Shortening of Construction Period and Improvement of Productivity by Applying the Large-scale Precast Method in the Construction of a Prestressed Concrete Liquefied Natural Gas Tank

大規模プレキャスト工法適用による PCLNG タンク建設の工期短縮と生産性向上


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1. Introduction

The No. 2 LNG tank (hereinafter referred to as the “No. 2 tank”) at the Hitachi LNG Terminal of Tokyo Gas Co., Ltd. is Japan’s largest above-ground prestressed concrete (PC) LNG tank. Constructed in Hitachi City, Ibaraki Prefecture, for receiving, storing, and supplying liquefied natural gas (LNG), the No. 2 tank has been operating since March 2021 (**Fig. 1**). The precast method was used for the outer tank of the No. 2 tank for the first time in Japan, thereby realizing drastic shortening of the construction period and improvement in productivity for PC LNG tank construction. This paper describes an overview of the development and its application and results.

Fig. 1 No. 2 tank at the Hitachi LNG Terminal

2. Outline of Construction

An outline of the Hitachi LNG Phase II construction project including the construction of the No. 2 tank is shown in **Table 1**. The client was Tokyo Gas Co., Ltd., and the primary contractor was Tokyo Gas Engineering Solutions Corporation. Kajima Corporation and IHI Plant Services Corporation organized the joint venture and participated in the design/construction as primary partners of the primary contractor.

The PC LNG tank comprises metallic inner and outer tanks and insulation between them overseen by a machinery contractor (hereinafter referred to as “machinery”), and a PC outer tank, bottom slab, and pile foundation overseen by a civil contractor (hereinafter referred to as “civil”) (**Fig. 2**). The outer tank is a cylindrical vertical type, and it is a large-scale prestressed concrete structure aimed at offering surrounding safety in the event that LNG stored at

Table 1 Hitachi LNG Terminal Phase II Construction

Project name / place	Hitachi LNG Terminal Phase II Construction: LNG Storage Tank Construction and other works / No. 5 Wharf Area, Hitach Port, Hitachi City, Ibaraki Prefecture, Japan
Construction period	Overall period: Apr. 1, 2018 – Jun. 30, 2021 LNG tank construction: 29 months (Aug. 2018 – Dec. 2020)
Major Items	Above-ground LNG tank: 1 unit (capacity 230000 kL) Steel pipe pile foundation, bottom slab, outer tank Ground reinforcement, exterior construction, on-site electrical work, pipe rack foundation, ancillary facilities (bottom heating system and others)

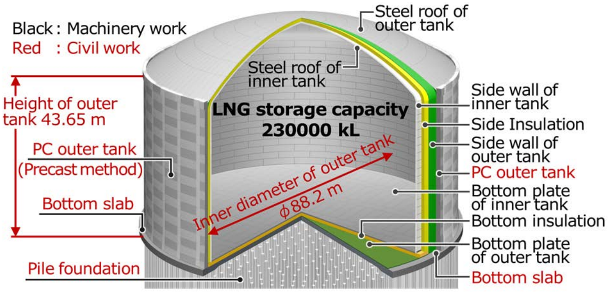


Fig. 2 Outline of PC LNG tank and division of roles

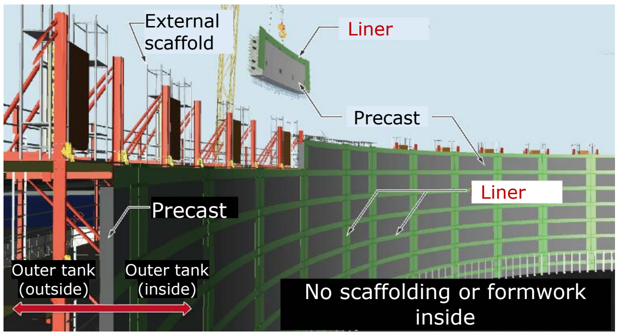


Fig. 3 Securing workspaces for machinery work

cryogenic temperature (−162°C) leaks from the inner tank.

The storage capacity of the No. 2 Tank is 230000 kL, the largest in Japan. The outer tank has an inner diameter of 88.2 m, a height of 43.65 m, and a wall thickness of 0.65 m. Concrete with a design strength of 30–60 N/mm^2 was selectively used for each part. In the bidding phase for the No. 2 tank, a shortened construction period leading to early completion was required in order to respond swiftly to the rising demand for LNG. Therefore, the precast technology was selected as technical solution to accelerate the construction of the outer tank.

