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Construction of a Jacket Type Steel Retaining Wall for the Kisarazu Man-made Island of the Trans-Tokyo Bay Highway

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The 15-km Trans-Tokyo-Bay Highway will span Tokyo Bay, linking Kawasaki City, Kanagawa Prefecture with Kisarazu City, Chiba Prefecture. This national project started in 1987 and is scheduled for completion in 1997, Kawasaki Steel was awarded contract as a member of a joint-venture in the construction of the middle section of Kisarazu Man-Made Island for this highway in June 1990. In the process of the execution of this one of the world biggest projects, the most remarkable exertion was, in addition to dealing with a total weight of about 19 000 metric-tons, to solve various technical problems of using jackets as retainning wall structures, such as, (1) establishment of the design method of the jacket-type steel retainning wall, which is the first attempt in the world, (2) establishment of the high-quality and efficient fabrication system, (3) consideration of safety in technical and managemental viewpoints for the transportation of large steel structures on the sea, and (4) development of the high-accuracy installation method of the jacket in the deep sea.

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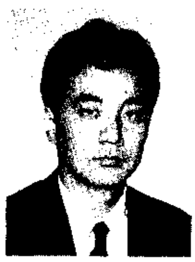

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1 Introduction

The Trans-Tokyo Bay Highway is an expressway of 15.1 km in total length linking Kawasaki City and Kisarazu City. On the Kawasaki side, where shipping traffic is very heavy, a tunnel of about 10 km in length is being constructed, the remainder being a bridge. Man-made islands are being constructed at two locations, one at the mid-point of the tunnel section and the other at the point connecting the tunnel to the bridge.[1,2] The latter, namely, Kisarazu Man-made Island, is situated at a point 5 km offshore of Kisarazu City and in a depth of about 25 m of water.

The scale of Kisarazu Man-made Island (**Fig. 1**) is one of the greatest in the world for water depth and area, and Kawasaki Steel Corp. was awarded the contract by Trans-Tokyo-Bay Highway Corporation for constructing a jacket-type steel retaining wall in a joint venture with two other companies. The work was completed in August 1992.

This report describes the jacket-type steel retaining wall for the sloping portion of the man-made island that links with the tunnel, which was constructed by utilizing the design and fabrication technology for offshore structures which has been developed by the Company.

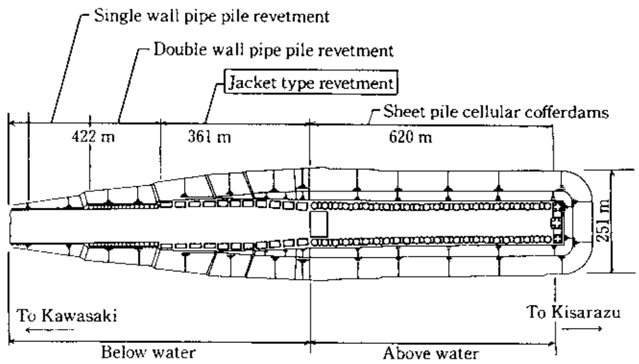

Fig. 1 Overview of Kisarazu Man-made Island

2 Outline of the Construction Work

The height of the embankment fill for the sloping portion of Kisarazu Man-made Island varies from 0 to 30 m. In the lower area, interlocked steel pipe pile single

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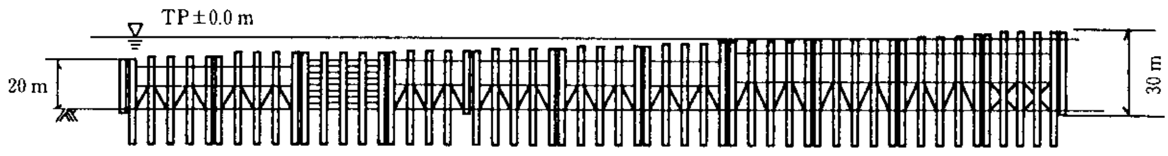

Fig. 2 Jacket type revetment (side view)

