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Design and Construction of a Steel Super Platform Structure

Hirotaka Miyoshi, Ryoji Takabe, Kazunori Shingu

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Urban developments using super platform structure have progressed because the structure is an efficient measures for developing area suffering from its limited utilization. Kawasaki Steel has made some areal developments using the structure. In particular, construction of wholesale housing complex built on an existing flood-regulating reservoir is a typical one. The merits of using a steel super platform structure are as follows: (1) Total weight can be reduced because each member is light; (2) deformation capacity is excellent because the structure is flexible; (3) construction period can be shortened by using pre-fabricated members. Moreover, the construction method maintains the function of flood control during construction.

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Hirotaka Miyoshi
Staff General Manager, Civil Engineering Dept., Construction Div., Engineering & Construction Div. Gr.


Ryoji Takabe
Staff Assistant General Manager, Civil Engineering Dept., Construction Div., Engineering & Construction Div. Gr.


Kazunori Shingu
Civil Engineering Dept., Construction Div., Engineering & Construction Div. Gr.

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Urban developments using super platform structure have progressed because the structure is an efficient measures for developing area suffering from its limited utilization. Kawasaki Steel has made some areal developments using the structure. In particular, construction of wholesale housing complex built on an existing flood-regulating reservoir is a typical one. The merits of using a steel super platform structure are as follows: (1) Total weight can be reduced because each member is light; (2) deformation capacity is excellent because the structure is flexible; (3) construction period can be shortened by using pre-fabricated members. Moreover, the construction method maintains the function of flood control during construction.

1 Introduction

For the past several years, urban development based on the concept of the "super platform structure" has been observed in various parts of Japan. In the super platform structure, the space above the structure is effectively utilized while also making use of the functions of the space below the structure. The adoption of the super platform structure in limited urban space is an effective urban measure for high-degree utilization of land that is utilized to a low degree or is not used at all.

This paper presents an outline of examples of development carried out by Kawasaki Steel and, in particular, the features of design and construction in a development project in which the super platform structure was used over a reservoir for the first time in Japan.

2 Examples of Development Using Steel Super Platform Structure

2.1 Utilization of Space over Reservoir (Saitama Pref. South Wholesale Housing Complex)

With flood-regulating ponds and reservoirs constructed in association with large-scale areal development, the highest priority has to date been given to maintaining the flood-regulating function, and more complex utilization has not been attempted. Against the social background of a chronic shortage of land in urban areas and suburbs, multi-purpose utilization of flood-regulating ponds is being promoted. However, the utilization of flood-regulating ponds has been limited to use of the pond bottom as tennis courts or sports fields during water shortages.

Giving attention to the flood-regulating pond that it owns as the site for expansion of a wholesale housing complex opened in 1983, the Saitama Pref. South Wholesale Housing Complex Cooperative Association carried out development using a super platform structure.[1)] A general view of the wholesale housing complex is shown in **Photo 1**. In this development project, a super platform structure covering about 45 000 m^2 was built over the flood-regulating pond, and the offices and warehouses of the wholesale housing complex were constructed on the platform. This example of the multi-purpose utilization of a flood-regulating pond using Japan's first large-scale super platform structure is described in detail in Chapter 3.