3. Aim of Adopting the Precast Method

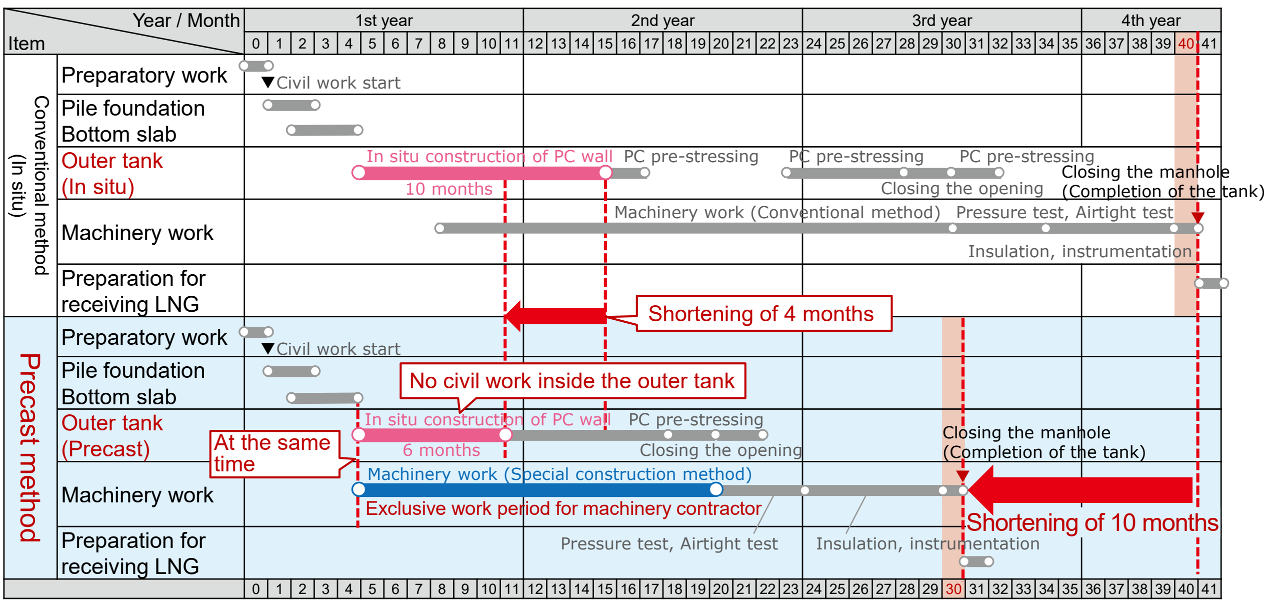
(1) Issues with Conventional Method

It is common for the outer tank to be constructed using cast-in-place concrete (hereinafter referred to as the conventional method). In addition, construction of a PC LNG tank is characterized by civil work and machinery work happening in parallel for a long period of time (upper part of **Table 2**). In particular, the construction of the outer tank by the civil contractor is intertwined with the machinery work, and this is often a constraint on the smooth progress of construction. Furthermore, with the conventional method, formwork and scaffolding for civil works must also be provided inside the outer tank as it is constructed, and therefore machinery work cannot begin immediately; instead, it must begin about 3 months after the start of outer tank construction. These were the issues involved in shortening the overall construction period of the PC LNG tank.

(2) Solving Problems by Using the Precast Method

To effectively shorten the construction period of the outer tank, precast construction was applied, aimed at ensuring the working period of the machinery contractor alone and leading to highly efficient and smooth machinery work without congestion. In this way, the authors aimed to shorten the overall construction period for the tank (lower part of **Table 2**). Also, to ensure that the tank interior was released to the machinery contractor as soon as possible, the inner formwork (liners) of the precast panel joints was set on the precast panels in advance, thereby completely eliminating civil construction facilities and operations inside the tank (**Fig. 3**). This innovation enabled

Table 2 Overall schedule for PC LNG tank (comparison between conventional method and precast method)



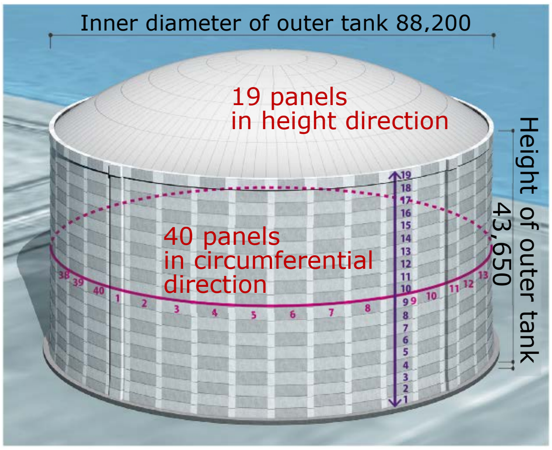


Fig. 4 Arrangement of precast panels (unit: mm)

