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Steel Structure, and Continuous Casting of Steel

Technical Features of Steel Structure Construction by Kawasaki Steel

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Steel structure construction by Kawasaki Steel consists of the following three basic techniques which are combined into total engineering: Advanced metallurgical techniques for production of steel construction materials; welding and joint techniques for the construction of steel structure; and structural planning and designing techniques based on structural analysis, dynamic analysis for earthquakes, fatigue analysis and corrosion prediction. Kawasaki Steel is developing these combined techniques as its own steel structure construction techniques. In this paper, technical features in the field of frame work for building, bridge, harbour structure, revetments, and so forth, are presented.

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1 Introduction

This paper presents an outline of the technical features of steel structure construction by Kawasaki Steel as the keynote article in this special issue on steel structures. The background includes the two main influences: One was the unprecedented Hanshin-Awaji Earthquake which struck Kobe and the neighboring area in January 1995 with heavy loss of life and a devastating impact on residences, plants, office buildings, elevated highway bridges, and other structures, and has led to a fundamental reevaluation of the reliability of structures, and requires the reconstruction of design and construction systems. As the second influence, Kawasaki Steel's Bridge & Steel Structure Div. was established in April 1994 in a form which combines the total capabilities of the Kawasaki Steel Group in order to expand and develop the company's steel structure business. The present time is a critical period for strengthening the department's business base so as to secure a position in the industry and improve its competitiveness. From the above, we are confident that on this occasion, a review of the trends in the steel structure technology in this company and an examination of the features of the technologies which the company possesses will be significant for ascertaining the direction of technology in this field in the future.

To describe briefly the features of Kawasaki Steel's steel structure technology, the company, as a maker of steel construction materials, supplies products suited to market needs, and in addition to joining techniques, such as welding and high strength bolts for its products, also possesses, in total, design technologies which include mechanical behavior analysis, fatigue analysis, and corrosion-proofing corresponding to the construction method and applied structures in construction members and whole structures comprised of such members, and is developing engineering by combining those element technologies. Specifically, the company supplies high-strength steel, low yield-stress ratio steel, fireproof steel, atmospheric corrosion resistant steel, non-magnetic steel, super mild steel, etc. for bridges and steel frames and large-size deformed bar, steel plates with deformed shapes, high-strength shear reinforcing bars, and other composing steel members for concrete, and has also aimed at quality improvement, efficiency improvement, and labor work elimination through the application and expanded use of electroslag welding, submerged arc welding, MIG, TIG, and other welding technologies as joint connecting techniques in the fields of use of these products. In design aspects, Kawasaki Steel has contributed to the creation of structures with excellent functionality and economy by providing design materials such as numerical analysis using FEM (finite

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element method) and structural analysis based on large-scale structural experiments, as well as research on techniques for durability improvement which includes fatigue, brittle fracture, and corrosion resistance.

The following describes, by type of structure, Kawasaki Steel's unique steel structure technologies which combine the element technologies mentioned above.

2 Architectural Structures

2.1 Building Steel Frames

2.1.1 Steel columns

It would be no exaggeration to say that the technologies relating to building steel frames are concentrated first in the development of columns as products; examples include build-up box columns (River Box),[1] jumbo-size rolled H-shape columns,[2] cold-formed box columns (River Column-P, R),[3] the concrete filled tube column (CFT),[4] and others.

Based on the application of efficient submerged arc welding (KX method) to make up build-up box columns by welding, the development of techniques for the quality of joints and cost reduction has been established, and products are being shipped to market. These products have won a favorable reputation with users by offering a higher degree of freedom in the selection of sectional dimensions than is offered by rolled box columns, and have now been adopted in large-scale steel frame construction, with the new construction of the Shinjuku Washington Hotel as a first example.