2.2 Utilization of Space above Railroad Track (Development of Shinjuku Station South Entrance Area)

The space above a railroad track in an urban area can

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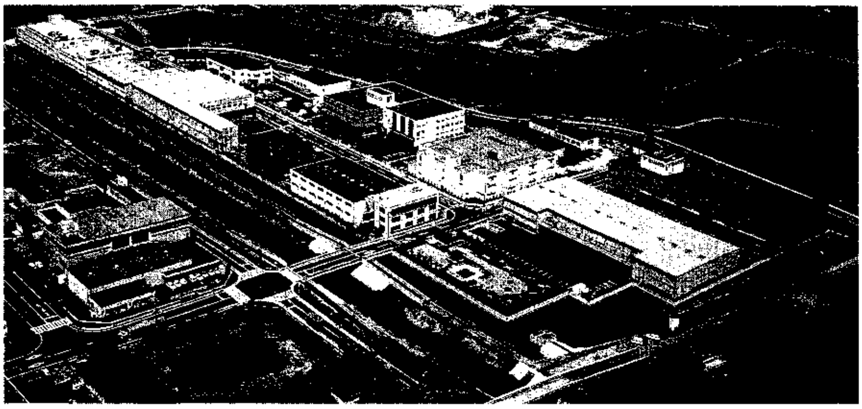

Photo 1 Ohmiya super platform structure

be effectively utilized to improve the town divided by the track in an integrated manner. However, it is difficult in many cases to secure sufficient adjoining work space for building the super platform structure above the track. In addition, because it is necessary to allow safe, normal movement of trains during the work, the construction method is an important problem.

Kawasaki Steel developed the "lifter wagon method" that enables construction to be carried out efficiently and in a short period using special wagons to build the super platform structure in places where a large work space cannot be obtained on the ground. The company put this method into practical use in the construction of a super platform structure in association with the development of the Shinjuku Station South Entrance Area (**Photo 2**).

The features of this method are as follows:

(1) Because the wagon moves on rails on the super platform structure which it is being used to build, a large surrounding work space is not required.

(2) Lifters that permit the control of the wagon level are installed in the supports that support the wagon on the rails, making it possible to maintain the horizontality of the working plane of cranes. Therefore, safe construction is possible.

(3) The machinery and materials necessary for construction are transported from behind the wagon by a pallet car moving on the rails used by the wagon, enabling efficient construction.

2.3 Construction of Station Square (Kurashiki City)

In the construction of a station square, a technique for separating pedestrian areas from roadways using a pedestrian deck is widely used. The space under the pedestrian deck is then used as a bus terminal and parking area, while the upper space serves as a free passage. This technique is a typical example of the application of a steel super platform structure. There are many examples of fabrication and construction, including the Okayama Pref. example shown in **Fig. 1**. This structure is handled as a bridge structure, and architectural and landscaping design in which the super platform structure is combined with street furniture, etc. is an important point.