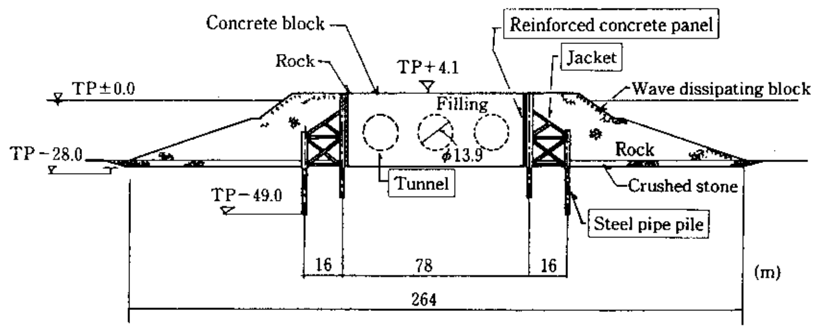

Fig. 3 Typical section of jacket type revetment

Table 1 Quantities of jacket works

	Quantity	Remarps
Jacket (t)	10 640	22 Jackets
Steel pipe pile (t)	8 620	220 pcs
Junction between jackets (t)	640	24 pcs
Concrete wall (pcs)	352	$d=60$ cm
Temporary stage for installation (t)	1 760	

Table 2 Schedules

	1989	1990	1991	1992
Detailed design	—	—	—	
Sea bed work		—	—	—
Fabrication of jackets		—	—	
Installation of jackets			—	—
Miscellaneous site work				—

and double wall were adopted, while in the area exceeding a height of 20 m, the jacket-type retaining wall shown in **Fig. 2** was adopted. This latter retaining wall was constructed, as shown in **Fig. 3**, to apply load to the embankment fill around the tunnel from both sides and to retain it in a stable condition for a long period.

The jackets were fabricated and installed as 11 units on each side (22 units in total) and, according to the filling height, five types of jacket of different sizes were designed and fabricated. **Table 1** shows the quantities involved in the jacket work.

Since these jackets are to be nearly completely immersed in water after installation, a temporary superstructure was installed on the top of the jacket before delivery from the fabrication yard. In addition, reinforced conerete panels were fitted to the jackets on site in order to construct a retaining wall, and inter-jacket connecting pipes, which would provide a wall between two adjoining jackets, were installed.

For corrosion prevention, 15-mm-thick steel plate encased in 135-mm-thick concrete was used, and the sacrificial anode method was used for cathodic protection in the seawater.

The work schedule for the jackets is shown in **Table 2.**

3 Design

3.1 Design of Jackets

The load on a jacket during service would act in one plane; hence the two-dimensional structural model supported by the ground that is shown in **Fig. 4** was used in the design analysis.[3)] No relevant design standard existed, since a jacket-type retaining wall had no precedent in the world. Thus, "Specifications for Highway Bridges" and "Technical Standards for Port and Harbour Facilities" were used as reference. For any items not covered by these specifications and standards, API-RP 2A[4)] was applied, this standard having been used to design jackets for offshore platforms. Marine Jast, an offshore structured analysis program developed by Kawasaki Steel, was used for the design analysis, this software also allowing buoyancy, wave force and pipe joint calculations to be efficiently carried out. **Table 3** shows the loading conditions for a main frame of the

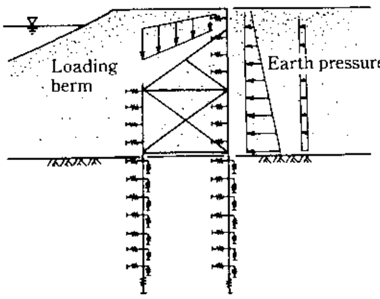

Fig. 4 Structural model

Table 3 Analysis case for a main frame of the biggest jacket(t)

Condition	Instal-lation	Normal	Settle-ment	Seismic
Dead weight	350.6	350.6	350.6	350.6
Loading berm	214.5	802.1	2406.2	791.9
Earth pressure	87.7	1307.9	1307.9	413.4
Wave force	286.7	—	—	—
Inertia force	—	—	—	913.2

biggest jacket.

The novel application of the jacket-type retaining wall required the authors to examine structures which would be easy to fabrication, and be safe and straight forward to install including such detailes as the connection between the retaining panel and the jacket and temporary structures for installation. This examination was conducted jointly with the persons in charge of fabrication and site installation.

3.2 Design of Piles

The piles were designed by assuming no contribution in bearing capacity from the bottom of the hole on the basis of the results of a loading test carried out by Trans-Tokyo Bay Highway Corporation. The maximum axial compression load was 1 641 t in the case of the pile with the maximum diameter (1 900 mm). A pile-driving analysis was carried out by using WEAP (wave equation analysis for pile driving), and the stress distribution in a pile during driving, selection of the hammer, etc. were all defined at the design stage.

4 Jacket Fabrication

4.1 Outline and Specifications for Fabrication

Fourteen jackets amounting to 7 940 t in total of steel were fabricated at the Kawasaki Steel's Harima and Chiba Fabrication Centers.[5] Each jacket is a pipe cubic-truss structure composed of 10 legs with braces to connect them.