Jumbo-size rolled H-shape columns have a maximum flange thickness of 80 mm, posing problems especially in the welding of beam-column connections and in mechanical behavior in the thickness direction, but intensive research on these problems in full-scale tests has made it possible to achieve the development of a commercial product with excellent energy damping characteristics in earthquakes, which was recently adopted in the construction of the Rinku Tower Gate, a development project related to the New Kansai Airport. In recent years, high quality products of this type have also been developed by applying Kawasaki Steel's leading edge rolling technology, TMCP (thermo-mechanical control process,) and an investigation of structural properties as above is now being conducted and should shortly reach the stage when it will be possible to supply this product to the market.

Solution of the structural properties of column joints with beams is also an important task with cold-formed box and concrete filled tube columns, and technical development of ring stiffener reinforcements, extra-thickness reinforcements, and simply-designed joints aimed at labor saving cost reductions, etc. has been accelerated. Among design techniques for these joints, the company has established a unique rational design system based on the application of yield line theory,[5] which makes it possible to predict the mechanical behavior of the said parts with high accuracy.

The requirements of joining work in beam-column connection and design are mutually contradictory, but in the recent Hanshin-Awaji earthquake disaster, the damage is estimated to center on these parts. In Kawasaki Steel, the examination of the mechanical behavior of the area around beam scallops and the development of non-scallop welding[6] have been completed in advance of this eventuality in a system which can respond to the needs of the times. For the future, it is considered necessary to diligently promote buckingless welding methods and welding methods for quality improvement and labor saving, etc.

2.1.2 Earthquake-proof braces and earthquake-proof walls

Imparting efficient earthquake-proof characteristics to steel skeleton construction demands a reconstruction of seismic design methods for above mentioned structural parts and execution with high quality, but the introduction of new vibration control techniques is also absolutely necessary.

Kawasaki Steel has recently developed earthquake-proof braces and walls[7,8] with high seismic damping characteristics using the features of super mild steel, which has low strength (200–300 N/mm^2) and high ductility (50% or more), establishing a new vibration control technique for steel skeleton construction (**Photo 1**).

This technology has also been adopted recently in actual projects, but in the future, the authors are confident that, if the popularization of this technology can be achieved, rational designs which fully demonstrate the superiority possessed by steel will be recognized, and it will make a major contribution to improving the competitiveness of steel skeleton construction.

Photo 1 Anti-earthquake wall panel for steel frame work

2.1.3 Efficiency improvement in steel skeleton making

On the other hand, Kawasaki Steel also possesses automation and full-automation (unmanned operation) technologies for steel skeleton joint welding as unique technologies in the field of steel skeleton making. The basic type of the steel skeleton normally comprises a column called the "shaft," to which four beam-end brackets are attached at 90° angles, but efficiency improvement in the welding of this crossing is linked to immediate cost reductions and is therefore required for improved competitiveness. Automation of vertical and horizontal welding as well as of flat welding has been established by Kawasaki Steel by introducing an articulated welding robot[9] for these parts with the aim of improving productivity in steel skeleton processing. At present, positive results have been obtained by introduction at plant lines. Projecting the future of this technology, continuous operation 24-hours-a-day will be realized through fully-automated (unmanned) operation, making it essential to establish weld defect inspection during operation and in-process control of welding and other key technologies, and much effort is currently being put into accomplishing these technical goals. If these technologies can be systematized, they can be used not only in steel skeleton fabrication, but also in the construction of other steel structures, and should make an important contribution to maintaining competitiveness with future international price parity in mind.

2.2 Non-residential Architecture

2.2.1 Multi-story warehouses and parking buildings

Kawasaki Steel has long been involved in the distribution warehouse business, but in connection with this item, we will discuss construction techniques for automatic warehouses. To begin with, research was conducted on the mechanical behavior of frames developed for use in automatic warehouses,[10] and earthquake-proof design techniques were established. Next, the company developed a material handling system applicable to the stacker crane, which is a key element in the warehouse material flow, and with construction technology unified in terms of both software and hardware, expanded its business. Recent examples of construction include an automatic warehouse at Dai Nippon Printing Company's Okayama Plant and the automatic coil warehouse at Kawasaki Steel's new No. 3 Hot Strip Mill, among others, and the record of similar projects is steadily growing.

