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# Construction of Steel Plants and Coastal Engineering Projects

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Kawasaki Steel Corporation has developed Chiba and Mizushima integrated steelworks on reclaimed lands. The construction of these works was not limited to the construction of plants but extended to the total development of the water front area near the Chiba and Mizushima Works. The surrounding region and the construction history of the two steelworks are described. The developed technologies, which are useful for any water front construction, are introduced, such as the interlocked steel pipe pile method, walled steel pipe pile well method, prefabricated corrugated cell bulkhead, underwater junction method, and fast offshore pile driving system.



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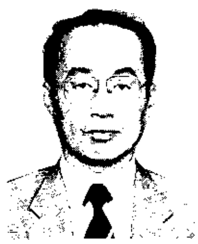

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## 1 Introduction

Japan comprises four large islands, Hokkaido, Honshu, Shikoku, and Kyushu, with many smaller surrounding islands. In addition, the coastal configuration is complex, and the total coastline is long, extending for 34 265 km. Thus, Japan with a coastline length per unit land area of 92.1 km/1000 $km^2$, has the second longest coastline next to Denmark in the world.[1] This has provided the lives of the inhabitants with a close relationship with the sea since ancient times. The nature of coastal area utilization, however, has changed with the passage of time.

Formerly, the coastal areas of Japan developed mainly around harbors and fishery and marine transportation bases, assuming an important role in the modernization of the country from the Meiji era onward and in the rebuilding of the economy after the Second World War and the subsequent period of high economic growth. Coastal areas have to date developed principally as spaces for the distribution of consumer goods and for industrial activities. Especially during the period of high economic growth, large-scale industrial areas were created by coastal land reclamation, with benefits to the economic prosperity of Japan which still continues today. In recent years, coastal development projects have been actively pursued in various parts of Japan, aimed at structuring a water-oriented living environment in which the following activities are well harmonized: ① the requirements of internationalization, ② the creation of an information-intensive economic climate, and ③ urban development of the society in the 21st century. The sophistication and qualitative improvement of society are to be promoted by introduction of a variety of functions relating to consumer distribution and industry, and at the same time various functions closely related to social and economic life will be established[2,3].

Kawasaki Steel Corp. has a long history of development of coastal areas, having assumed a pioneering role in the creation of coastal industrial zones during the period of high economic growth in Japan by the construction of integrated steelworks on reclaimed lands at

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Chiba and Mizushima. In the construction of both of these plants, a number of new techniques were developed related to extensive dredging, land reclamation, improvement of soft ground in coastal areas, and the construction of foundations and buildings for large-scale heavy equipment such as blast furnaces, steelmaking equipment, and rolling mills, as well as the establishment of infrastructure facilities such as harbors, roads, railways, and pipe lines. In areas adjacent to these steelworks, a variety of amenities were constructed, and residential facilities were also created in the surrounding region, leading to the establishment of coastal cities centered around the steelworks. Thus, it may be safely said that the construction of Chiba and Mizushima Works involved a history of comprehensive engineering, not limited to plant installation but also including regional development along the coastline.

This paper reviews the history of the construction of these plants and at the same time introduces the principal techniques developed during the construction period.

## 2 Present Status of Chiba and Mizushima Works and Surrounding Areas

### 2.1 Location

**Figure 1** shows the location of Chiba and Mizushima Works. Chiba Works is located south of Chiba City on

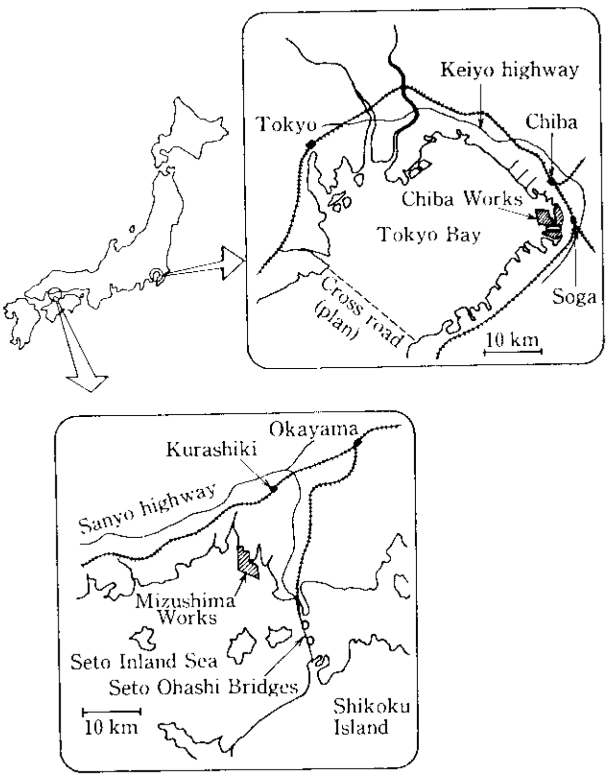


Fig. 1 Location of Chiba and Mizushima Works

the northeast side of Tokyo Bay. On the southern side, the Keiyo Industrial Area extends to the vicinity of Kisarazu City. Chiba Works has developed along with Chiba City since it was established in the Keiyo Industrial Area in 1951.