The quality specifications were as follows: JIS specifications were adopted for steel materials, the WES specifications additionally being used; for panel point main pipe, JIS and Specifications for Highway Bridges form basic. For the control of finished form, JIS and the said Specifications were used based on the orderer's standard.

4.2 Fabrication and Assembly of Jackets

The most effective use of limited time, man-power and yard space for jacket fabrication was achieved by applying mass production methods. In this method, 10 plane panels and two large assembly units were simultaneously fabricated as basic work, with appropriate quantities of materials progressively fabricated and supplied to each sequence process of "material fabrication—plane panel assembly—full assembly" in the flow diagram manner.

Particular attention was paid to ensure adequate quality of the welded joints, several kinds of weldability tests being carried out beforehand to determine the most suitable steel material specifications and welding conditions. As a result, TMCP (thermomechanical control process) steel, which has high resistance to weld cracking, was used for the main pipes in the welded joint areas, and particular attention was paid to the steel composition such as applying restrictions on carbon equivalent. The non-gas-type flux-cored welding method was adopted, taking into consideration the quality of the joint and out-door workability.

The jacket assembly procedure is shown in **Fig. 5**. For plane panel fabrication, all in-plane braces were fitted, as shown in **Photo 1**, to the legs, a retaining-panel supporting member having been fitted to each leg beforehand. After completing the plane panel fabrication, the out-of-plane braces were attached. Any accessories which would not obstruct short-distance transportation and full assembly were fitted at this stage in order to minimize subsequent high-elevation working and to improve safety and operability.

The plane panels were transported to the full-assembly yard on two railway trucks. The lower-stage brace of a panel was then placed on two roller units, which had been positioned beforehand, and the panel was tipped upright by hoisting the upper part of the legs with two cranes. To control any instability during hoisting due to transfer of the position of the center of gravity of a panel, wires were attached to both sides of the panel and slowly wound in/released to ensure safety.

Technical control points at the time of full assembly were the root-gap of the panel-point weld and the prediction and countermeasures for the welding shrinkage. For the former, a thoroughgoing measurement control was taken from the viewpoint of weld zone quality assurance, and for the latter, shrinkage was taken into consideration at the time of brace cutting based on actual results in the past. Prior to welding the panel

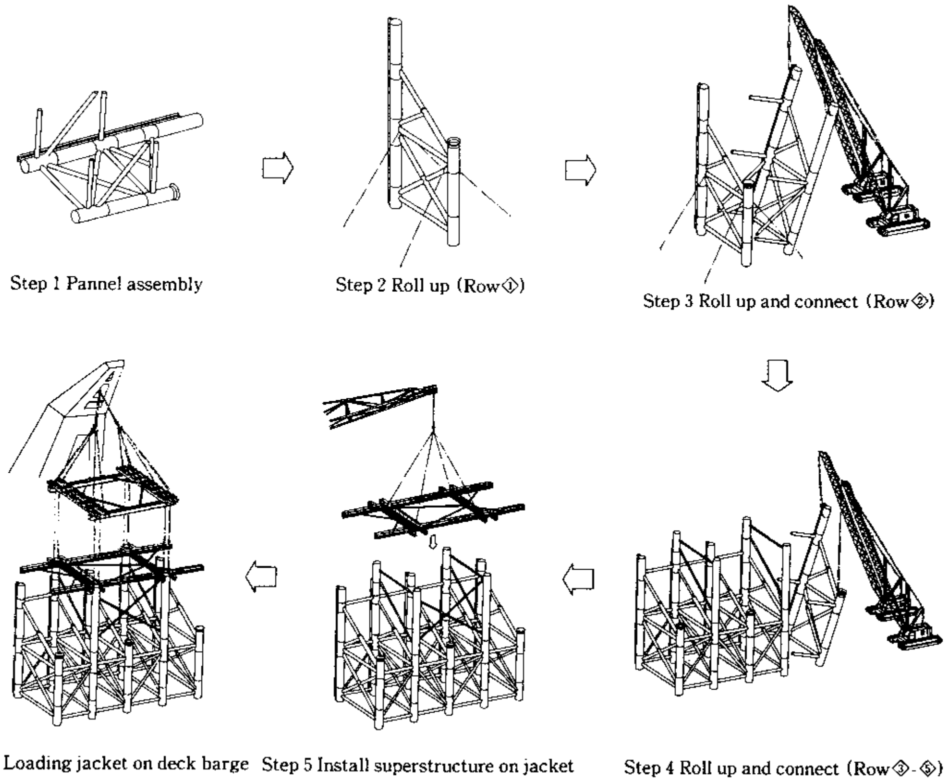

Fig. 5 Assembling procedure of jacket

Photo 1 Panel assembly of jacket at Harima fabrication yard

nodes together, the dimensions between two panels, the skew and the level were measured to ensure assembly accuracy.