This technology can also be applied to multi-story parking buildings; for example, Kawasaki Steel has completed a total product called "CARNEST" by combining space creation techniques in multi-level underground parking facilities constructed in subterranean space below roadways,[11] and is currently taking orders for this type of structure. Efficiency improvement and the application of high technology to material handling are expected to show increasing progress, in combination with demand for convenience, but Kawasaki Steel is continuing to expand the range of applications and is accumulating study data in order to meet the needs of society with more refined technologies.

2.2.2 Clean rooms

As with the commercialization of automatic warehouses, which are structures combining building construction techniques around the core technology of material handling automation, as described above, Kawasaki Steel has also developed plant construction technologies around a core of clean room technology. These plants were developed as products by establishing clean room design techniques based on air current analysis,[12] recent representative examples of construction being Fujitsu Corporation's Shinetsu Plant, Citizen's Hachinohe Plant, and others.

2.2.3 Long span roof construction

The Super Wing construction method was developed as a long span roof construction method for factories, sports facilities, and other structures where large column-free space is needed,[13] and is a rational construction method in which the size of the truss section can be minimized by inserting cables in the lower chord of large-scale roof trusses and introducing pre-stress (**Photo 2**). Examples of construction by this method include the Yokohama Plant Japan Spring Co. and the Delta Center Sports Arena in Salt Lake City, Utah (USA). In addition to the Super Wing method, the company also possesses roof construction technology by "the KT Roof Truss,"[14] which is a type of roof space truss, and has systematized the design and construction of large-scale roofs.

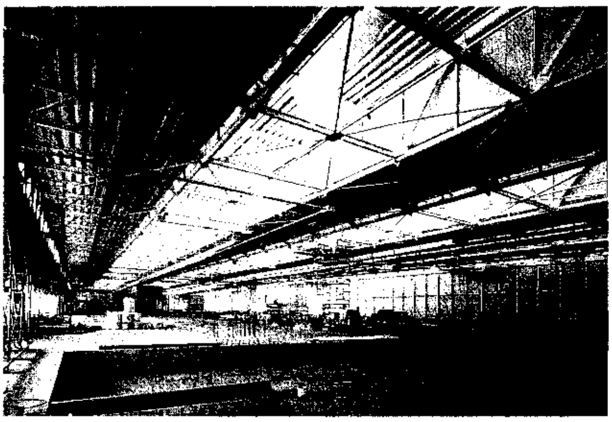

Photo 2 Large spanned truss roof "Super Wing"

2.2.4 Standardized urban buildings

The company's standardized urban building, "Excel-Core"[15] is marketed as a applied steel-skeleton structure product for replacement demand for store and office buildings in cramped urban areas. The construction materials, beginning with the steel skeleton, have been standardized and systematized, and auxiliary techniques such as the steel footing beam, one-side bolt joint for box columns, scaffoldless construction method for curtain walls, etc. has been completed. This technology has already been applied in the Kameido Building of Kawatetsu Steel Products Co., a member of the Kawasaki Steel Group, and is also being used in the new construction of Kawasaki Steel's Kobe Head Office Building, which was damaged in the Hanshin-Awaji Earthquake.