In recent years, the area surrounding Chiba Works has attracted attention as a location which incorporates the various projects described below. Among various concepts related to the development of the coastline along Tokyo Bay, two projects are worthy of note, the planned construction of the Trans-Tokyo Bay Highway connecting Kawasaki City with Kisarazu City, which is to be open to traffic in 1995, and a project involving the installation of facilities for an international trade fair to be held at the New Makuhari Metropolitan Subcenter in the Western part of Chiba City and scheduled for completion in 1989[4]. For these projects, Chiba Works and the surrounding area are now in the limelight.

Mizushima Works, in contrast to Chiba, is located in a distinctly natural environment on the northern coast of the Seto Inland Sea, south of Kurashiki City, in Okayama Prefecture. Since the Mizushima Works was established in 1961, this area developed as the center of the Mizushima Coastal Industrial Zone. The surrounding area includes tourist resorts such as Kurashiki, where the warehouses and residences have retained the Edo period atmosphere through restoration, the scenic beauty of Mt. Washu, and the Inland Sea, an area popular for water sports fishing and island tours. In addition, the area has become a gateway connecting the Main Island of Honshu with Shikoku since the opening to traffic of the Kojima-Sakaide route of the Honshu-Shikoku Bridges (Seto Ohashi).

### 2.2 Steelworks and Surrounding Regions

**Figure 2** shows Chiba Works and the surrounding area. Chiba Works consists of the Main Plant, Oihama

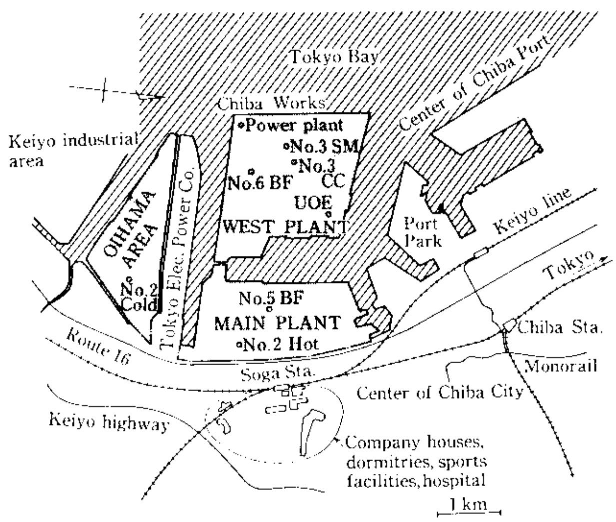


Fig. 2 Chiba Works and its circumference

area, and the West Plant, which is created by land reclamation along the shore south of Chiba City. The JR Uchibo- and Sotobo-lines and the Tokyo-Chiba (Keiyo) Highway are adjacent to the Main Plant, and company facilities such as dormitories, housing, and a hospital are in the area near Soga Station. These installations are an integral part of the area around Chiba Station, and as such, form the center of Chiba City. North of the integrated steelworks, a sea route provides access to the harbor for large vessels of up to 150 thousand DWT. This area is actually the center of Chiba Harbor. In recent years, the development of the area surrounding Chiba Works has had an economic impact so significant that a Chiba Express Line addition to the JR Keiyo Line is scheduled to open to traffic. Soga Station has become a focal point for traffic connecting Tokyo with the Boso Peninsula. A monorail line in Chiba City was opened in March 1988 and is expected to be extended to the coast, and redevelopment of Chiba Harbor is now progressing. As stated above, this region forms a complex type of urban coastal area, which encompasses Chiba Works as an industrial zone, a residential zone centered around Chiba and Soga Stations, and a consumer distribution and business district centered around Chiba Station and Chiba Harbor. There is also a leisure area west of Chiba City. This is an interesting example of a case in which an integrated steel plant constructed on reclaimed land has given birth to an industrial zone, and also promoted the development of an urban-style residential area. Although Chiba Works is faced with environmental problems because of its location close to a city, the steelworks is considered an excellent example of coastline usage aimed at the environmental compatibility of a steel manufacturing industrial area and residential facilities along a waterfront.

**Figure 3** shows Mizushima Works and its surrounding area. Mizushima Works faces the Seto Inland Sea, which is a natural waterway. The steelworks has been developed by the reclamation of a shoaling beach along the coast and a delta formed at the mouth of the Takahashi River, one of the largest rivers in the Chugoku District. In the area surrounding this region, one of Japan's leading industrial areas has developed, centered around an oil-fired thermal power station, and including a number of industrial plants. On the Takahashi River and in Mizushima Harbor, gas and petroleum pipelines have been laid, supplying energy to the adjacent plants. The north area of the steelworks includes dormitories, company housing, and athletic facilities, and at the foot of Mt. Washu, leisure facilities such as a recreation area and a riding club have been established. In recent years, simultaneously with the construction of the Honshu-Shikoku (Seto-Ohashi) Bridges, a comprehensive development project for Mt. Washu has been effected, and includes the construction of a golf course laid out near Mt. Washu, in which KSC participated, as well as a unique waterfront area constructed to include a luxury resort not far from the steelworks.