A temporary superstructure was assembled as a single unit on the ground, lifted on to the top of the jacket, and welded to the legs.

All weld zones of steel pipes were given non-destructive inspection in full lengths; radiographical test to circumferential butt joints, and ultrasonic test to panel points.

Table 4 Tolerances and results of dimensional inspection after jacket fabrication (Jacket type KJ-5 and 6)

	Tolerance	Actual
Horizontal distance from any column to the column adjacent	± 24 mm	− 9 ~ + 9 mm
Diagonals of a rectangular plan layout	± 32 mm	−14 ~ +10 mm
Diagonals in the vertical	± 32 mm	−14 ~ +11 mm

Table 4 shows typical results of the dimensional inspection after jacket fabrication.

5 Loading and Transportation of Jackets

Ten jackets fabricated at the Harima Fabrication Center were loaded two at a time on a 6 000-t flat-deck barge and towed to the installation site in five voyages (**Photo 2**). Particular attention was paid to safety during loading and transportation due to the size and weight of the jackets. A three-dimensional structural analysis was conducted on each jacket under hoisting conditions, and a vibration analysis was run under wave conditions of a significant height of 5.9 m and a period of 10 s. A thorough technical evaluation was carried out of the requied tug-boat capacity for safe transportation, hawser strength, stability of the flat-deck barge, security of the

Photo 2 Transportation of jackets

jackets, and strength of lashings. A detailed transportation plan was made, and the transportation route, time schedule and port of refuge during rough weather were prepared.

A 3 600-t floating crane was used for loading the jackets on to the barge, and two jackets were loaded in series. A tug-boat of the 3 500-t class was used to tow the barge, and the 345 mile tow was completed in less than 60 h at an average speed of 6 knots.

The four jackets that were fabricated at the Chiba Fabrication Center in Tokyo Bay were transported by a 1 800 to 3 000-t floating crane to the installation site in four trips of one jacket at a time. During the voyage through Akashi Straits and Uraga Channel, an auxiliary tug boat and a patrol vessel stood by on the recommendation of the Maritime Safety Agency and other authorities concerned. Starting 24 h before the departure from the port, an operation control room was set up in the site office of the joint venture to monitor the sea, weather and towing conditions during transportation. Full emergency control measures were planned to thoroughly ensure navigational safety.

6 Site Installation of the Jackets

6.1 Outline and Features of the Installation Work

The jackets, after having been transported by sea from the two fabrication yards to the site, were installed on the sea bed in the prescribed position by a floating crane. A steel pipe pile was inserted into each leg (10 legs/jacket), and the pile was driven in with a hammer. The gap between the leg and the steel pipe pile was grouted to connect them securely, which located the jacket firmly on the sea-bed.

Worthy of special mention here is that, differing from the case of a conventional offshore oil-platform jacket which is installed as a single unit on the sea-bed, the revetment jackets (11 units on each side) were installed consecutively and connections made between them; hence, regardless of the difficult environmental conditions, each jacket had to be positioned to a very high accuracy in horizontal displacement, height and inclination.

Environmental conditions for installing the jacket:

(1) The work site is in relatively very deep water at the center of Tokyo Bay (25 to 30 m water depth).
(2) Compared with coastal areas, the weather and sea conditions of this central area are severe.
(3) The sea lanes in this area are the busiest in Japan (1 400 vessels/day)

The high accuracy of construction that was required, together with economy, safety, limited construction period, and rigorous environmental conditions dictated installation by using temporary support piles.[6)]

6.2 Installation with Temporary Support Piles

This method, as shown in **Fig. 6**, uses four temporary steel pipe piles to support one jacket. These temporary piles are driven into the sea-bed to high height accuracy before installing the jacket. The jacket is then placed on the pile head to give temporary support while setting the plan position of the jacket to high accuracy. The main points of this construction method are shown next.

(1) In order to set the height of the temporary pile head to within ±12 mm (the target value ±5 mm), the final penetration is controlled by using a hydraulic hammer (MHH 250 with an impact energy of 25 t·m) with micro-adjustment to the final ram stroke.
(2) To handle pile driving work in the water depth involved, a long follower having a total length of 38 m was used for pile driving which measured an average driven length of 11 m.
(3) In order to quickly calculate the pile head height above the sea bed from measurements on the above-the-surface part of the follower, coordinate calculations were done by computer.