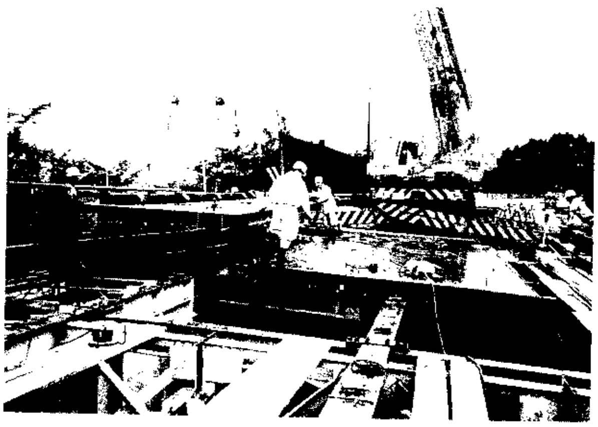

Photo 3 Renewing works of damaged bridge deck by steel deck

3 Civil Engineering Structures

3.1 Bridges and Roadway Structures

3.1.1 Bridge floor decks

The first of the company's structural technologies for bridges which should be mentioned is the steel deck plate for reconstruction of the reinforced concrete slabs of existing roadway bridges. This technology is a revolutionary method which makes it possible to reconstruct, in a short time and without stopping the traffic flow, the RC slabs of bridges damaged by dramatically increased traffic volumes. The "Battledeck"[16] steel deck plate for reconstruction was developed by the company and is applied in this method. As features, a somewhat heavy gauge (16–22 mm) deck plate is used, and the structural form is simple, with cut-tee (CT) shapes welded in the longitudinal direction of the bridge as stiffeners. As the result, it is possible to create a fatigue-resistant structure and reduce deck weight.

With this steel deck plate, consideration is given to reducing the work load at the site by shipping the plate with the pre-pavement applied in the plant; the road face is then executed by placing the final pavement at the site. In applying this method, additional cross beams are installed in an appropriate amount in advance of other work at the bridge to be reconstructed, and cutting and removing half of the road face when the beam work is complete so that traffic can continue to move as before on the unremoved part of the roadway. The portion where the road face has been removed is finished to a condition which allows installation of the steel deck plate, and the reconstruction is completed by connecting the steel deck plates and existing main girders with bolts. After work on the first half of the road face has been completed, the remaining half is reconstructed by the same method while traffic passes on the already-finished roadway. It can therefore be said that this product is well-suited to road conditions in Japan, and it has been adopted in the Tomei Expressway Tanaka Bridge (**Photo 3**) based on experience with construction work in the company.

This method was made possible by the superior features of steel, such as its light weight, prefabricability, etc. and the construction of systematic techniques for execution. Because the repaired bridge also has an additional margin where stress is concerned, equivalent to the reduction in weight in comparison with the original structure, and moreover, because the load distribution is improved by the installation of additional cross beams and the bearing force is increased, bridges reconstructed by this method show remarkably improved durability.

3.1.2 Suspension pipeline bridges without stiffening girders

A second structural technology meriting special attention is the suspension pipeline bridge without stiffening girders.[17] This type of structure is used on gas pipe line routes over valleys in mountainous areas and at river crossing points, and embodies the bold concept of using the pipe itself as a structural member without stiffening trusses or girders, and attaching the suspension cables and storm cables directly to the pipe. Numerical analysis, structural experiments, and stability against wind as demonstrated by wind tunnel experiments, etc. are incorporated in the design of this structure, and execution techniques based on stability of the execution work have also been established. The first practical example of this technology was the Kosutegawa Bridge (**Photo 4**) in the gas pipe line on the extremely mountainous route from Niigata on the Japan Sea coast to Sendai on the Pacific side of the main Japanese island of Honshu.

3.1.3 Suspension type monorail girder

In this structure,[18] the track of car comprises a track girder with an open section and steel pipe columns, and is being constructed for the first time in

