Development of Precast-Form Caisson

Caisson fabrication method offering substantial labor-saving

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Summary

In recent years, the number of skilled civil engineering workers has been in continuous decline. As a result, port and harbor construction work faces labor shortages, while the aging worker population and an increasing number of unskilled workers have also necessitated efforts to reduce labor requirements on construction projects. At the same time, fiscal reform has led to demand for reduced construction costs, and port and harbor improvements now need to be made within limited budgets without sacrificing quality.

As a contribution to labor and cost saving, we have developed a precast-form caisson that takes full advantage of precasting techniques.

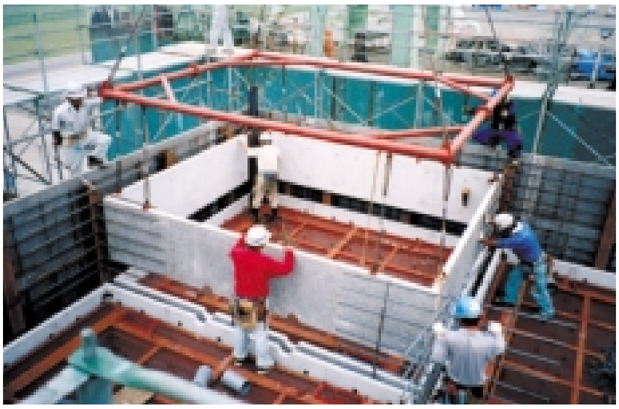

Photo 1. Precast-form caisson under fabrication

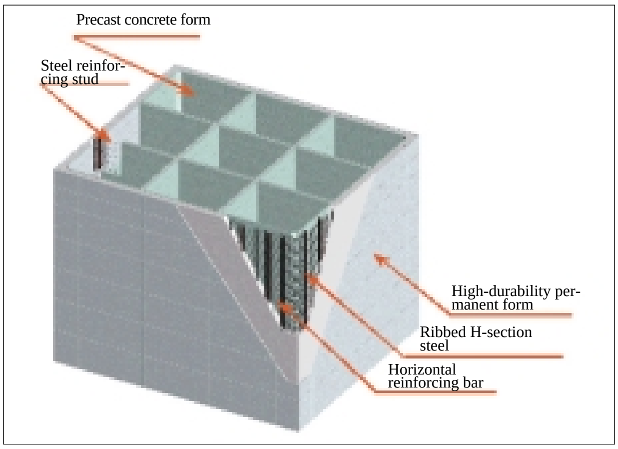

Fig. 1 Conceptual drawing of precast-form caisson

Outline of precast-form caisson

This new caisson fabrication method is an application to port and harbor structures of technology originally developed to increase the earthquake-resistance of road bridge piers while achieving more rapid construction.

Typically, reinforced concrete caissons are fabricated on floating docks (FD) by ironworkers and timbermen. A combination of factors, including a shortage of skilled workers, the aging worker population, and greater reliance on unskilled workers, has led to growing concern over quality assurance as well as an increase in industrial accidents. The cost of fabricating caissons by this conventional method depends greatly on total manpower and the number of working days on FDs (that is, FD hire). The precast-form caisson was developed in order to (i) simplify the construction and removal of forms, (ii) simplify the assembly of steel reinforcement, and (iii) use standardized materials and precast forms.

Features of materials used

(i) High-durability form

A high-durability permanent form 50 mm in thickness improves resistance to freezing, thawing, and cracking in seawater while saving labor during construction. The concrete used for the outer caisson wall has a compressive strength of 70 N/mm², a flexural strength of 12 N/mm², and a stainless steel fiber content of 1.5% by volume. A freezing and thawing test verified that no loss of durability occurred after more than 800 cycles.