**Table 1** shows the scale of Chiba and Mizushima Works and the surrounding facilities. Chiba Works has 12 000 employees and covers a land area of 863 ha, with a reclaimed land volume of 72 million $m^3$, while the figures for Mizushima are 10 200 employees, an area of 1128 ha, and a reclaimed land volume totalling 72 million $m^3$.

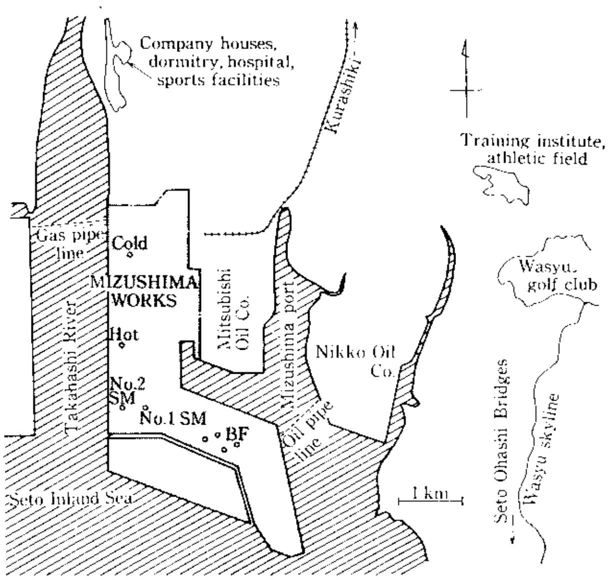


Fig. 3 Mizushima Works and its circumference

Table 1 Summary of Chiba and Mizushima Works

| | Items | | Chiba | Mizushima |
|---|---|---|---|---|
| Works | Area of land | (ha) | 863 | 1 128 |
| | Reclamation | (million $m^3$) | 72 | 98 |
| | Berth and revetment | (km) | 20 | 22 |
| | Railway | (km) | 113 | 87 |
| | Pipe line | (km) | 270 | 207 |
| | Pure water | ($m^3$/d) | 1 461 000 | 2 137 000 |
| | Sea water | ($m^3$/d) | 1 578 000 | 481 000 |
| | Electric power | (MWH/month) | 245 000 | 216 000 |
| | Number of employee | | 12 000 | 10 200 |
| Welfare facilities | Dormitory | (people) | 1 700 | 1 200 |
| | Company house | (people) | 2 400 | 3 200 |
| | Training institute | (people) | 580 | 610 |
| | Hospital | ($m^2$) | 14 416 | 32 000 |
| | Gymnasium | ($m^2$) | 6 437 | 7 661 |
| | Tennis court | | 6 | 9 |
| | Athletic field | ($m^2$) | 40 100 | 95 470 |

## 3 History of Steelworks Construction[5)]

In constructing an integrated steelworks to meet increasing worldwide demand for steel after World War II, the essential site conditions were: ① an extensive site to meet the physical requirements of iron and steel production, ② habor facilities ensuring easy transportation of raw materials such as iron ore, and coal, and finished products, and ③ a favorable environment in terms of soil and climatic conditions, availability of power and sufficient water for industrial use, ④ an adequate labor force, convenient traffic conditions, and ⑤ proximity to the market. As regions closely meeting these requirements, the coastal areas of Chiba and Mizushima were selected, and land was reclaimed for steelworks construction. **Photo 1** shows the reclamation work for the Main Plant at Chiba Works (1952), and **Photo 2**, the area before the reclamation for Mizushima Works (1961). The area surrounded by broken lines is the site selected for land reclamation.

Photo 1 Reclamation of Chiba Works main plant (1952)

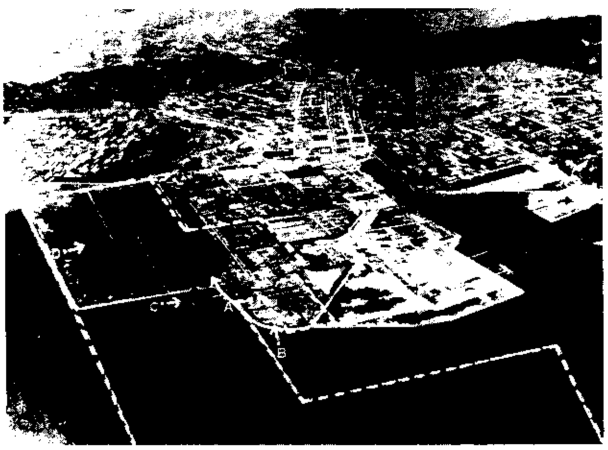

Photo 2 Before reclamation of Mizushima Works (1961)

**Figures** 4 and 5 show the ground profiles of the Chiba and Mizushima sites respectively. The Main Plant of Chiba Works is located on land created by the reclamation of a shallow sea area near the old coastline, while the West Plant is on a manmade island created by reclamation of an area offshore of the Main Plant. Mizushima Works was built on old reclaimed land and land created by the reclamation of a large area along the coast.

