and 1961. Since steel pipe piles of 500, 600 and 700 mm diameter were put into practical use, these steel products rapidly came into general use because they could be driven easily with a conventional driving hammer and provided high capacity. This now constitutes an important foundation construction method for heavy structures. Technical problems to be solved also increased, however, for example, larger diameters (1 500 to 2 000 m), reliability of welded joints, corrosion, negative friction, and noise and vibration pollution from pile drivers. The company's civil engineers continued research and development through the Japanese Association for Steel Pipe Piles, Japanese Society of Soil Mechanics and Foundation Engineering, and the Architectural Institute of Japan. As a result, unique, innovative technology was developed, such as the automatic field welding process for steel pipe piles, underwater cutter of steel pipe piles, Kawasaki slip layer steel pipe (KSLP) piles—mitigation measures against negative friction, and heavy duty Kawasaki plastic-coated pipe (KPP) piles. A recent important technical problem is to develop a low-noise, small-vibration pile driver.

For details of steel pipe pile foundations representative literature[18-20] will be of use.

4 Technology Related to Harbors, Dredging, Reclamation and Offshore Structures

The dredging and reclamation work for Chiba Works was started at the east district in 1951. Dredging and reclamation were carried out in the A-district in 1960, in the Oihama district in 1962, and in the West district in 1969. Dredging and reclamation work was substantially completed in December 1976 when the present reclaimed land area assumed its present form. Land with an area of 863 ha and a total volume of earth and sand of 72 million m^3 was reclaimed. The average volume of earth and sand per m^2 was 8.4 m^3. At Mizushima Works, dredging and reclamation started in 1962 and ended in March 1975. Land with an area of

1 128 ha and a total volume of earth and sand of 98 million m^3 was reclaimed. The average layer thickness of earth and sand per m^2 was 8.7 m. By way of comparison a reclaimed land volume of 180 million m^3 and a reclaimed land area of 511 ha are planned for the New Kansai International Airport to be built in Osaka Bay. The reclaimed land volume for this airport corresponds to the total volume of the two KSC works. At both works, dredging was carried out night and day using large (8 000 hp) pump dredgers. The earth and sand necessary for reclamation were obtained by dredging channels for large ships to depths of −16 to −18 m. In this dredging and reclamation work, the corrugated cell method[21)] (persons concerned were awarded the 1968 Nishiyama Bronze Prize) and the coupled pile-anchored sheet piling bulkhead method[22)] (persons concerned were awarded the 1972 Nishiyama Bronze Prize) developed by KSC's civil engineers were principal techniques used for rapid, economical completion of revetments with total lengths of 13 km and 8.8 km. Integrated steelworks require large raw material quays, i.e. 150 000 DWT class for receiving iron ore and coal, and product shipment quays of 30 000 to 80 000 DWT class. Quays with a total length of 5 130 m at Chiba and 6 160 m at Mizushima were constructed.

The principal quays and their technical specifications are described below.

(1) 1953–Chiba Front Quay (−9.5 m Berths G, H and I)
The first ship received at this quay was the Koei Maru (10 000 DWT). June 1 is the anniversary of the opening of Chiba Port.

(2) 1956–Chiba Scrap Quay (−4.5 m Berth Q)
This quay was constructed by driving reinforced concrete sheet piles of hollow triangular section in front of a rubble-mound revetment. The water jet method was employed using the hollow stem as the pipe for jetting operations.

(3) 1961–Chiba No. 2 Front Quay (−12.0 m Berth L)
This prefabricated cellular bulkhead used linear steel sheet piles. Steel sheet piles were used for the quay structure for the first time at KSC and cathodic protection with the impressed current method was also adopted.

(4) 1964–Mizushima Quay (−7.0 m Birth A)
For this quay, interlocked steel pipe piles were used for the first time at Mizushima. After the completion of the quay, turning basins were created by dredging previously reclaimed land.

(5) 1968–Mizushima Ore Quay (−16.0 m and −18.0 m Berths E and F)[23)]
This ore quay of the detached pier type was constructed of steel pipe piles and designed to accomodate 160 000 DWT vessels.

(6) 1971–Mizushima Product Quay (−11.5 m Berth T)[24)]
This quay is of the circular steel pipe pile well type, which makes best use of the section modulus of steel pipe piles. It was constructed using a method in which the quay structure and a temporary structure are used in combination.

(7) 1971–Chiba Large Quay (−18.0 m Berth EB)
This is a detached pier constructed with steel pipe piles used for iron ore and coal designed to accomodate 158 000 DWT vessels. It was constructed at the same time as the reclamation for Chiba West.

(8) 1973–Chiba UO Quay (−11.5 m Berth EA)
From this detached pier, the world's largest UO pipe (64 inches in outside diameter) is shipped. VL-shaped combined sheet piles and Z-shaped sheet piles were used in constructing attached revetments. This work contributed greatly to the development of KSC's steel sheet pile technology.

(9) 1978–Chiba Large Raw Material Quay (−18.0 m Berth J)[25)]
This raw materials quay for 154 000 DWT vessels was constructed using KSC's unique techniques, such as the underwater junction method and marine jacket method.