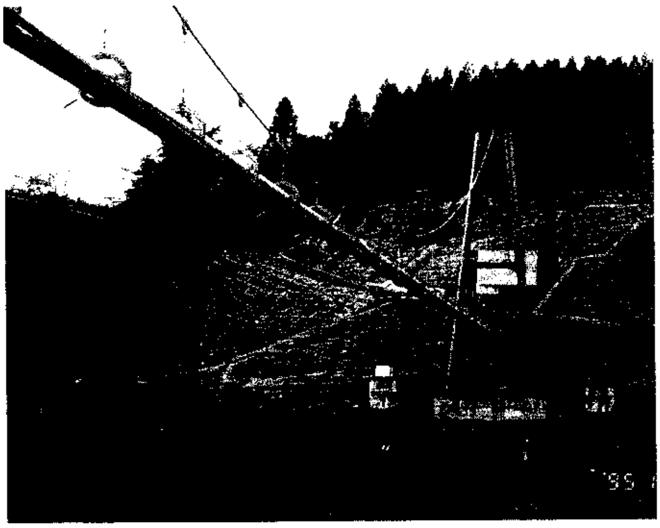

Photo 4 Newly developed suspension type pipeling bridge

Photo 5 Suspension type monorail structure

Japan in Chiba City as a medium transportation system for an urban environment (**Photo 5**). An open section must necessarily be used for monorail cars to travel suspended from the track girder, although the open section is disadvantageous from the viewpoint of static design. Warping torsion theory was therefore used in the design. Further, the fact that the monorail was to share construction space with an urban roadway required a highly complex design technology with three-dimensional curved alignment. In addition to these difficulties, design for fatigue due to repeated traffic loads was also extremely important; this challenge was met by carrying out experiments for strength proof with a model and full-size girder. To reduce construction costs, a girder structure of the outside rib stiffened type was adopted. In the track girder, high-level control techniques for welding strain were necessary because a open-section girder with three-dimensional curvature was used, as described above, and welding was strictly controlled to maintain fatigue strength. Where the steel pipe columns were concerned, the outer diameter was limited to 1 200 mm because the monorail is an urban structure, requiring the use of heavy-walled pipe (50–90 mm). For this reason, the guarantee of material properties during cold bending working was a problem, but the company was able to surmount this difficulty by making full use of the steel material technologies which it possesses as a steelmaker. On the other hand, the high order of difficulty of the design and manufacturing techniques was instrumental in pushing the company's bridge-related technology to a new level, where it is today.

3.1.4 Composed slab bridge

As the next representative technology, this section will describe the composed slab bridge "KCSB,"[19] which statically combines steel and concrete to realize a more compact bridge type and is mainly used over rivers in cities. Because this structure is applied to improvement measures against flooding, it features a deck of the minimum possible thickness so as not to impede the flow section of the river. The design techniques for conventional reinforced concrete slab bridges were not necessarily adequate to meet this requirement, and a unique design technique was therefore required which would take advantage of the excellent concrete adhesion performance of deformed cut-tee shapes, which are a Kawasaki Steel product. In this structure, a box-like steel deck with cut-tee shapes welded to the steel plate on the bottom of the deck is prefabricated and transported to the site, where the concrete is placed to complete the bridge. The steel deck itself can be employed as a form for the concrete, contributing to a clean site work and a shorter completion period. Because of these advantages, a considerable number of orders have been received from various prefectural governments, to make up an excellent record of jobs with this type of bridge.

3.1.5 Bridge design and construction technology

In addition to the above, manufacturing cost reductions are of course required, and improved design and construction techniques for long span suspension type bridges are necessary if the company is to further expand its bridge-related business. In the area of manufacturing, as mentioned in with architectural construction, the introduction of robot mechatronics is indispensable. The company is therefore carrying out advanced technical development to enable the automation of all-position welding, and following a steady course, is making positive efforts in techniques for improving durability, centering on fatigue and corrosion resistance, use techniques for high-strength steel, techniques for large heat input welding and preheating-free welding, and others. In terms of design and construction, in addition to expanding its efforts in fatigue and wind-resistance design techniques for cables, erection simulation, and landscape simulation technology, the company is also making improvements in fundamental research on compatibility techniques for concrete, etc.

3.2 Shore and Port Structures

Broadly classified, the structural techniques in this field comprise two "lines," one being the offshore structure line, which is related to oil drilling facilities in offshore areas and has long been treated as important pillar of the company's business, and the other being the revetment line, which takes the interaction of construction materials such as steel sheet pile and sheet pipe pile and filled sand into consideration in the design system.