**Table 2** shows the history of the construction of the two steelworks and the major technologies developed. Reclamation for the Main Plant of Chiba Works started in 1951, and the construction of the front berth, No. 1 blast furnace, and No. 1 Steelmaking Plant was completed in 1953, with production operations started at the same time. Subsequently, additional blast furnaces were added and the construction of rolling mills was carried out. As production increased, however, a new site became necessary, resulting in the construction of Mizushima Works along with the reclamation of the Oihama Region at Chiba Works, beginning in 1962. As shown in Figs. 4 and 5, the subsurface soils at the Main Plant of Chiba Works consist of good quality sand, whereas at Mizushima Works, the site was prepared on a weak stratum containing clay and silt 15 to 20 m thick. In addition, under pressure to commence operations quickly, engineers were forced to overcome construction difficulties. New technologies were therefore developed to overcome these stringent conditions. Typi-

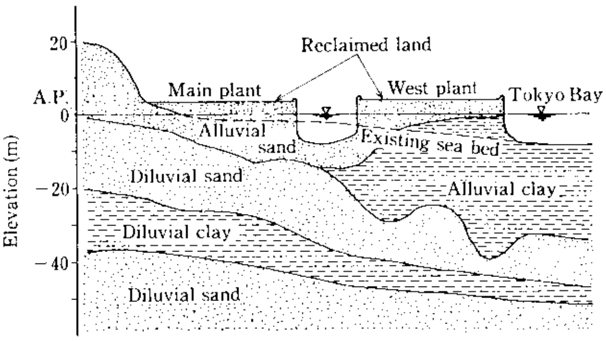


Fig. 4 Subsurface soil profile of Chiba Works

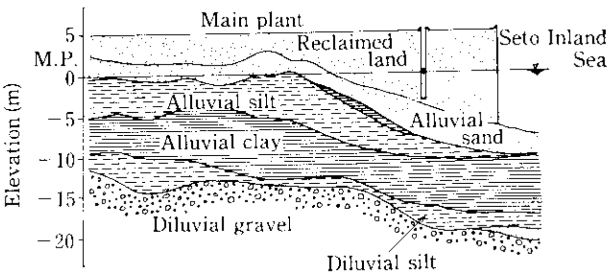


Fig. 5 Subsurface soil profile of Mizushima Works

Table 2 History of construction and developed technologies

| | | 1960 — 1970 — 1980 — (Year) |
|---|---|---|
| Chiba Works | Main plant | ○Reclamation start ○No.3 BF<br>○Front berth ○No.4 BF, No.2 SM ○No.1 CC, connection bridge<br>○No.5 BF ○No.2 CC<br>○No.1 BF, SM, US ○J berth<br>○No.2 BF, No.1 HOT, No 1 COLD |
| | Oihama area | ○Reclamation start ○EGL, APL<br>○No.2 COLD ○No.3 CAL |
| | West plant | ○Reclamation start ○Power plant, No.6 BF<br>○EB berth No.3 SM, No.3 US<br>○EA, SA berth ○No.3 CC<br>○UOE ○NA berth |
| Mizushima Works | | ○Reclamation start ○No.2 SM, No.3 BF, No.2 CC<br>○No.4 BF<br>○No 1 US ○No.6 CC<br>○No.1 BF, No.1 SM<br>○No.1 CC ○No.3,5 CC<br>○COLD, No.2 US, HOT |
| **Developed technologies** | | **○Interlocked steel pipe pile** **○Fast marine erect**<br>**○Corrugated cell**<br>**○Walled steel pipe pile well** **○Under water junction method**<br>**○Sheet pile revetment supported by combined piles** |

BF: Blast furnace SM: Steel making shop US: Universal slabbing mill CC: Continuous casting plant

cal examples include berth and revetment techniques using the interlocked steel pipe pile method,[6] prefabricated corrugated cell bulkheads,[7] and the walled steel pipe pile well method[8] developed for the blast furnace foundations.

After the completion of one cycle of construction for the major equipment at Mizushima Works, the next stage of construction activities at Chiba Works began. The reclamation for the West Plant site[9] started in June 1969. **Figure 6** shows the outline of the reclamation of the manmade island for the West Plant. The reclamation was conducted concurrently with the dredging of the channel in the harbor, and concluded in December 1976 with a reclaimed volume for 414 ha, of about 50 million m$^3$. The subsurface soil conditions at the West Plant, as shown in Fig. 4, consist of clay and silt up to 35 to 40 m in thickness. This layer was much softer than that at Mizushima Works. After the execution of numerous studies based on experience obtained at Mizushima, the development of technologies adaptable to soft ground was realized.