(10) 1975–Chiba West Product Quay (−15.5 m Berth NA)[26)]
This is an export quay for 80 000 DWT vessels. It was constructed using the latest techniques, such as maintenance-free heavy duty Kawasaki plastic-coated pipe (KPP) piles and the self-traveling erection pile (STEP) installation method.

Joint researches on methods of double sheet pile wall structures design was undertaken with Port and Harbor Research Institute, Ministry of Transport, starting in 1981.[27)] This double sheet pile wall design method is one of KSC's unique civil engineering techniques for ports and harbors, and is based on the Ohbori equation. It has become very popular as a civil engineering design method. The computer program for this method was developed by KSC.

Corrosion protection technology[28)] used for waterfront structures at Chiba and Mizushima includes: (1) corrosion allowance method, (2) impressed current method, (3) aluminum electrode method, and (4) heavy duty corrosion protection method, which were adopted in this order at intervals of about ten years. Although maintenance costs are high for all of these methods, the heavy duty corrosion protection method has been used most recently. This method was put into practical use for steel pipe piles at the Kota Kinabalu Port expansion project carried out by the company in Malaysia (1985) and in the construction of the new products berth for 80 000 DWT vessels at Chiba Wroks (1985). The development of corrosion protection techniques at the level of practical application is now being carried out for steel sheet piles and steel pipe sheet piles.

In 1986, the self-traveling erect pile installation method was developed and put into practical use as a new civil engineering technique for ports and harbors. This method does not use floating pile driving equipment,[29,30] and was awarded the 1985 Prize for Technique Development by the Japan Society of Civil Engineers (JSCE). The Association for Self-Traveling Erect Pile Installation Method (President: Kazutaka Tsutsumi, ex-Senior Managing Director, KSC) was subsequently founded by 20 major construction companies, and the promotion of this method for waterfront development projects is under way.

For offshore structures, KSC's engineers have acquired design and fabrication techniques in accordance with a technical agreement with Etudes Petrolieres Marines of France (1978). The maintenance of fabrication yards, including the East Harima Fabrication Center, was continued and four offshore jackets were fabricated between 1980 and 1982 for the Bombay High Oil and Gas Development Project undertaken by the Oil and Natural Gas Commission of India. With this project, the KSC group's techniques for fabricating offshore structures were established. Orders for other large jackets, such as Chevron's "Hermosa" (1983) and Shell's "Bullwinkle" (1985), were received. Precedent-setting results were achieved in the fabrication of these components.

Although the business climate for offshore structures is unfavorable due to the strong yen, KSC has ample computer software related to the design, planning, fabrication, and execution of work related to jackets, piles, and components, and this is available to customers. The company is proud of having completed the fabrication of the second largest number of offshore structures (following Nippon Steel Corporation) among Japanese steel and shipbuilding companies.

5 Technology Related to Steel Structures

Since 1965, steel structure design and construction has made rapid progress due to the advent of wide flange H shapes. During this period, there was keen competition among wide flange beam manufacturers including KSC in developing applications and new methods to expand the market for wide flange beams. At the same time, prefabricated H-frames began to be used. Standardization and systematization were actively carried out in addition to studies on methods of erecting and connecting steel frames.

During this period, computers also came into use. Integrated design programs presently in general use were developed in the field of structural design and became important tools. The computer was a particularly important tool for steel manufacturers, whose steelmaking operations required the type of large computer which is needed to conduct complex structural analyses.

In 1970 the Structure Research Laboratories (the predecessor of KSC's present R & D Center) opened, and a 1 000-t testing machine for structures and various fatigue testing machines were installed. Many experiments and studies, including mock-up tests, were conducted using these testing machines in order to clarify both static and dynamic characteristics. Another of the company's important advantages was accumulated experience and knowledge acquired through the construction of a number of steel structures of various types, including converter facilities and power plants, and in the construction of steel plants and related facilities.

In the field of steel-frame fabrication and assembly, a rectangular hollow section column (RIVER BOX) was developed[31] in 1974 by applying the high efficiency KX welding process. This technique was developed into an application technique for heavy steel-frame members of over 100 mm in thickness. KSC leads the industry with this unique technology.

Studies on methods of erecting steel frames were conducted actively in the latter half of the 1960s, especially for mass production methods[32] for truss structures, high-rise apartment buildings, etc., and formed the basis for the company's present architectural technology. In the latter half of the 1970s, extensive studies of actual damage to crane girders were conducted with respect to durability and design methods for crane girders. Results of these investigations contributed to technical improvements in fatigue design. In the first half of the 1980s, studies were made on the earthquake-proof capacity of high-rise rack warehouses for heavy articles using mock vibration tests. Valuable technical data was obtained concerning earthquake measurement and aseismatic design techniques.[33]

KSC's engineers have demonstrated high quality performance capabilities for steel-frame erection techniques that require thorough examination during the stage of structural design such as the lift-up method adopted in erecting the roof of the Mizushima Gymnasium, and the large-assembly method (nonscaffold method).

As is apparent from the foregoing, many achievements obtained in actual buildings, as well as technical developments made using large experimental facilities and large computers, are the most significant feature of KSC's architectural techniques. The recent development of the Super Wing prestressed steel roof truss method is another outstanding example.