(ii) Precast concrete permanent form

The use of a permanent form eliminates the need for

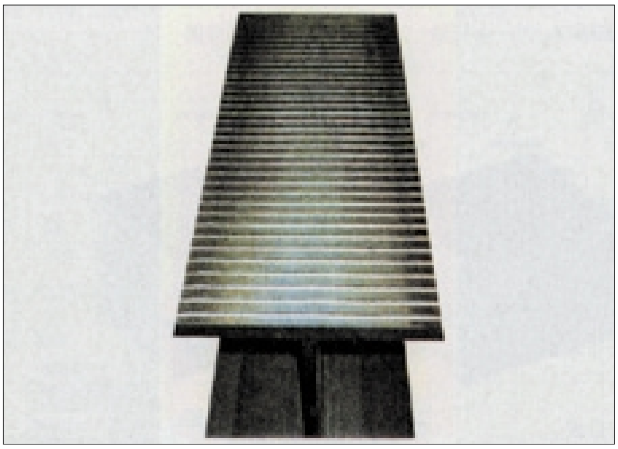

Photo 2. Ribbed H-section steel

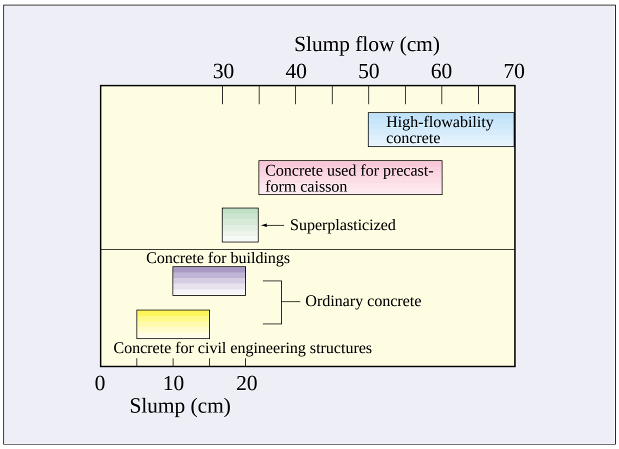

Fig. 2. Flowability of concrete used for precast-form caisson

Table 1. Mix proportion of concrete used for side and partition walls

Specified design strength (N/mm^2)	Air content (%)	Max. coarse aggregate size (mm)	Slump flow (cm)	Max. water-to-cement ratio (%)	Min. cement content per unit volume of concrete (kg/m^3)	Type of admixture
24	4.5	20	50	50	300	High-performance air-entraining and water-reducing agent

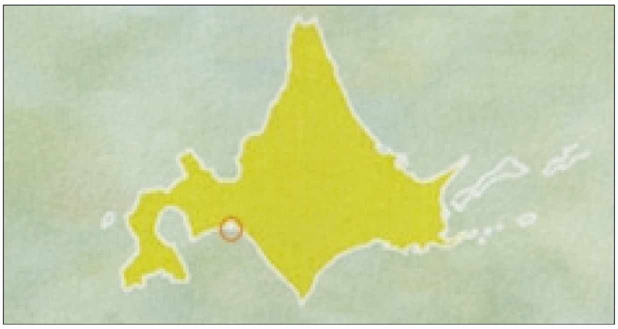

Fig. 3 Location of Tomakomai Port

on-site arrangement of reinforcing bars within the side and partition walls. The precast concrete permanent form that forms the inner wall of the caisson incorporates pre-arranged reinforcing bars for the side and partition walls.

(iii) Ribbed H-section steel

To minimize reinforcing bar assembly work, H-section steel is used instead of vertical reinforcing bars. Ribs protruding by 1.5 mm and spaced at intervals of 15 mm increase adhesion between steel and concrete. A pulling test verified that this type of steel reinforcement has a strength comparable to D51 reinforcing bars. A beam bending test was implemented to study the design of the steel reinforcement and the spacing between steel sections with the aim of controlling crack width. This indicated that the cross-sectional dimensions of the steel should be designed to have the same cross-sectional area as the equivalent reinforcing bars. Crack width can be controlled within allowable limits by ensuring that the spacing between H-section steel sections is at least twice the depth of the steel section and no more than ten times or 200 cm its depth, whichever is smaller.