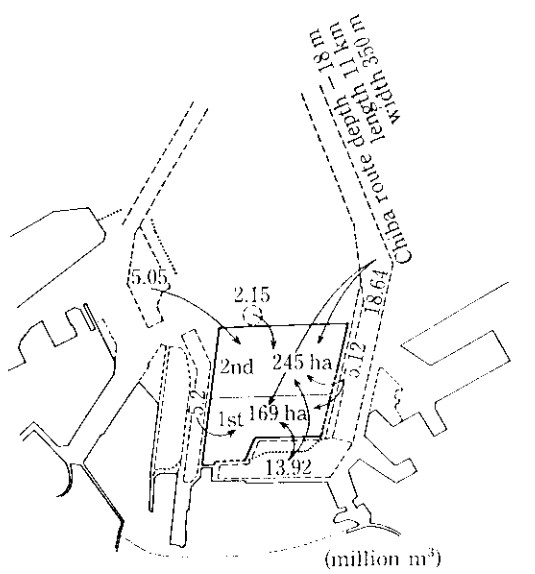


Fig. 6 Dredging and reclamation of West Plant

These included technologies adaptable to soft ground, such as sheet pile revetments supported by combined piles[10], construction of the blast furnace foundation[11] by the double walled steel pipe pile well method, and the real-time construction control (RCC) system[12], in which field measurement data is analyzed and fed back into the design. In addition, soil improvement technologies such as the clay-mixing-consolidation (CMC) method[13] were also developed.

Other technologies developed through the construction of the steelworks included berth and revetment construction techniques such as the underwater junction method[14], the Marine Erect pile driving system[15], a behavior calculation system for double sheet pile wall structures[16], a method of calculating the force of breaking waves on pier support piles[17]; foundation construction techniques such as a bearing capacity calculation method for piles using friction meter tests[18]; infrastructure equipment techniques such as steel sleepers[19]; and architectural techniques such as the Super Wing long

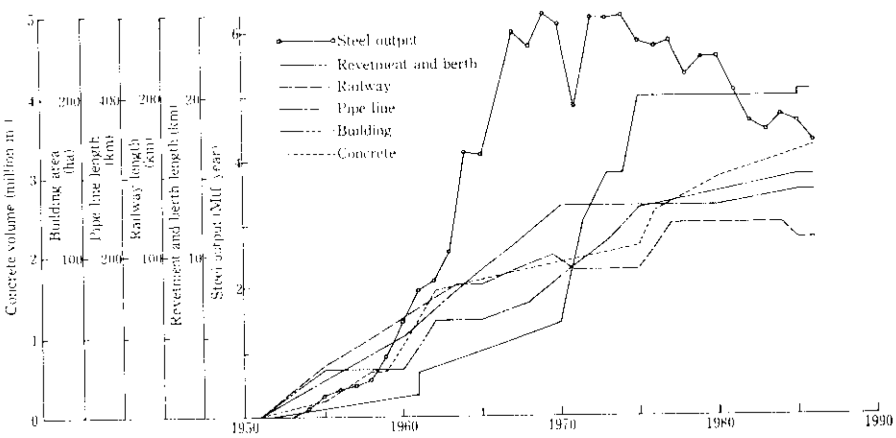


Fig. 7 Change in construction quantity with time (Chiba Works)

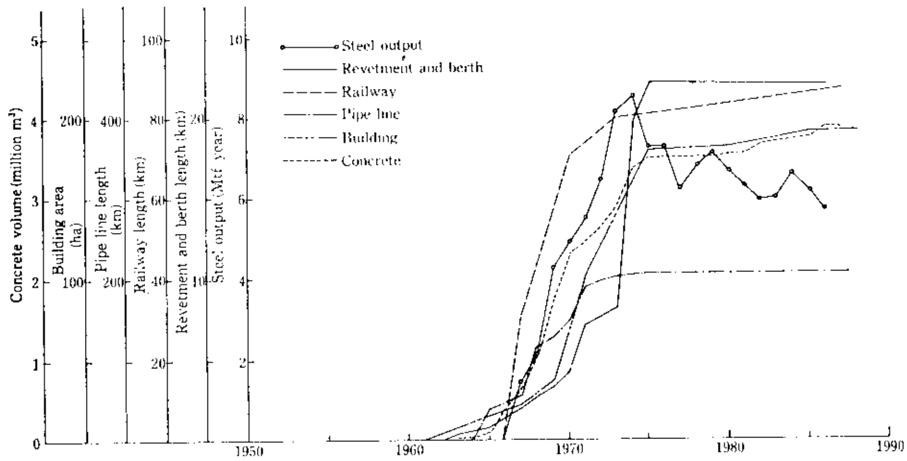


Fig. 8 Change in construction quantity with time (Mizushima Works)

span structure and the automatically controlled high-rise rack type warehouse.[20] Typical examples of these technologies will be discussed later.