6 Technology Related to Architectural and Structural Designs and Environmental Protection

KSC's architectural and structural design techniques have been developed on the basis of the company's experience in the construction of integrated steelworks and related facilities at Chiba and Mizushima over a period of almost 40 years since construction of Chiba Works began in 1951. These techniques include a series of methods from the design to the execution of work and maintenance for not only steelmaking facilities, but also various types of buildings, including housing, hospitals, and resort and sports facilities. Historically, the environment in the time period of development was such that positive attempts were made to develop new techniques; that is, there were many opportunities for technological innovation during the construction of the above-mentioned KSC's own facilities and for many years it was possible to evaluate methods on the basis of continuing practical experience.

KSC's new materials for construction include enameled steel panels, which were applied for the total exterior facing of the Kobe Head Office building in 1964 and contributed greatly to the enhancement of the KSC group's techniques of building material technology. Atmospheric corrosion-resistant steels were developed in the latter half of the 1960s and applied to the roof of the Nippon University Ryogoku Auditorium and the external walls of the Chiba Research Laboratories. These products fostered the development of techniques, such as RS coats using a rust stabilizing treatment process. The application of new materials such as stainless steels and surface-treated steels to buildings constructed by KSC resulted in the establishment of techniques and later led to orders for buildings being received in the third and fourth development streams.

In 1969, mass production methods (for example, the KS method) for high-rise housing were developed. These techniques were improved by application to company housing at Chiba and Mizushima and formed the basis of the company's present techniques for high-rise housing. In the construction of the Mizushima Gymnasium, the column sliding method and large roof lift-up method using jacks were developed. These methods contributed greatly to the enhancement of the KSC group's specialized construction technology. The features of these techniques are incorporated in the recently developed Super Wing prestressed steel truss roofing method.

In the engineering field, KSC not only developed the design and execution techniques for plant buildings, but also has the knowledge and experience necessary for implementing recent commercial architectural techniques. Examples include the clean room at the High Technology Research Center of Technical Research Div., intelligent buildings such as the Mizushima General Office Building, and energy-saving facilities using solar heating systems (Kobe Motoyama Sports Center and Ashiya Gymnasium). In addition, the company has accumulated comprehensive software capabilities which can be adopted to the total coordination and management of regional development projects.

In the area of environmental protection, KSC has technical experience with the tree-planting activities conducted in accordance with agreements on pollution control made in 1969 with Chiba City and in 1971 in Kurashiki City, where Mizushima Works is located. This experience is presently being put to use in constructing golf courses and resorts development. Within the Chiba Wroks compound, there are 520 000 trees, including 2 000 cherry trees in a green tract of 810 000 m^2. These trees provide the company's employees with a beautiful, healthy, and restful environment. Further, techniques related to noise, ventilation, insulation, and condensation have been confirmed and established through the construction of KSC buildings. These techniques are very useful in the field of civil engineering.

7 Technology Related to Pipelines and Water Supply

KSC's first water supply facilities were built in 1952, when the Chiba No. 1 seawater intake for cooling water for the blast furnaces, power plant, coke ovens, etc. was constructed.[2] At that time, clean industrial water was supplied from 30 deep wells using settling basin techniques.

The origin of the company's present water supply technology dates back to 1963, when the pipelines for phase-1 work for 0.9 m^3/s (900 mm in diameter, total length about 20 km) were completed after an industrial water concession of 1.8 m^3/s from Lake Inba-numa was obtained. In 1971, the pipelines for the remaining 0.9 m^3/s (1 350 mm in diameter) were completed in phase-2 work as a joint enterprise with Chiba Prefecture. The Lake Inba-numa water filtering plant has been operating reliably for 25 years since 1963, and, as a result, an industrial water volume of 155 000 m^3/day is now supplied.

Materials for industrial water piping were developed in the following order: ordinary cast-iron pipe (lead caulking), mortar-lined cast-iron pipe (mechanical joint), ductile cast-iron pipe (mechanical joint), coated steel pipe (welded joint). In addition, the following techniques were also developed:

(1) Internal automatic coater for medium- and small-diameter pipe of less than 600 mm in diameter
(2) Kawasaki-type electroslag automatic internal girth welding method for large-diameter pipe[34]
(3) Methods of connecting expanded pipe joints, Z-joints, R-joints, etc.

During this same time, the technical scope of the pipeline techniques for steel pipe developed for water supply purposes was later expanded to oil pipeline technology. Among others, rapid recovery and repair techniques for industrial water leakage is one of the unique techniques established by Kawatetsu Civil Engineering Company, Ltd., KSC's affiliated company.

Unique techniques developed based on KSC's water supply technology include various dehydration and sludge treatment, sludge deodorization, composting, rinse treatment, and reclaimed palm oil recovery (patented) techniques, as well as recovery techniques for reclaimed fatty acid fuel oil, and treatment techniques for alkalis, chromium, zinc, fluorine, and waste oil.

Examples of principal pipeline work are piping work for the Narita aviation fuel pipeline in the Lake Inbanuma canal district (1982), pipeline laying along the left shore of Niigata East Port (1983), submarine oxygen pipeline laying across Mizushima Port[35], Yurihara gas pipeline laying (1984), Mizushima–Kurashiki gas duct laying (1985), the Manila water supply projects PG6 (1985) and PG7 (1987), and laying of the Singapore submarine water supply pipeline (1987).