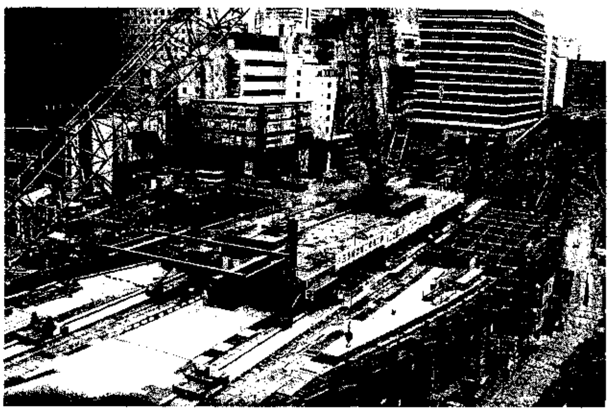

Photo 2 Lifter wagon method

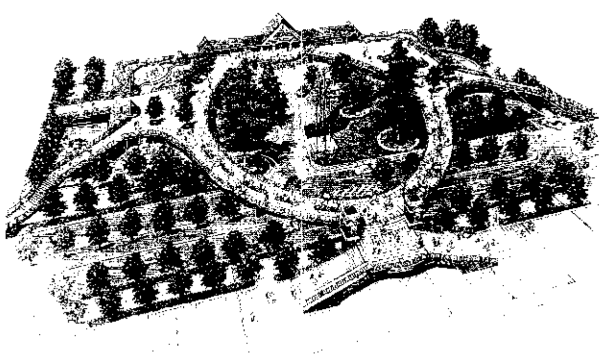

Fig. 1 Pedestrian deck

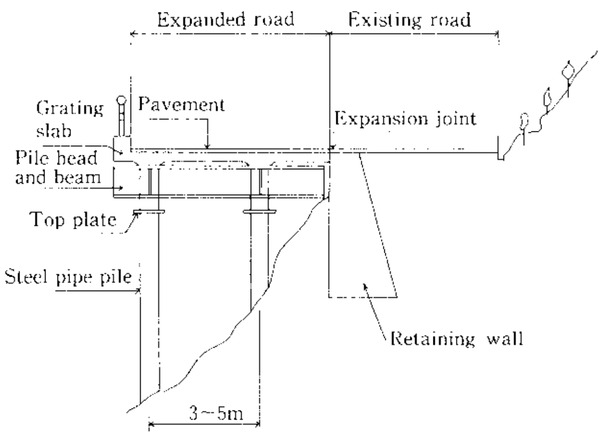

Fig. 2 Typical section of the expanded road

Table 1 Major quantities for the construction of Ohmiya super platform structure

Area of super platform structure		
Tenants	(m^2)	37 114
Road	(m^2)	6 081
Park	(m^2)	1 805
Total	(m^2)	45 000
Improvement of reservoir bottom (gutter, landscaping)	(m^2)	59 694
No. of steel pipe pile (ϕ508~800mm)		1 583 (9 186 t)
Steel pile head and beam (weather proof steel)	(t)	5 036
Concrete (RC slab)	(m^3)	12 000

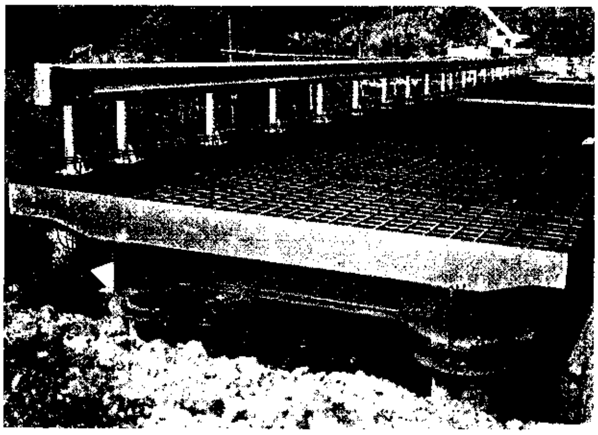

Photo 3 Expanded road

2.4 Width Increase of Mountain Road (Hyogo Pref.)

In increasing the width of a mountain road, the conventional method has presented various problems, such as the generation of large volumes of cut and mounded soil and the formation of steep slopes of cut-earth and embankment surfaces with poor stability. Therefore, the road width was increased using the super platform structure shown in **Fig. 2**. The features of this method are as follows:

(1) Steel pipe piles are driven at a pitch of 4–6 m, and beams are rigidly connected to the pile heads. Grating slabs are then installed on the pile heads, concrete is poured, and the road is paved.
(2) By prefabricating beams and grating slabs in parallel with the substructure work, the amount of field work is reduced and it is possible to shorten the construction period.
(3) Interference with existing traffic is minimized.

The superstructure of this super platform structure is designed in accordance with the Specifications for Highway Bridges II Steel Bridge and the Steel Highway Bridge Design Manual, and its substructure is designed in accordance with the Specifications for Highway Bridges IV Substructure and V Aseismatic Design and the Pile Foundation Manual. This method has been adopted in several projects, such as the Hyogo Pref. example shown in **Photo 3**.

3 Steel Super Platform Structure Using Space over Reservoir

3.1 Development Planning

The major quantities related to this development project are shown in **Table 1**. The site for 13 tenants and a road and park as land for public use were constructed on the super platform structure. The use of the space under the super platform structure was limited to a flood-regulating pond, and it was decided not to use this under space for other purposes. The whole bottom of the pond was paved with concrete in consideration of drainage efficiency, and a drainage canal was constructed in the center.