**Figures** 7 and **8** illustrate the changes in the following parameters in the construction of Chiba and Mizushima Works respectively: the total length of revetments and berths, railways, and pipe lines, the areas of buildings, the volume of concrete, and the production of crude steel. The reclamations for the Oihama Area and the West Plant at Chiba Works were conducted in stages after the reclamation for the Main Plant. This continuously increased the total length of revetment and berth, and was accompanied by a simultaneous extension of equipment. Other construction increased linearly until around 1975. At Mizushima Works, on the other hand, a drastic increase in the production of crude steel as well as other products was effected during the years from 1966 to 1974, prompted by the rapid construction characteristic of the period of high economic rate of growth during these years.

## 4 Coastal Development Technologies Resulting from Steelworks Construction

The construction of both Chiba and Mizushima Works required the creation of land in sea to support a group of large-scale industrial plant structures to which raw materials were to be carried in bulk and from which products would be shipped, and which would provide a suitable working and living environment for tens of thousands of employees. Comprehensive engineering similar to that required in urban development was fostered during the construction of these plants, while the development and implementation of strategies to minimize steel production time was carried out on new land. These goals were achieved by the establishment of optimum plans in the layouts and construction of various facilities, including factors such as the location of production equipment, harbors, roads, railways, bridges, water supply lines, and other infrastructure based on detailed investigation of natural conditions such as topographic, soil, climatic, waves, and tidal current, and various other conditions such as power and water supply, traffic, and the environment.

Of the numerous technologies developed in the course of the steelworks construction, the development of design and construction technologies for revetments and berths deserves special attention, since both steelworks were constructed on reclaimed land. These revetment and berth construction technologies offer great advantages for the future development of coastal areas. The major technologies will be introduced in the following paragraphs.

### 4.1 Interlocked Steel Pipe Pile Method

The interlocked steel pipe pile method is a construction method applicable to the wall construction of various civil engineering structures, including retaining walls, temporary cofferdams, foot protection work, embankments, break water revetments, and berths. In this method, steel pipe piles provided with interlocking joints are placed by continuous driving in a wall shape. This technique was developed in the course of constructing the berth at Mizushima Works[6]. **Photo 3** shows an example of the technique adopted for the construction of a double sheet pile wall bulkhead. Using this technique, bending resistance can be increased without increasing the total steel weight per unit of construction length by enlarging the outside diameter within the design limits allowed for the wall thickness of the steel pipe. This permits sufficient flexibility relative to the size of the structure. Interlocked steel pipe piles, having the properties of piles as well, can be expected to have a fairly high bearing capacity, which is particularly useful for quay walls for the loading and unloading of heavy loads. These excellent characteristics contributed to the extensive adoption of this method in the construction of revetments and berths. In recent years, this technique has also been adopted for the construction of berths in the Industrial Estate Project on Leyte Island in the Philippines.

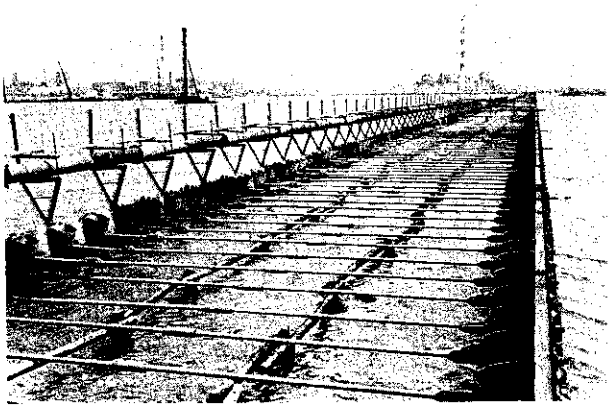

Photo 3 Interlocked steel pipe bulkhead method showing tie rods connecting rows of pipe piles at Mizushima Works

### 4.2 Walled Steel Pipe Pile Well Method

The walled steel pipe pile well method is applied to the construction of foundations to support heavy structures by producing a well structure using a pipe pile wall configuration of circular shape. The method was first adopted[8] in the foundation construction for the blast furnaces at Mizushima Works in place of the reinforced concrete well, large diameter steel pipe pile, or pneumatic caisson methods which up to that time, had been used for the construction of blast furnace foundations.

This method features the creation of a gravity type load-bearing aseismatic structure on a strong debris layer by boring through the soft silty layer, and allows safe, reliable, and rapid construction under subsurface conditions of a loose upper sand stratum and weak silty layer. Where this method is applied to underwater foundations, such as those in coastal and river projects, its capability of serving as a pile well main unit and temporary cofferdam helps reduce the time and cost of construction. Thus, the method has come into wide use as in underwater foundations for bridges spanning rivers. **Photo 4** shows an example of a bridge foundation under construction.