8 Technology Related to Railroad Tracks, Roads, and Bridges

KSC's track technology is represented by design, construction and maintenance techniques used for narrow-gauge railway tracks with iron sleepers,[36] on which 350-t torpedo-type cars[37] have safely traveled. The development of iron sleepers was conducted in 1960 during the construction of Mizushima Works, and a signal apparatus suited to iron sleepers was put into practical use at the same time. The technology was later improved and then applied to the construction of the west district in Chiba. These techniques have also been supplied in Brazil (Tubarão), Canada, Indonesia, and other countries. This technology was awarded the Nishiyama Bronze Prize in 1969.

Paving of roads at Chiba and Mizushima Works began on a full scale in the latter half of the 1960s. At present, a road area of 460 000 m^2 (of approximately 550 000 m^2) at Chiba is paved and a road area of 760 000 m^2 (of approximately 1 050 000 m^2) at Mizushima is paved. Blast-furnace slag is used as the subbase course materials for these roads. Although hot asphalt containing blast-furnace slag as the aggregate was initially used as the surface layer material, hot asphalt containing converter slag was developed in 1978 and was applied for the pavement of the roads at both steelworks. The fact that blast-furnace slag and converter slag are used as the subbase course material and surface layer material for the road pavements is one of the features of the company's road construction technique.

In the field of bridge construction, KSC obtained the first Japanese patent for prestressed concrete method (metallic double corn method) in 1962. The design and construction procedures for this metallic double corn method were subsequently established by the Japan Society of Civil Engineers (JSCE). Many achievements were realized in the design and execution of work in connection with the New Tokaido (Nagoya district), Joetsu, and Tohoku Main rail lines, the Tomei Expressway, and elsewhere. In addition, this method was also adopted in a dam intake tower bridge in Hong Kong and the Thailand–Malaysia Expressway, where KSC was involved in the design and construction execution.

Almost simultaneously with the development of the metallic double corn method, KSC developed the Kawatetsu H-beam bridge and prepared a system of standard design drawings, introducing labor-saving and economy in the design and execution of construction. These standard designs have since been adopted for many bridges. The company has recently developed the unique Kawatetsu composite slab bridge, and many bridges of this type have already been erected. The company has also fabricated and exported noncoated atmospheric corrosion-resistant steel bridges (for example, a three-span continuous plate girder bridge) to Saudi Arabia. The total weight of these steel bridges amounts to approximately 5 000 t. In addition, the company fabricated a pipeline bridge (4 500 t) with a guaranteed Charpy value of 2.8 kgf·m at a very low temperature of −45.6°C for the United States (Alaska) and has constructed numerous steel bridges, including railroad and highway bridges, in Southeast Asia. Recently, KSC received orders for two bridge projects in the Philippines and carried out the field construction.

9 Technology Related to Construction Materials and Process Products

The second development stream began in 1962 when the Construction Materials Research Section was established in what was at the time the Tokyo Branch Office, employing Shimpei Warita and Tadashi Sagara from the Ministry of Construction. Early research and development activities concerned reinforced bars, wide flange beams, and corrugated cells.

KSC possesses a range of techniques for steel pipe piles and steel pipe sheet piles, which have been the company's traditional area of civil engineering expertise. It also possesses many design and execution techniques jointly developed with the Japanese Association for Steel Pipe Piles, Japanese Society of Soil Mechanics and Foundation Engineering, and others. For the field welding of joints in steel pipe piles, the semi-automatic welding (River joint) method was developed in 1969. The KH-P automatic welding method was developed in 1974 and 1976. The latter method is considered almost perfect as a field welding technique. Recently, heavy duty coating steel pipe piles and steel pipe sheet piles were developed, and their use in construction is gradually expanding.

For the interlocked steel pipe pile method, staff members involved were awarded the Nishiyama Silver Prize in 1970 and the Nishiyama Gold Prize in 1973. In the 1970s, this method had a market share of more than 50% (fiscal 1978) and was one of KSC's leading products. The company has developed unique design methods for elastic design, three-dimensional frame analysis, and temporary cofferdam design, and related execution techniques, such as the waterproof joint method using clay mortar in the joint tube, the precut joint method for steel pipe sheet piles, and the underwater cutting method, all of which are popular with consultants and construction companies.

The technical level of the development of wide beam flanges and steel sheet piles was raised after the start-up of the Mizushima wide flange beam mill in 1968. In 1972, the coupled pile-anchored sheet piling bulkhead method was adopted on a large scale for land reclamation work for the Chiba West district (persons concerned were awarded the Nishiyama Bronze Prize). The company can supply four types of steel sheet piles; U type, Z type, linear type, and H type in a total of 23 sizes. Research and development is being carried out on heavy duty coating steel sheet piles, which have recently been much in demand.

KSC developed H steel sheet piles (1978), corner steel sheet piles (1984), and wide steel sheet piles (1986), in addition to the T steel sheet piles necessary for linear steel sheet pile cells. The development of a new design method for linear steel sheet pile cellular bulkheads is presently being investigated and it is anticipated that these cells will soon become competitive with steel plate cells.