Maintaining the flood-regulating function of the flood-regulating pond during and after the construction as before was the most important consideration in this developments.

3.2 Design

3.2.1 Outline of design and features

The construction of this super platform structure is shown schematically in **Fig. 3**. Steel pipe piles were driven at prescribed intervals (about 6 m) into the pond and concrete slabs were cast after the installation of pile heads and beams. An example of the soil profile under the super platform structure is shown in **Fig. 4**. As is apparent from this columnar section, the whole section

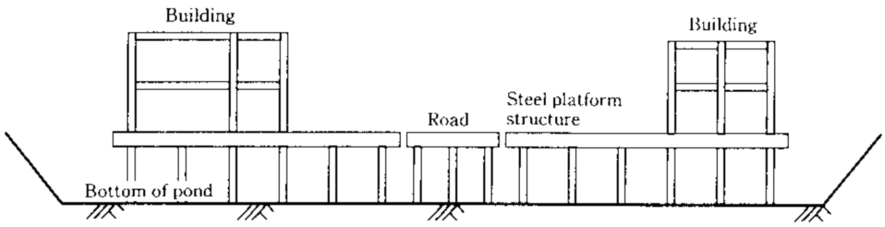

Fig. 3 Typical section of the platform

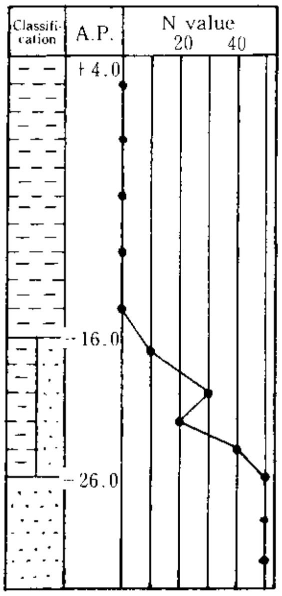

Fig. 4 Soil profile

of the flood-regulating pond is composed of a soft silt layer with an N-value of 0 and qu-value of about 0.4 from the ground surface (ground height of the bottom of pond) to about −20 m and an alternate layer composed of a sand layer and cohesive soil with N-value of 20 to 50 from −20 m to −30 m. This was ascertained by boring at about 40 places in the whole pond. With a sand layer having an N-value of 40 or more serving as the bearing stratum, the foundation piles were driven up to 4 D (D: pile outside diameter) or more. The pile diameter was 508–800 mm, and the pile length obtained from the results of the boring, loading test, etc. was about 37 m on average.

To comply with the Building Standard Law and City Planning Law, it is necessary to observe the broad principle of "one site-one building." The super platform structure for each tenant site, road, or park was therefore constructed as an independent structure, and expansion joints were installed at the boundaries. Based on the results of a dynamic response analysis using input seismic waves, the respective structures were built at intervals of 120 mm, and gratings of special form capable of absorbing this amplitude of 120 mm were developed and adopted in the joint areas that provided entrances to each tenant site from the road.

3.2.2 Adoption of steel structure

A steel structure was adopted as shown below for this super platform structure in order to meet the development requirement that "construction must permit a construction method that does not hinder the flood-regulating function not only after the completion of the super platform structure, but also during the construction work."

(1) It is very difficult to consider a long cut-off or coffering in a flood-regulating pond where ponding may occur at any time. It was decided to use steel pipe piles as foundation piles because it is not necessary to consider the protection of the structure if construction machines such as pile drivers are removed from the pond during a ponding.

(2) For the super platform structure itself, steel pipe piles were left projecting from the ground without using the underground beams, footings, or braces that are usually employed in building structures, and these steel pipe piles were connected directly to the beams of the super platform structure to form rigid frames. This type of construction is also observed in harbor piers. This structure permits the adoption of a construction method capable of maintaining the flood-regulating function during the construction work, which will be described later.