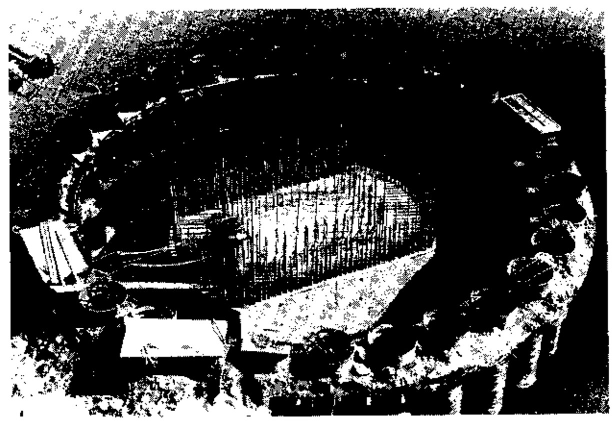

Photo 4 Walled steel pipe pile well method applied in heavy bridge foundation

### 4.3 Prefabricated Corrugated Cell Bulkhead

A cellular bulkhead type structure is one made into a gravity type structure by back-filling a cellular type shell composed of steel piles or steel plates. Stability can be maintained with this type of structure with backfill in the cell and only a small amount of steel. In addition, its large resistance to external forces makes it quite suitable for use in breakwaters and revetments. Initially, this method was used in pile cell form, but it was later supplanted by the steel sheet cell type. A corrugated cellular cofferdam using corrugated sheets produced by the corrugation of thin sheets was also developed during the construction of Mizushima Works[7].

This method permits economical and rapid construc-

Photo 5 Prefabricated corrugated cell bulkhead method at Mizushima Works

tion because the use of corrugated steel sheets facilitates the formation of a cellular shell of high rigidity with thin steel sheets. The light weight of the structure also makes for easy transportation and assembly by bolting. Filling with sand creates a wall capable of withstanding external forces such as waves. **Photo** 5 shows the construction of a corrugated cellular revetment at Mizushima Works. In rcent years, this method has been adopted for the construction of a 5 000 DWT berth at Batangas, Philippines, indicating its overseas acceptance.

### 4.4 Underwater Junction Method

The underwater junction method is one in which a truss-shaped structure is created through the installation of diagonal bracing and horizontal struts on steel pipe piles which have been driven into water. First, an external pipe, one size larger than the driven pile, is dropped from the upper part of the pile. Next, the pile and external pipe are secured with expansion mortar poured into the gap between the two. A truss structure is then formed by joining the pipes using braces with the external pipes, which have been prefabricated so that diagonal braces can be installed, as a junction point. Joining individual piles into a single structure with braces gives the structure high rigidity, making it possible to reduce the number of piles and the pile diameter[14].

This technique, which was developed during the construction of the 150 thousand DWT raw material berth at Chiba Works, has since been adopted for the construction of highway bridges and fishing piers. **Photo 6** shows the construction of the raw material berth at Chiba Works, where the junction portions of external pipes joined with braces are being suspended prior to installation.

### 4.5 Marine Erect Pile Driving System

The marine erect pile driving system is a method in which, in the driving of foundation piles for piers, the pile driver is advanced over piles already driven to drive other piles aligned on the pile line ahead on erecting beams. **Photo** 7 shows the driving of pipe piles for the foundation of a new products-berth.[15,21]

This method improves pile driving accuracy because the operation is not disturbed by waves, raising opera-

Photo 6 Underwater junction being installed at Chiba raw material berth

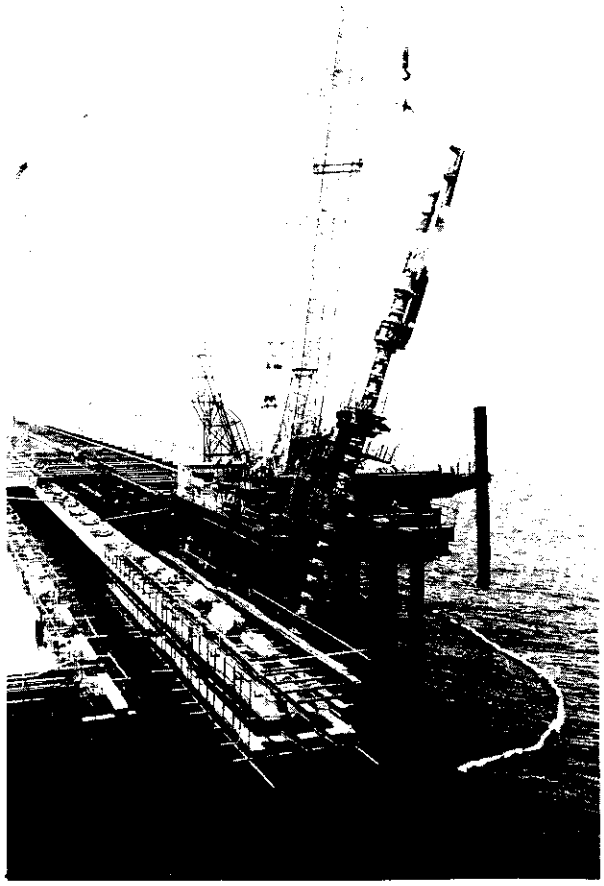

Photo 7 Pile driving by fast marin erect system at Chiba product berth

tional efficiency while reducing the number of operations. Further, with this method it is possible to drive batter piles and handle long large diameter piles. The ease of assembly and disassembly also helps reduce relocation costs. The method is extremely effective in the construction of projection type piers, detached piers, and access causeways to manmade islands.