One of KSC's techniques worthy of special mention is the design method for double sheet pile wall structures based on the Ohbori equation developed jointly with Port and Harbor Research Institute, Ministry of Transport. The computer program for this method is the intellectual property of KSC. The method provides distinct advantages as one of KSC's unique techniques, if properly combined with the real-time construction control method mentioned in (4) of Chapter 2 and aseismatic design methods now being developed.

Although wide flange beams are available as main structural members for buildings, the development of light-gauge built-up H-sections led to the growth of steel-frame structural members. In the latter half of the 1980s, HISLEND H-shapes became a promising product in the field of medium-height steel reinforced concrete composite structures.

The square-pipe column fabrication system (River Box W), which uses a high-speed, high-efficiency one-pass automatic welding method, was developed by KSC in 1974 prior to any other steelmaker. It is presently among the most promising products of the KSC group because trends toward taller structures and the use of extra-heavy members.

Although the boltless roofing method (River Rock 50, 30, and 160 seams) using no bolts or clips and the metallic roof tile PLEGEL were introduced from abroad, they were improved by the KSC group for use under Japanese climatic conditions.

Further, KSC has developed new building materials such as River Wall metallic series and fluoroplastic steel facing panels Resinowall, Wall 21, GRANCERA, QL Deck, stainless steel Lumina Color and various light poles.

10 Technology Related to Construction Management

The scope of the steel plant erection necessitates the participation of civil engineers in the decision making process from the very first stage of planning. For instance, the most important factors in determing site conditions for an integrated steelworks includes raw material transportation, energy sources, land reclamation, subsurface soil conditions, infrastructure (ports and harbors, utilities, roads, railroad tracks, housing), plant layouts and product markets. Participation in the site selection for both Chiba and Mizushima Works proved useful in the site selection for several overseas projects including Philippine Sinter Corporation[38], Companhia Siderurgica de Tubarão, and the Wologisi Mining project (Liberia).

These successful projects were able to be accomplished by KSC's tradition of comprehensive training on the job for engineers: from the owner's standpoint, to have on-site experiences ranged from planning, design, management of construction execution, operation to maintenance, of civil and architectural works in plant construction. Through these experiences, lots of multidiciplinary engineers, who can interpret drawings, plan and schedule execution of works, implement "safety first" policy in construction execution and make cost estimation, have been fostered. KSC's engineering activities are uniquely characterized by these engineers.

After the establishment of the company's Engineering Center in 1973 and the Engineering & Construction Division in 1976, the construction management capacity obtained in the first development stream was gradually increased in the third stream, and the company's overall technical capabilities have been evidenced in many overseas projects since 1979 in a variety of ways, including site preparation, cooperation with local partners, budget control, schedule control, procurement of equipment and materials, and negotiations with consultants.

KSC established the Steel Structure Research Laboratories in 1970, which was restructured as the Research and Development Center in 1984 to extend its technical capabilities. The research staff of this center can quickly cope with requirements of the construction industry concerning technologies related to new steel products and methods.

After the establishment of the Head Office Repairs and Maintenance Section in 1950 and the Chiba Civil Engineering & Construction Department in 1951, the management of contract affairs for civil and architectural works was conducted at the plant level for 37 years until July 1987, when it was transferred to the Materials Procurement Department when the civil and construction departments of the works were consolidated and transferred to the Head Office. At the time of this move, company-wide standards for design, execution control, and the estimation of construction costs and unit prices, as well as code systems for standards and a computer system for budgeting were completed. These standards and systems contribute to improving the efficiency of budgeting and contract execution in civil and architectural projects.

Simultaneously with the consolidation of the civil and architectural departments from the works in Head Office in 1987, design activities were transferred to Kawatetsu Engineering, Ltd. and execution control affairs were transferred to Kawatetsu Civil Engineering Co., Ltd. Thus the centralized civil and architectural engineering department at the Head Office can provide overall technical capabilities while flexibly and effectively utilizing the techniques and engineers of the entire KSC group.

The total volume of concrete used for the construction of Chiba and Mizushima Works amounted to approximately 8 million m^3. Each plant contributed to the supply of materials for concrete, such as granular blast-furnace slag, granulated slag, Rivermcnt, and blast-furnace slag cement with the operational cooperation of various ready-mix concrete plants. For the development of techniques for applying granulated slag to civil engineering projects, researchers were awarded the Prize of Contribution to Reuse of Resources by the Clean Japan Center in 1982.

At KSC, all civil and architectural engineers of KSC group have gathered once a year since 1971 to participate in a technical conference. This civil and architectural technology conference provides a forum where technical information can be exchanged and young engineers can acquire additional technical expertise. Since the number of papers has increased and the improvement in the contents of the papers was remarkable, an Outstanding Paper Prize (the Ueno Prize) was founded by senior engineers of the company in 1985. To date, 140 papers and reports have been published in Kawasaki Steel Giho (Japanese edition), and 324 papers and reports in the Journal of the Japan Society of Civil Engineers, the Journal of the Architectural Institute Japan, and elsewhere. Further, the number of patents and utility models applications submitted in the civil and architectural field has grown to 923, while the number of technically qualified staff members in the civil and architectural field involved with principal technology has reached 312. Many techniques have been recorded, maintained and used as technological resources of KSC's civil and architectural work.