(3) It was necessary to minimize the overall load because the adoption of the above pier structure in a harbor was being tried for the first time and the soil was soft. Structures tend to be top-heavy if concrete construction is adopted. By adopting steel construction, the total weight was reduced and, at the same time, the largest possible deformation capacity was ensured.

As mentioned above, various advantages were obtained by adopting a structure in which steel pipe piles project from the ground. However, corrosion protection posed a problem. To solve this problem, the past ponding condition was investigated, and it was found that ponding above the flood stage occurs once or twice a year. Therefore, corrosion protection was applied to the part from the bottom of the pond to the flood stage of rivers and the part from the bottom of the pond to the

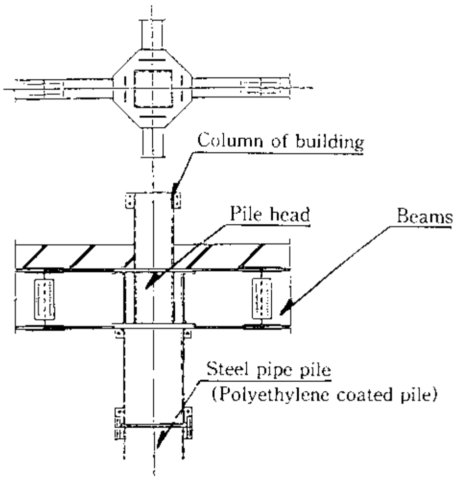

Fig. 5 Joint of pile head

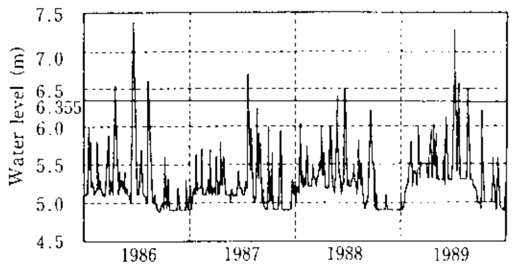

Fig. 6 Alteration of water level in Fukasaku River

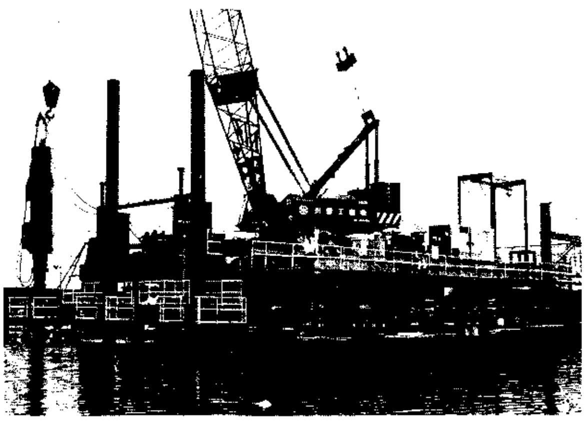

Photo 4 STEP method over the flood-regulating reservoir

ground-water level. KPP piles (Kawasaki plastic-coated pipe piles) were used in the upper parts of the foundation piles exposed alternately to water and air by the ponding of the flood-regulating pond (3 m above the ground level and 4 m below it, a total of 7 m). River-Ten (weathering steel) was used in the beams and pile heads above these upper parts of the foundation piles, and polyethylene shrink tubes were wrapped around the connections between the KPP piles and weathering steel to provide corrosion protection and avoid the need for maintenance.

3.2.3 Connection to buildings on super platform structure

In this development, the building permit for the office and warehouse buildings constructed on the super platform structure was obtained for buildings forming a integral structure with the super platform. The building columns were connected directly to the foundation piles of the super platform structure at the pile heads rigidly connected to the piles. The construction of the pile-to-column connection is shown in **Fig. 5**. In this construction of a super platform structure, the verification of aseismicity was an important examination item. A dynamic response analysis was conducted in addition to static and dynamic soil tests and a horizontal loading test in the field using full-size piles, confirming that the deformation capacity of the connections is greater than required by the Building Standard Law.