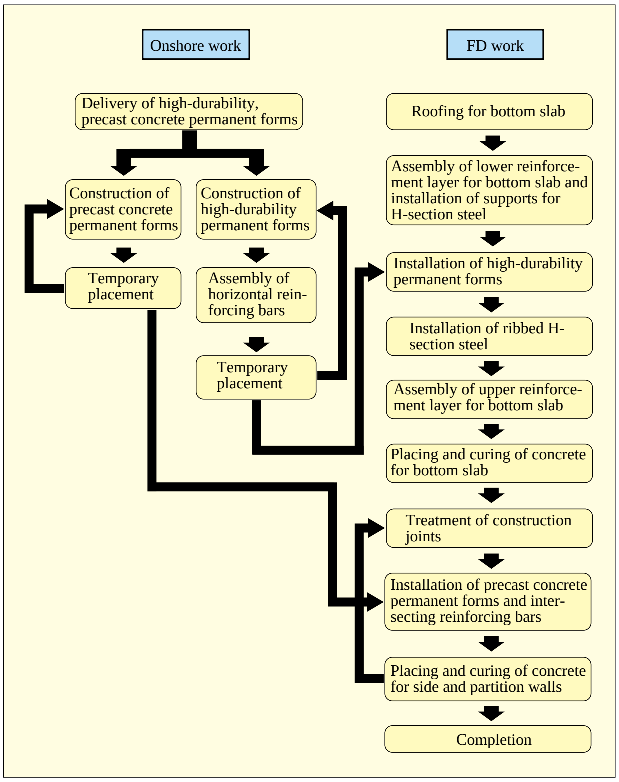

Fig. 4. Block flow diagram of precast-form caisson fabrication

(iv) Concrete for side and partition walls

The clearance between the forms of a partition wall

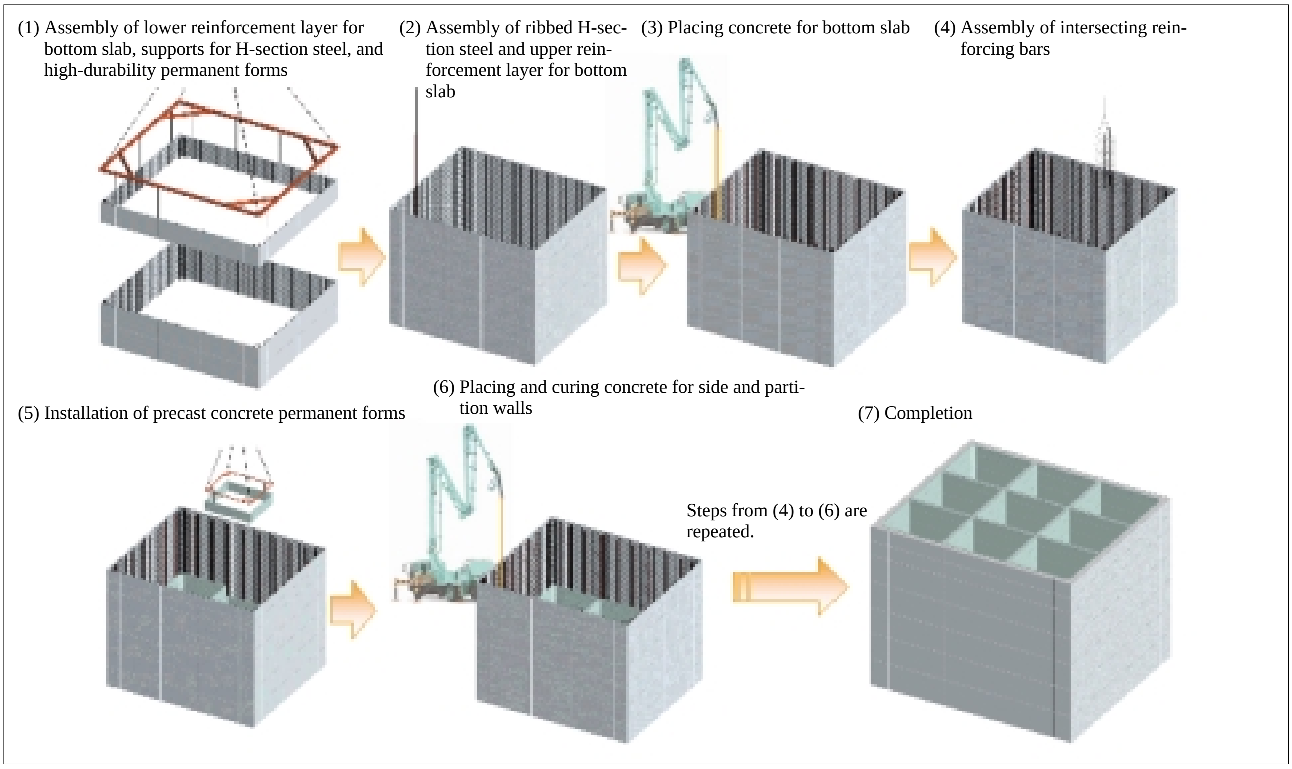

Fig. 5 Fabrication process for precast form on FD

Photo 3. Assembly of high-durability permanent forms

Photo 4. Assembly of horizontal reinforcing bars of side walls

Photo 5. Assembly of ribbed H-section steel

Photo 6. Assembly of reinforcing bars at the intersection of partition walls

is as little as 10 cm, and one lot of concrete is placed in considerable height, 5 m. As a consequence, the use of ordinary concrete may lead to insufficient compaction. Further, since the formwork is permanent, it is difficult to check whether proper filling has taken place deep in the form structure. Both superplasticized and high-flowability concretes are available to deal with such situations, as shown in Figure 2. The former, with a slump

Table 2. Comparison of fabrication progress with conventional method and the precast-form caisson

Fabrication of caisson by the conventional method

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Steel reinforcement work	■	■	■							■	■					■	■					■	■																	
Formwork				■	■	■			■			■	■					■	■					■	■						■	■								
Concrete work							■							■						■						■														
Treatment of construction joints and curing								■							■						■						■	■	■	■	■	■								
Sinking of caisson																																	■							

Total calendar working days: 27 days x 1.65 (service factor) + 6 (for curing concrete) = 50.6 days

Fabrication of precast-form caisson

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Steel reinforcement work	■			■																
Installation of supports for H-section steel	■																			
Installation of high-durability permanent forms (including horizontal reinforcing bars on the outside of side walls)		■	■																	
Installation of ribbed H-section steel			■	■																
Installation of precast concrete permanent forms (including tie bars and intersecting reinforcing bars)						■	■		■	■	■									
Concrete work				■				■			■									
Treatment of construction joints and curing					■			■	■			■	■	■	■	■	■			
Sinking of caisson																		■		

Total calendar working days: 12 days x 1.65 (service factor) + 6 (for curing concrete) = 25.8 days