3.2.1 Offshore structures

Offshore structures have their origin in the jacket structures used in oil drilling rigs. The needs of structure design for external forces such as waves and earthquakes have been met by the development of the design software "Marinjust." Moreover, because jacket structures are essentially space frames made up of steel pipes as structural elements, structural node design for the intersections of numerous parts is an important task. In particular, the data necessary for evaluating resistance to load force was accumulated by carrying out a large number of structural analyses[20] and experiments in connection with stress concentrations affecting T-type and K-type nodes, fatigue experiments[21] in relation to repeated loading, etc.

In the fabrication of these structures, the groove form at the nodes changes shape in a complex manner, and weld defects are inevitably present because all-position welding must be used; a method of allowable defect estimation[22] was therefore established from the viewpoint of fracture mechanics by comparing stress concentrations and the CTOD values of actual joints. As a matter of course, the company possesses welding methods for these node areas, quality inspection techniques, techniques for improving fabrication accuracy based on welding strain control, and others as essential technologies, and by totalizing these respective techniques, was able to fabricate Shell Oil Company's Bullwinkle Jacket,[23] which is a jacket of the world's largest class.

Around the same period, the company developed TMCP steel as new functional steel material whose excellent weldability and improved flexibility have made an important contribution to node structure design.

This type of offshore structure receives variable repeat loading from tidal currents and waves, but the fatigue phenomena of the steel material in the sea water differ from those in the atmosphere; thus, it is frequently said that there is no fatigue limit under the corrosive environment of sea water. At the time of construction of the Bullwinkle jacket, Kawasaki Steel carried out experimental research[24] on high-tensile steel and TMCP steel using tubular joints, accumulating new knowledge on the superiority of TMCP steel and the presence or absence of corrosion protection. In addition, the company also carried out model experiments on the effect of the breaking wave force which acts with impact on structures in offshore areas using a wave-making apparatus, and proposed a calculation formula for the breaking wave force and a method of impact response analysis using that equation.[25]

Advanced technologies such as those described above are being used effectively as inherited technologies even today, although the company is no longer involved in this particular industry; for example, such technologies have been put to good use on a continuing basis in the jacket-type revetment, etc. used in the revetments for the manmade islands of the Trans-Tokyo Bay, which is now under construction, and research is progressing on this technology as a candidate for the foundation structures in plans for highways across the mouth of Tokyo Bay, the Kitan Straits (near Osaka, between Awaji Island and Wakayama Prefecture), and other expected future projects.

Another construction method similar to the jacket structure is the "underwater frame work method,"[26] a unique technology developed by Kawasaki Steel. Although this method is used mainly in landing piers, mooring dolphins, and similar, it is unique in that the nodes are made up, as the name suggests, at an underwater site. Specifically, one steel pipe pile is driven first; a diagonal block consisting of a second pipe which has an outer diameter one size larger than the first pipe and serves as the main code is then inserted in jacket fashion from the top of the steel pipe pile to form a double-walled pipe structure, and the work is fixed and completed by filling the clearance between the two pipes with mortar. The record of practical use of this method includes fishing piers constructed in Aomori and Chiba Prefectures. Because this method enables simpler construction of a space frame at the site than conventional pile type landing piers, it is rational in terms of both design and economy and is therefore expected to be used in practical applications in port structures.