11 Overseas Development of Civil and Architectural Engineering

Since KSC's supervisors were sent to Thailand's G.S. Steel in 1966, the company's civil and architectural engineers have participated in overseas projects for more than 20 years. Plant construction projects have included Thai Tin Plate (1972), Philippine Sinter Corporation (1974), Brazil's Tubarão and Capanema (1973-83), and an electrolytic tinning line in Malaysia (1980). The company has also participated in feasibility studies for smelting reduction of iron ore and electric furnace projects in the Middle East and Central America (1974-1977), a feasibility study of the Wologisi Mine project in Liberia, and a feasibility study for an integrated steelworks in Thailand conducted by the Japan International Cooperation Agency (JICA) and the Japan Iron and Steel Federation (1979).

Projects related to ports and harbors include sea berths for Philippine Sinter Corporation (1977), Lusteveco Quay (1978), NPC's power plant barge mooring facilities (1979 and 1984) and a Cebu dolomite ore loading facility (1980) in the Philippines, a Hsinta offshore coal unloading facility (1981-1982) in Taiwan, Philphos Port on the island of Leyte in the Philippines (1982), a Columbian fishing port pier (1983), Malaysia's Kota Kinabalu Port Expansion (1985), Indonesia's Panjang Port (1987), Mozambique's Quelimane Port (1987) and Nasipit Port in the Philippines (1987). The overall capabilities obtained by taking advantage of civil engineering technology related to port and harbor facilities are traditional features of KSC's civil engineering and contribute greatly to its engineering activities. The Philphos Harbor on the island of Leyte in the Philippines and the Hsinta offshore coal unloading facility project in Taiwan were awarded the 1985 Nishiyama Silver Prize for their technological achievements and contribution to Engineering and Construction Division activities.

In the field of steel structures, the supply of steel frames was the first step in overseas market development. Major achievements in steel-frame supply include electric furnaces and a CC plant for NISIC (1976), and warehouses for OSCO (1977) and Bandar Shahpour (1978), all in Iran; the Shangri-La Hotel (1978), Castle Peak Power Plant (1979), and UAE Ruwais (1979), the Cheung Kong Building (1982), and Lamma Power Plant (1983) in Hong Kong; Taiwan's CSC plants (1979); Pasar in the Philippines (1980); the NCB building (1980) and Aramco (1981) in Saudi Arabia; Bahrain's ALBA (1980); Thailand's Mae Moh Power Plant (1981); Malaysia's PNB building (1982); Alaska ARCO in the United States (1984); a Sawmill building in Burma (1983); Singapore's Paragon Shopping Center (1984), China's Shenzhen Development Center (1985) and Shijazung Steam Power Plant (1986); and Indonesia' Surabaya Steam Power Plant (1985). In the decade up to 1986, when the exchange rate fell to the ¥150 to the dollar level, the company supplied a total of 258 000 t of steel frames to 14 countries.

Other examples of building construction projects involving innovative technology worthy of special mention include the construction of the Philphos fertilizer plant in the Philippines in 1982, the supply of Riverwall materials for Singapore subway station buildings, and construction of a Burmese textile finishing plant building, a Hyatt Regency resort in Australia, and a resort hotel on the island of Maui in Hawaii, all of which were carried out in 1986.

Examples of water supply construction projects include the Manila waterworks PG6 and PG7 in the Philippines in 1980 and water-works and sewerage on the island of Palau in 1984 and 1986, water treatment facilities in Sandakan Malaysia in 1986 and in the Marshall Islands in 1987. In addition, the Singapore submarine pipe lines were laid between 1985 and 1987, and depot and workshop improvements were made in the Jabotapek railway project in Indonesia from 1987 to 1988.

The most noteworthy feature of KSC's civil and architectural techniques in overseas development is the overall management skills for overseas projects acquired through the construction of the Philippine Sinter Corporation on Mindanao Island and the Companhia Siderurgica de Tubarão Steelworks in Brazil. This valuable experience provided impetus for the company's overseas development of engineering activities. What is worthy of special mention is the fact that according to Engineering News Record (1987 edition), KSC stood 98th among the world's 200 major companies in the volume of orders for overseas projects. The company was ranked 160th only one year earlier, indicating the rapid pace of the overseas development of its engineering activities. Internationalization efforts have included the employment of engineers from the Philippines, Portugal, and the United States, and have clearly contributed to overseas engineering development.

12 Conclusions

The features of KSC's civil engineering and building construction technology, which has a history of 38 years, have been described from the viewpoint of four main streams of development. Field-practice-based engineering founded on practical experience is the tradition of the company. The number of past general managers who have played the driving role in the civil and architectural departments has now reached 29, and it is strongly hoped that the company's young engineers will build on their legacy.

As is apparent from the development of the interlocked steel pipe pile method in civil engineering and the development of steel-frame structures in general construction, KSC develops new techniques, in the construction of its own facilities, improves the design on the basis of experience, and then offers the product for commercial use. This is what is meant by field-practice-based engineering.