3.3 Construction of Steel Super Platform Structrue

3.3.1 Method of work over water

As mentioned above, a major prerequisite for constructing this super platform structure was that it does not hinder the flood-regulating function during or after the construction work. In preparing the construction schedule, therefore, river stage data on the Fukasaku River (primary river adjoining the flood-regulating pond) for the past several years were obtained and the change in water level was arranged as shown in **Fig. 6**. It was predicted from this figure that the river would overflow the deversoir (level AP + 6 335 or more) and flood the flood-regulating pond three times/year on average and that flooding would be concentrated in autumn when typhoons are common and the autumn rain front is active. For structural reasons related to the flood-control pond, a drainage period of about two weeks is necessary when the flood-regulating pond is submerged, and an interruption of work of about a month in total was feared during the flood period. Furthermore, the ground of the site is very soft, as mentioned above, and large-scale soil improvement work was judged to be necessary before the construction of the super platform structure if the conventional construction method was adopted, with pile driving and beam erection from the bottom of the pond using construction heavy machines. To solve this problem, it was dicided to adopt the STEP method[1-4] (**Photo 4**), which permits work over water construction, is not affected by ponding, and does not require work heavy machines on the bottom of the pond. However, when the whole construction area was observed, it was found that the greater part of the construction period would not coincide with the flood period and the com-

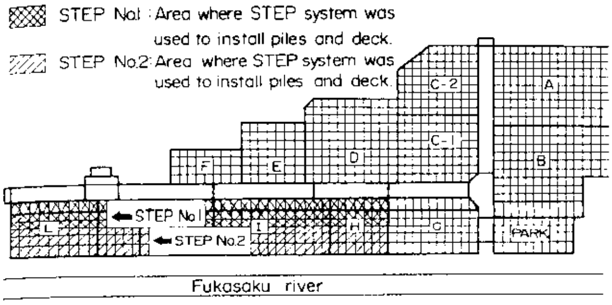

Fig. 7 Construction area with STEP method

pletion of the work would be difficult within the construction period using only the STEP method. In consideration of the order and period of construction and the area where the soil was especially soft, therefore, it was decided as shown in **Fig. 7** to use two STEP machines for an area corresponding to about 30% of the whole and to adopt the conventional method for the remaining part.

3.3.2 Comparison of construction methods

One of the most difficult construction problems in building the super platform structure was how to erect the columns of buildings with high accuracy by compensating for plane errors in pile driving. Although plane errors of about ±50 mm are generated in normal pile driving, different measures were taken for the above two methods to solve this problem. The construction flow for the two methods is shown in **Fig. 8**. The features of the measures taken to compensate for plane errors in pile driving in the two methods are described below:

(1) Conventional method

In this method, the pile head is attached to each pile one by one and the beams of the super platform structure are installed after piles are driven in a group within the prescribed range (**Photo 5**). Piles are rigidly connected to pile heads by welding. In attaching the pile heads, accurate positioning was conducted using erection pieces. For pile driving errors, the deviation from the regular position of the pile core was measured after pile driving, the data were fed back to the pile head fabricator, and pile heads adjusted for pile core error were transported to the site and installed. For this reason, delays of about 1–2 weeks after pile driving occurred at the site.

(2) STEP method

In this method, three adjacent piles are driven, prefabricated pile heads and beams for three piles are installed (**Photo 6**), and the STEP machine moves onto the super platform structure built by the machine itself, where it then repeats the pile driving for the next row of piles and the installation of pile heads and beams. In piles driving, pile positioning is performed by a pile holder accompanying the STEP machine,