3.2.2 Shore protection structures

Steel sheet pile and sheet pipe pile, which are principal construction materials for civil engineering, are used as the outer shell in sand-filled "double-walled structures"[27] which serve as revetments and coffering for underwater work. In this type of structure, the water pressure and earth pressure which act on the wall are resisted by the bending capacity of the piles which are driven in two rows and the shear deformation capacity of the filled sand. A method of theoretical analysis for the structure has been proposed, and a design method was established through experimental confirmation. As representative results, this type of structure was adopted in the coffer damming for construction of the Amagasaki Lock, and application is also planned for the Yokohama Rinkō Road now under construction. At present, technical research for improvement is being carried out with this structure to realize completely self-standing walls, which will make it possible to free the space inside the coffer dam from struts and other obstructions. Concretely, to increase the bending rigidity of the wall, insertion of a partition wall of steel in place of the filled sand is being considered, and the establishment of the design method was recently completed.[28] Because open use of the space inside the coffer dam will be possible, as described above, shortening of the term of work should be achieved when the improved structure is materialized; the improved structure can also contribute to reducing the cost of construction work by eliminating the need for temporary members such as the struts and their supporting columns. Finally, it also appears that, with skillful design, this structure can be applied as a revetment with advantages in terms of earthquake resistance, because it is a flexible, lightweight type of wall with good penetration.

The "sheet pile coffer dam"[29] is a structure with the same wall form as the double-walled sheet pile wall described above. The structure is formed by driving steel sheet piles in a closed circle, which is filled with sand; these circular "cells" are then linked together in one line to create a wall. This structure is used mainly in revetments. An extensive record of work has already been achieved, but in one recent example, the structure was adopted in a revetment at Hekinan Thermal Power Plant of Chubu Electric Powper Co., Inc.. The problem with this type of structure was to reflect the mechanically combined action of the steel sheet piles and the filled sand in the actual design, but a rational design method was established from the results of model experiments and numerical analyses, and the structure is now widely recognized and is supplied for practical applications.

In addition to the port structures described above, research is also being conducted on wave dissipation techniques aimed at the creation of areas of calm water, and a slit type wave dissipation revetment has been developed as a structure which applies wave dissipation techniques. This structure is simple, comprising steel pipe piles placed at appropriate intervals, but can easily realize a wave dissipation ratio of about 50%.

4 Other Structures

A structure common to the fields of both civil and architectural construction is the "man-made steel deck land." Projects of this type executed by Kawasaki Steel include the Ohmiya Man-made Steel Deck Land, which was constructed over a regulating pond for flood water.[30] Here, steel pipe piles driven in advance were used as support columns, and the heads of the columns were joined in two directions by steel beams; a steel deck was then laid and finished by executing pavement over the deck.

The notable point in the construction of this structure was the pile driving technique, which was the bargeless pile-driving method "STEP" developed by Kawasaki Steel in the construction of landing piers and sea berths. In constructing landing piers and sea berths, steel pipe piles are normally driven by a pile driver mounted on a pile driving barge, but because the barge shakes due to the effect of waves, the difficult point in this method was the possibility of delays in the term of work due to unavoidable interruptions in case of difficulty in securing the accuracy of pile driving or high waves. The STEP method[30] is a revolutionary technique that solves all these problems, in which piles driven from the land are successively joined with girders, and staging is then laid out for use by a wagon on which the pile driver is mounted. New staging is laid as the pile driving work advances, and the deck is extended by continuous sliding on the staging.

Because the Ohmiya Man-made Steel Deck Land was located above a regulating pond, the application of this method was extremely effective. Structurally, design techniques were established for the pipe piles which form the foundation and the two-dimensional grillage which serves as the main material of the man-made deck. The project was completed successfully by solving new technical problems such as the earthquake-proof design of the deck and the connections with the building foundations constructed on the deck. The method has also been adopted in the redevelopment project at the east end of Shinjuku Station, and construction is progressing based on a positive evaluation, with no interference with the railway traffic at this station, which in terms of the daily passenger count is considered to be the busiest in the world.

This man-made deck is also of great significance as it represents the birth of a new type of structure, and is therefore linked to expansion in the field of steel material use. The future is expected to see an increase in applications related to the effective use of over-river space and over-track space, as well as construction over regulating ponds, as described in the main example here.