The efficient utilization of civil and architectural engineers was discussed within the company in the first half of the 1970s. As a result, the Engineering Center (EC) was established in 1973 and the present Engineering Division (ED) in 1976 to ensure that the techniques developed in the first and second development streams could be applied outside the company. In the Engineering Center period, most activities consisted of overseas construction projects directly related to KSC, such as the construction of a subsidiary sinter operation (Philippine Sinter Corp.) and the feasibility study for construction of a partly owned steelworks in Brazil (Companhia Siderurgica de Tubarão). After the Engineering and Construction Division was established, orders for various overseas projects (as mentioned above) were received and both hard- and software were marketed, mainly to the developing countries in Southeast Asia, the Middle East, and Africa. Recently, urban development projects such as hotel and housing construction have been carried out in advanced countries including the United States and Australia.

At home, the company continues to carry out construction projects such as condominiums, golf links, and tennis courts, in an integrated manner covering planning and design through the execution of construction.

The civil and architectural engineers of the KSC group are engaged in regional development projects such as resort, urban, and water-front development, by making full use of the technical experience gained at home and abroad, and will continue to accept challenges in new fields related to the construction industry.

As mentioned above, many architectural techniques have been developed and applied by maximizing the distinct advantages of being a steel maker with steel technology applicable to steel construction materials. The improvement of techniques began at the level of individual, elementary techniques and advanced to combined civil and architectural techniques, and has since advanced from combined techniques to what may be called comprehensive techniques. It is one of the strong points of the company's civil and architectural engineers that combined and comprehensive civil and architectural techniques are well utilized. These techniques are developed with the cooperation of partners, and it will be necessary to continue extensive technical and information exchange with various sectors of the construction industry in the future. The supply of technology capable of meeting new social needs in the 21st century is required, and the company's civil and architectural techniques will be expanded accordingly with a guiding policy compatible with society's needs and aspirations both at home and abroad.

In the midst of the three major global trends toward internationalization, high technology, and the development of a highly information-oriented society, the company's four major streams of civil engineering and building construction technology flow together to form a single great river, contributing to the improvement of society and the quality of life.