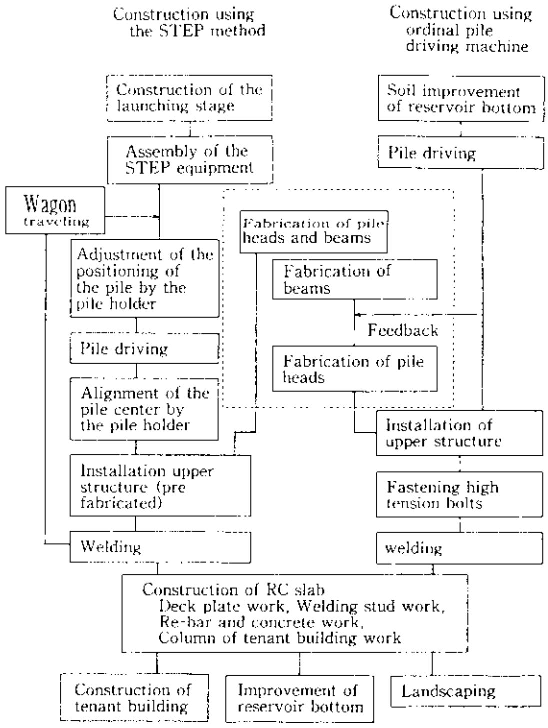

Fig. 8 Construction flow chart

Photo 5 Installation of pile heads by ordinary method

and the piles are held during pile driving. As a result, pile driving was carried out with a high accuracy of within ±30 mm. Furthermore, a correction function was provided for minor adjustments of pile position during the erection of the pile heads and beams, permitting fabrication of pile heads without waiting for pile driving data, and the installation of the prefabricated pile heads and beams, shortening the construction period. An error correction test in which corrections of up to ±50 mm were teken into consideration was conducted at the site before the start of construction, and changes with time in the residual stresses

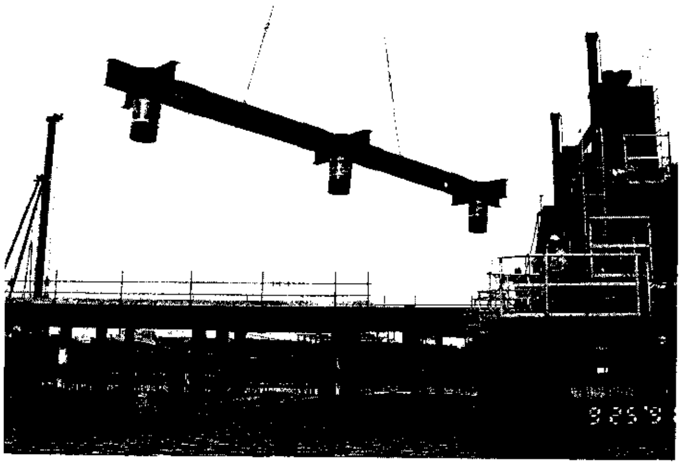

Photo 6 Installation of prefabricated pile heads by STEP method

caused by the correction of pile position were measured and incorporated in the design. This idea was made possible by the use of steel members, which are relatively light in weight and flexible.

4 Conclusion

In this paper, the features of the disign and construction of a steel super platform structure were described, taking as an example the development on a flood-regulating pond. The advantages of the steel construction which characterizes the design and constrution of the super platform structure are as folows:

(1) The weight of each member is small compared with concrete members, and it is possible to reduce the total weight of the structure.
(2) The structure is very tough and flexible.
(3) Prefabrication of members is possible, shortening the field construction period.

The construction period was shortened by adopting the over-water method and installing prefabricated members, making the best use of the advantages of steel construction. The super platform structure was built in a short period of about 14 months after the start of pile driving, and the buildings on the super platform structure were built soon after.

The aseismicity of civil, engineering and building structures has been a critical issue since the devastating earthquake in the Hanshin-Awaji district in January 1995. For the aseismatic performance of this super platform structure, it has been ascertained that the deformation capacity of the structure is greater than that specified in the Building Standard Law. The authors intend to continue with research in the future in order to contribute to the solution of the aseismicity problem by taking full advantage of steel construction.

The authors would like to express their sincere appreciation to all those who gave guidance and cooperation in the projects described above and in the preparation of this paper.

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