5 Conclusion

The preceding pages have presented an outline of the content and features of the steel structure technologies possessed by Kawasaki Steel by type of structure, covering approximately the last 15 years. As the most essential features, as mentioned in the introduction, because Kawasaki Steel is a steelmaker, it is itself capable of improving and developing new materials for construction, and has maintained and expanded its share of the steel structure market by conducting research on steel structure design techniques and welding techniques as use technologies, while as a maker of steel structures, the company has also aimed at strengthening its competitiveness in steel structures by introducing a combined technology of welding and mechatronics, and at cultivating new fields of use for steel materials by developing new construction methods. These efforts will undoubtedly become increasingly important in the future, and must be continued and strengthened.

In closing, the future tasks and prospects for the field of steel structures are summarized below.

In the field of architectural structures, first and foremost, we must concentrate all our knowledge and abilities on recovery from the earthquake disaster. It is necessary to establish new design and construction methods by establishing reinforcing methods for steel frame connections and proposing steel materials and joint details with improved earthquake resistance. For example, urgent matters include the use of TMCP steel, which is excellent in weldability and toughness, and the development of quality improvement techniques by improving the scallop form and introducing backingless welding methods and automatic welding techniques for field use. Where the steel skeleton as a whole is concerned, as described in this paper, after introducing new techniques such as damping of earthquakes using super mild steel and concrete filled tube columns, it is essential to devote ourselves to maintaining and expanding this 8 million ton market by establishing cost competitive and high-reliability design systems, establishing interior and exterior systems which consider sound, heat, vibration, and other factors affecting dwellability, standardizing designs and parts, and improving the efficiency of labor-saving construction methods and material handling. Recently, Japan's steelmakers inaugurated a joint research project (Steel House Project) aimed at applying sheet materials to single-family houses, which is an important task for new market development, and it is expected that a large market can be created by taking advantage of the high strength, light weight, good workability, stable supply, fire resistance, and other excellent properties of steel. As shown by this example, it is important that efforts to commercialize new product of cold-formed sheet metal be developed in a forward-looking manner.

In civil construction, the problem of responding to earthquake damage has inevitably become a key task in the last year since the Hanshin-Awaji Earthquake, urgently requiring the reconstruction of design systems in consideration of maintaining the horizontal bearing capacity of steel bridge piers during earthquakes. At present, diligent efforts are in progress, making full use of experiments and numerical analyses, and proposals for new structures based on a dual approach from the directions of both new functional steel materials and design technology are required.

In the field of bridges, the most essential task is construction cost reduction; the main stream is continuing to run in the direction of reducing processing operation accounts by the simplification of structures by design methods which include the use of thick sections with few stiffeners, bridges with fewer main girders, etc. In this connection, fabrication by the site side, the introduction of at-site welding, and similar practices are also under study in some quarters. To cope with these trends, it will be necessary to research and propose functional steel materials capable of withstanding large heat-input welding, preheating-free steel materials, variable thickness plates, and other steel materials, and to develop welding methods with guaranteed high quality and high-efficiency automatic welding techniques for the site. More effective technical proposals for durability improvement techniques such as fatigue and corrosion resistance are required. As mentioned in this paper, it may also be surmised that fully-automatic, unmanned production technology will be promoted rapidly as a matter of corporate survival in order to secure competitiveness at international parity level prices.

In harbor structures, proposals for revetment structures with high earthquake resistance making use of the features of steel materials are needed, and the development of new products and new technologies with excellent features in terms of cost, working method, and durable reliability suited to future deep-water port renewal plans are also absolutely necessary.

It is also necessary to make continuing efforts to realize structures other than bridges and port structures, for example, new structures such as the man-made deck mentioned in this paper, and new plans in connection with compatibility with concrete and others.

Kawasaki Steel is committed to meeting the challenges posed by all these tasks by taking advantage of the combined capabilities of its steel material manufacturing division, engineering division, and Kawasaki Steel Group companies.

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