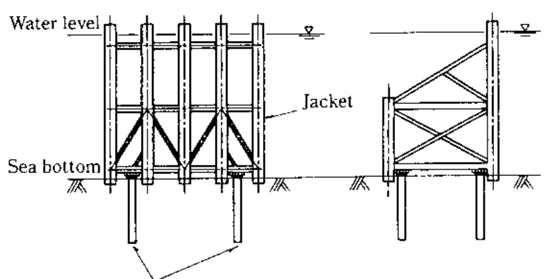

Fig. 6 Temporary supporting pile in water

6.3 Installing the Jackets

The jackets were installed with a 1 800-t-lift floating crane which is one of the largest of this kind of vessel

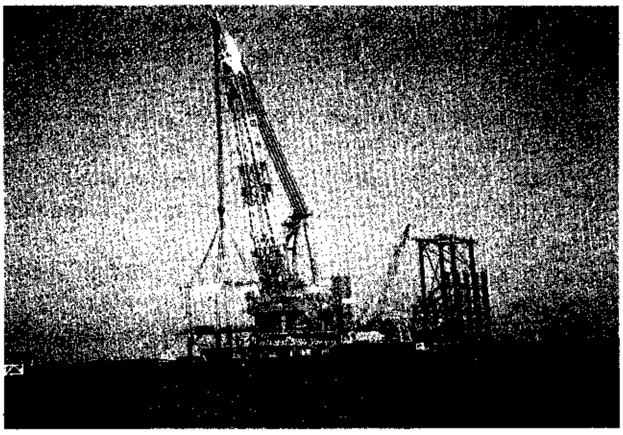

Photo 3 Installation work of the jacket

Table 5 Results of jacket installation

	Tolerance	Actual
Inclination	1/200	1/522 (max.)
Horizontal diplacement from normal line (mm)	100	53 (ave.)
Elevation (mm)	150	29 (ave.)

in Japan (**Photo 3**). This jacket installation work was the climax of the present job for installing large steel structures in relatively deep water, so precise judgement was required of whether or not the operation was possible. This was done by collecting and analyzing beforehand detailed local information such as the wind velocity, with direction and wave height at the work site. The jackets were carefully installed by using lifting beams so that the unbalanced load and impact load would be a minimum. The following work was also done during installation:

(1) The three-dimensional displacement of the underwater center of gravity was obtained, which accompanies changes in buoyancy that act on the asymmetrical jacket, and changes in the inclination of the jacket until it settled on the sea-bed were dynamically calculated to help with the control of installation work.

(2) Two electro-optical surveying instruments were used to enable the three-dimensional coordinates of the jacket to be calculated in realtime, this information being passed to the floating crane.

Table 5 shows the positioning accuracy achieved for installing the jackets. All the parameters of inclination and horizontal and vertical displacements fully satisfy the allowable values.

6.4 Steel Pipe Piling

When driving the steel pipe piles, the soil characteristics were considered. After initial driving of the pile through the sea-bed subsoil, which was comparatively poor, by using a vibro-hammer (VW2-2500E, 2 500 kg·cm), the piles were finally driven through the support layer by using a large hydraulic hammer (IHC-S500, 51 t·m). Since there was little information about the bearing capacity of large-diameter piles, whose construction records are few, and insufficient data on the driving mechanism, conventional rebound measurement was used. Simultaneously, changes at the time of impact and subsequent time-elapsed changes upon re-impact were mesured by a pile-driving analyzer (PDA) in order to directly confirm that the designed loading capacity, which had been derived from the loading test, had been reached, besides accumulating many other data.

7 Summary

Jacket-type steel retaining wall construction work on Kisarazu Man-made Island for the Trans-Tokyo Bay Highway, in which jackets are fully used as the retaining wall structure for the first time in the world, was completed in August 1992 on schedule and without any accidents. The major engineering aspects in the execution of this work are described below.

(1) A design method for the jacket-type steel retaining wall, which is based on related engineering standards, was both domestic and foreign established for the first time.

(2) A high level of quality control was established in the fabrication yards, and the work completed rapidly by applying mass production techniques.

(3) Construction of a jacket-type steel retaining wall for the first time was successfully completed by applying a high-accuracy jacket installation method in a relatively large depth of water.

The authors express their gratitude to the staff of Trans-Tokyo-Bay Highway Corporation for giving valuable guidance, and to the staff of Maeda Corporation and Daito Kogyo Co., Ltd., who are the other members of the aforesaid joint venture.

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