## 5 Development of Engineering Activities

In the development of its domestic and overseas engineering activities, the company was able to use to full advantage the experience acquired as a coastal area developer in the construction of two integrated steelworks and a variety of infrastructure facilities such as company housing, hospitals, and educational facilities, gymnasiums, etc.

The present period has been called a second era of reconstruction of the Japanese Archipelago, as the nation prepares to enter the 21st century as a mature economic society. In particular, an increase in large scale development in and around the national capital region and local development represented by resort construction are now drawing attention. Numerous concepts are being brought forward regarding the construction of a city, which would stand on a man-made island and include a number of high-rise intelligent buildings and teleports, in areas, of intensive land utilization such as Tokyo. Other projects such as the construction of industrial trade fair buildings and international conference halls on reclaimed coastal land are either in the planning stage or already under construction. In addition, resort construction plans, which include marina and marine communities have been presented in various parts of Japan.

The field of local development with such waterfront projects at its center is one of the pillars of the company's engineering activities. The company's policy for local development is based on three points: (1) efficient utilization of company-owned land, (2) purchase of land for development, and (3) the creation of new ventures with the company's participation in management and administration. The foundation of local development activities is a user-oriented business philosophy, a capability of carrying out large projects, to date cultivated in the areas of steelmaking and engineering, and the company's social credibility, financial capabilities, and an ability to marshall a wide range of technical and other resources within the company group.

Another pillar of the company's engineering activities is overseas harbor construction projects. Beginning with the construction[22] of a sinter plant with a large-scale berth capable of accommodating vessels of the 250 thousand DWT class on Mindanao Island for Philippine Sinter Corp. between 1974 and 1977, the company has handled a number of overseas coastal development projects. The map in **Fig. 9** shows the location of completed and progressing projects in Southeast Asia. From the beginning, the results at PSC were recognized, which prompted further orders for harbor construction in the Phillipines. Since that time, projects have been completed in a number of countries such as Taiwan, Malaysia, and Indonesia, winning the company a high reputation as a marine contractor. Many technologies developed in steelworks construction have been put to use in overseas projects, as represented by a petroleum berth at Batangas, the Philippines (1979) using the prefabricated corrugated cell bulkhead method, harbor facilities at Leyte, the Philippines (1981-1984), where an interlocked steel pipe pile wall berth and double sheet pile

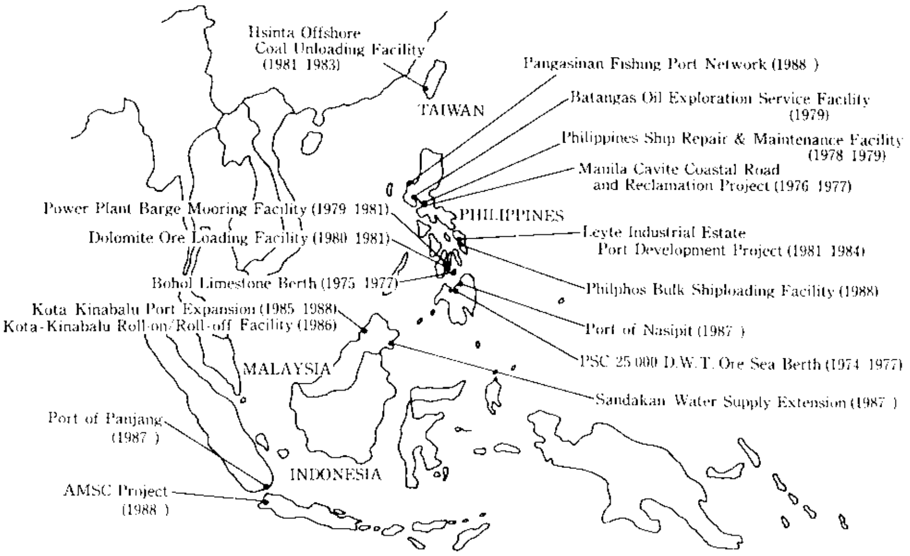


Fig. 9 Water front engineering in South-East Asia

wall berth were constructed, a coal pier in Hsinta, the Republic of China (1981-1983), which employed large-diameter UOE steel pipes for 1500 mm outside diameter piles, a pier in Kota-Kinabalu, Malaysia (1986) using heavy duty anticorrosion treated steel pipe piles (KPP piles), and a harbor pier at Panjang, Indonesia (1987).

## 6 Conclusions

The construction of Chiba and Mizushima Works show a history of coastal development, and stimulated a variety of forms of local development while providing a basis for the development of numerous construction technologies. In recent years, the nature of sea area utilization, as discussed above, hs shifted from an industrial orientation to a living-environment orientation. In this connection, it is expected that the company's engineering capabilities, which have been cultivated through the construction of coastal steelworks, will be given free play in the various types of coastal development projects expected to evolve on a large scale in the future. For its part, the company will devote itself to the development of further new techniques, as well as positive participation in domestic and overseas local development projects.

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