References

1) Publication Group for the Memories of C. Ueno in Kawasaki Steel Corp.: "Memories of Cyozaburo Ueno", (1985)
2) Engineering and Construction Dept. in Chiba Works of Kawasaki Steel Corp.: "Memorial Issue of the 35th anniversary of Engineering and Construction Department", (1987)
3) M. Tominaga, M. Nei, Y. Echigo, S. Kenmochi, S. Kage, and M. Hashimoto: "Construction of Large Scale Plant Foundations on Reclaimed Land", *Kiso-Ko (The foundation Engineering and Equipment)*, **4**(1976)5, 55-90
4) K. Hijikuro and M. Tominaga: "Soil Improvement Method for 40t/m^2 Ore Bed (Part 1, Part 2)", 15th Simposium on Soil Mechanics and Foundation Engineering, (1971)
5) M. Nei, I. Jo, and Y. Tanaka: "Soil Improvement in Chiba West Plant of Kawasaki Steel Corporation", *Tsuchi-to-Kiso (JSSMFE)*, **24**(1976)9, 33-40
6) K. Tsutsumi, M. Nei, and I. Jo: "Improvement Work for Weak Ground at Chiba West Site", *Kawasaki Steel Giho*, **10**(1979)2·3, 5-18
7) M. Tominaga, Y. Echigo, M. Hashimoto, and T. Kimura: "Realtime Construction Control Computer Simulation System (1)", The 11th Japan National Conference on Soil Mechanics and Foundation Engineering, JSSMFE, (1976), 1013-1016
8) M. Tominaga, Y. Echigo, M. Hashimoto, and T. Kimura: "Realtime Construction Control Computer Simulation System (2)", The 12th Japan National Conference on Soil Mechanics and Foundation Engineering, JSSMFE, (1977), 1121-1124
9) M. Tominaga, Y. Echigo, M. Hashimoto, and T. Kimura: "Realtime Construction Control Computer Simulation System (3)", The 13th Japan National Conference on Soil Mechanics and Foundation Engineering, JSSMFE, (1978), 1181-1184
10) M. Tominaga, M. Hashimoto: "Construction Control for Enbankment Based on Field Measurement of Lateral Displacement", *Tsuchi-to-Kiso (JSSMFE)*, **22**(1974)11, 43-45
11) M. Tominaga: "Case Histories of Soil Mechanics and Foundation Engineering C (The Example in Kawasaki Steel Corporation)", Case Histories of Soil Mechanics and Foundation Engineering 1, (1983), The Japanese Society of Soil Mechanics and Foundation Engineering (JSSMFE)
12) C. Ueno: "On the Application of Well Foundation Method in Chiba Works of Kawasaki Steel Corporation", Technical Conference of the Japan Society of Civil Engineers, (1954)
13) M. Komatsu, K. Hijikuro, and M. Tominaga: "Deep Foundation Method by Large Diameter Steel Pipe Pile Well", *Journal of the Japan Society of Civil Engineers*, **53**(1968)3, 19-24
14) Kawasaki Steel Corporation: "Tetsu", No. 123, (1984)
15) K. Hijikuro: "Reserch on Design and Construction Method for Heavy Structure Foundation by Steel Pipe Pile Well", Doctor's Thesis of Kyoto University, (1971)
16) F. Shima and K. Hijikuro: "New Construction Method of Bridge Foundation—Steel Pipe Pile Well Method", *Journal of the Japan Society of Civil Engineers*, **57**(1972)9, 12-19
17) M. Ishida, M. Hara, S. Nishiyama, and I. Jo: "Earthquake Response Analysis of No. 6 Blast Furnace of Chiba Works", *Kawasaki Steel Giho*, **13**(1981)2, 97-108
18) H. Yamahara: "Bearing Capacity Mechanism and Application Example of Steel Pipe Pile", *Tsuchi-to-Kiso (JSSMFE)*, **17**(1969)11, 19-27
19) M. Tominaga, Y. Echigo, and S. Kage: "Bearing Capacity of Large Diameter Steel Pipe Pile", Proc. of The 11th Japan National Conference of Soil Mechanics and Foundation Engineering, (1976), 653-656
20) M. Tominaga, T. Kimura, K. Shiota, and T. Fukaya: "A Method for Predicting Pile Behavior Based on the In-Situ Friction Meter", *Tsuchi-to-Kiso (JSSMFE)*, **35**(1987)12, 43-48
21) M. Komatsu, F. Shima, R. Mase, and C. Kato: "Corrugated Pipe Cellular Cofferdam Engineering Method", *Kawasaki Steel Giho*, **1**(1969)1, 78-91
22) M. Nei and H. Furuya: "Sheet Pile Bulkhead Series Supported by Coupled Pile", *Kawasaki Steel Giho*, 4(1972)2, 194-203
23) M. Komatsu, K. Hijikuro, and Y. Echigo: "Design and Construction of Ore Berth in Kawasaki Steel Corporation Mizushima Works −16 m, 160,000 DWT Class Ore Berth" *Seko-Gijyutsu*, **5**(1972)5, 89-100
24) K. Hijikuro, M. Nagano, K. Fujii, and T. Kamii: "Construction of −11.5 m Berth by Steel Pipe Pile Well Method", *Seko-Gijyutsu*, **5**(1972)5, 89-100
25) K. Tsutsumi, M. Nei, and I. Jo: "Construction of 154,000 DWT Raw Material Berth", 25th Kouwan-Koji Hokoku-Kai, (1979), 217-222
26) M. Tominaga, S. Kenmochi, T. Kimura, and I. Okumura: "Innovative Technology Utilized for Industrial Berth Construction", Proceedings of JSCE, 385(1987), 116-125
27) K. Ohbori, Y. Shoji, K. Takahashi, H. Ueda, M. Hara, Y. Kawai, and K. Shiota: "Static Behavior of Double Sheet Pile Wall Structure", *Report of the Port and Harbour Research Institute*, **23**(1984)1, 103-151
28) M. Hashimoto, K. Okamoto, and T. Morikawa: "Cathodic Protection System and the Maintenance of Harbor Facilities at Mizushima Works", *Kawasaki Steel Giho*, **17**(1985)2, 185-192
29) M. Tominaga, S. Gennami, and T. Koshiro: "Development of Self-Traveling Pile Driving (STEP) System", *Kensetsu-no-Kikai-Ka*, **432**(1986), 21-26
30) T. Sakaki, Y. Aoki, and K. Sugimoto: "Self-Traveling Pile Driving (STEP) System" *Kiso-Ko (The foundation Engineering and Equipment)*, **14**(1986)4, 68-71
31) S. Yamaguchi, K. Akahide, S. Takizawa, K. Agusa, M. Nagayasu, and M. Nishimura: "Development of Steel Box Column River Box W by KX Welding Method", *Kawasaki Steel Giho*, **8**(1976)1, 116
32) H. Ogino, S. Yamaguchi, I. Miyashita, and M. Yoshida: "Mass Products Method of Multi-Storied Apartment Houses (K-S Construction Method)", *Kawasaki Steel Giho*, **3**(1971)1, 65
33) H. Takemoto, J. Hashimoto, and M. Ichinose: "Construction of a High-Rise Rack Type Warehouse for Heavy Products", *Kawasaki Steel Technical Report*, No. **17**(1987), 104-108
34) T. Fujimoto, Y. Hori, S. Kato, H. Akashi, J. Tsuboi, and M. Saito: "Kawasaki Type Electroslag Automatic Internal Girth Welding Method for Large Diameter Pipes—KEIP System", *Kawasaki Steel Giho*, **11**(1979)3, 155
35) K. Kawamoto, H. Shirasuna, and H. Konno: "Construction of Submarine Pipeline between NIKKO and KAWATETSU", *Kawasaki Steel Giho*, **6**(1974)4, 124
36) Y. Odaka: "Steel Sleeper and Elastic Fastening Device", *Kawasaki Steel Giho*, **3**(1971)4, 152-161
37) H. Obata, T. Ozeki, J. Katsuki, H. Marushima, M. Furuuchi, and M. Takahashi: "Large-Size Torpedo Car with Narrow Rail Gauge at West Plant of Chiba Works", *Kawasaki Steel Giho*, **10**(1978)2·3, 137
38) H. Shimizu, H. Furuya, and T. Sakaki: "Planning and Designing of Civil Engineering Works for the Philippine Sinter Plant", *Kawasaki Steel Giho*, **9**(1977)1·2, 69-82