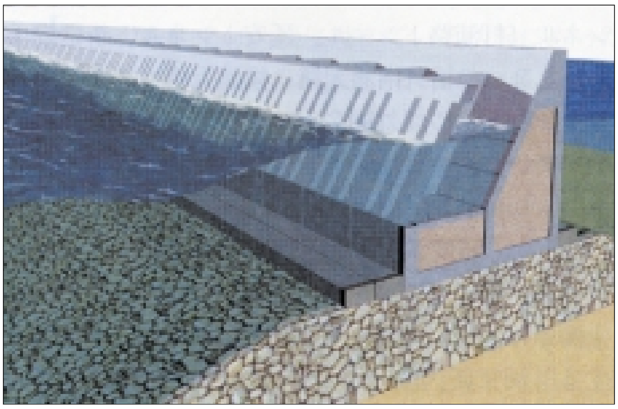

Fig. 6 Conceptual drawing of the inclined sea wall with slits

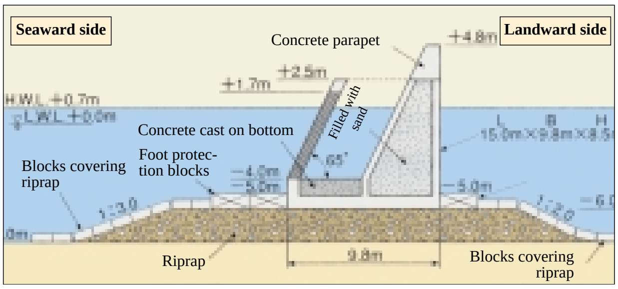

Fig. 7 Standard cross section of inclined sea wall with slits

of about 18 cm, tends to segregate because of its low viscosity. On the other hand, the latter has good filling properties but costs more. Accordingly, concrete with intermediate properties and delivering high flowability for ease of compaction was chosen for the side and partition walls. A full-scale model test using a 4.6 m high by 3 m long by 150 mm thick wall was carried out to verify the filling properties and quality of the concrete. Table 1 summarizes the mix proportion of the concrete used.

Implementation

To test the new method, a single caisson was fabricated onshore at Tomakomai Port (Photo 3). The caisson measures 14 m long, 12 m deep, and 11 m high, and consists of nine compartments. It weighs 1,209 tons in total. This relatively small structure is for use as a breakwater in open waters.

Caissons are usually fabricated on offshore FDs. This design was also fabricated on an offshore FD for comparison purposes, as shown in Figure 4.

For fabrication in the onshore yard, shop-fabricated high-durability permanent forms and ribbed H-section steel were unitized using reinforcing bars. On the FD, unitized forms were installed, ribbed H-section steel and reinforcing bars arranged, and then the concrete was placed. Filling of concrete deep in the side and partition walls was checked by measuring changes in temperature with thermocouples fitted at difficult-to-fill locations, such as within the steel flanges and where reinforcing bars meet partition walls. All the thermocouples indicated temperature rises, verifying that the concrete flowed correctly into all voids.

Labor and cost savings

Comparing the total number of ironworkers and timbermen used by the two fabrication methods, the conventional operation took a total of 280 man-days, while fabrication of the precast-form caisson required 67 man-days, a labor reduction of approximately 75%. As can be seen from Table 2, fabrication by the conventional method took 50.6 days while fabrication of the precast form caisson took 25.8 days, attaining an approximately 50% saving in time.

These savings resulting from a simplification of operations, such as the use of ribbed H-section steel, the onshore assembly of precast concrete permanent forms, and the unitization of reinforcing bars, as well as eliminating the need to remove forms.

The total cost of constructing the precast-form caisson was 99.4% that of the conventional caisson. There are two reasons for this marginal cost saving: first, full advantage of high-durability permanent forms was not taken, particularly as the number of compartments was not reduced, and secondly the cost of the forms was high because only one caisson was fabricated.

An application of the caisson to a sea breakwater with an inclined front and slit openings

The new caisson fabrication method is being applied to an inclined caisson with slits fabricated at the Fukushima fishing port facing Tsugara Strait is presented below. This caisson is to form a breakwater with an inclined seaward face and slit-shaped openings. The inclined face has the effect of increasing the vertical component of wave forces, thus increasing the resistance of the caisson to sliding over the seabed. The slits, which lead into a rearward space containing free water, have the effect of breaking up wave forces and providing a place for fish to gather. The precast form method was chosen to enhance durability and improve the constructability of the diagonal members forming the slits.

The effectiveness of the new fabrication method is currently being evaluated. The use of steel members to support the permanent form at the inclined section simplified fabrication and resulted in more rapid construction.

Conclusions

It has been demonstrated that the precast-form caisson can yield considerable labor savings during fabrication, and the hoped-for reduction in construction costs, though small, was achieved. Future efforts to reduce construction costs will focus on reducing the number of compartments in the caisson, the mass production of high-durability permanent forms, and the standardization of the forms into secondary products (standard items).