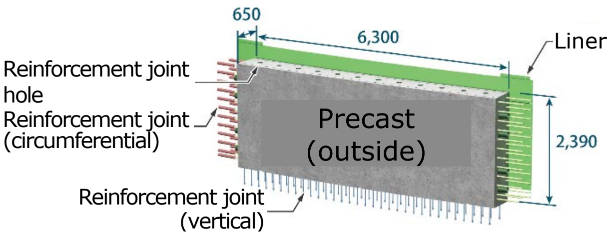


Fig. 5 Image of precast panel (unit: mm)

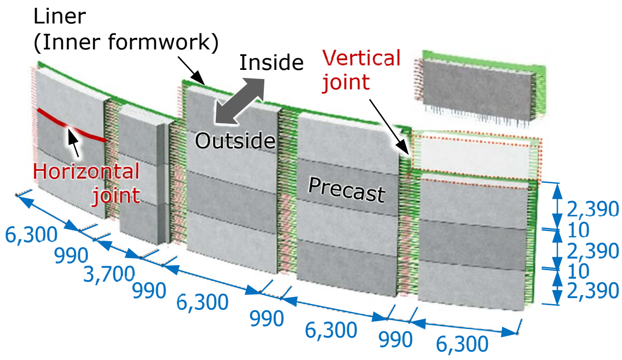


Fig. 6 Joints of precast panels (unit: mm)

construction of the outer tank and the machinery work to progress simultaneously, thereby further reducing the overall construction period. Improved productivity can also be expected from the labor-saving benefits of the precast method. Based on the concept described above, the authors developed a precast method for constructing the outer tank aimed at shortening of construction period and improving productivity.

4. Solving Critical Issues of Joint Structures

Considering land transportation and handling within the manufacturing plant, the precast panels are 6.3 m wide, 2.39 m high, 0.65 m thick, and weigh less than about 240 kN. There are 19 panels in the height direction and 40 in the circumferential direction (**Figs. 4** and **5**).

When applying the precast method to the outer tank, the joints of the precast panels had to achieve the same performance as that with the conventional method. In particular, the outer tank must remain liquid-tight in the event of LNG leaking at cryogenic temperature. For this reason, the joints of the precast panels are connected by casting in situ infill concrete to ensure the same performance as that of the cast-in-place joints of the conventional method (**Fig. 6**).

Fig. 7 Performance test of joint

The left and right joints of a precast panel (hereinafter, the vertical joints) were constructed in situ using shrinkage-compensating concrete because they have little impact on the installation time of a precast panel, and the circumferential reinforcements were connected by mortar-filled machinery joints. By contrast, the upper and lower joints (hereinafter, the horizontal joints) were designed to shorten the installation time and make quality-assurance easier because they greatly affect the installation time of a precast panel. A horizontal joint had a minimum clearance height of about 10 mm, and the clearance was filled with shrinkage-compensating mortar. The vertical reinforcements were connected by lap joints specially improved for this specific structure, namely, lap joints with machinery anchorages and shrinkage-compensating mortar filling.

5. Verification of the Precast Method

Preliminary tests confirmed that the bearing strength of the vertical and horizontal joints is the same as that for an outer tank constructed by the conventional method. For example, a performance test confirmed that a horizontal reinforcement joint has the required bearing strength [1] (**Fig. 7**). Because the shrinkage-compensating mortar used for the horizontal joints must have ultra-high fluidity and moderate inflatability to flow spontaneously and fill the clearances, materials that satisfy these requirements were selected.

To confirm the construction procedure and progress ensuring reliable and shortened construction, a mock-up test with a full-scale precast panel was carried out using the specifications of the vertical and horizontal joints determined in the preliminary tests.

6. Construction of the Outer Tank

This section reports the actual construction of the No. 2 tank to which the developed technology was applied. The plan was to manufacture six precast panels per day

Fig. 8 Manufacturing of precast panels

Fig. 9 Construction by the precast method

and install eight per day. Therefore, manufacturing at the plant began 5 months before the start of outer tank construction such that the installation would proceed without delay (**Fig. 8**).

The precast panels manufactured at the plant (740 pieces; the opening for construction is of in situ concrete structure) were transported to the site on a high-floor trailer and installed after mounting the liners. A 200-ton crawler crane was used for the installation, and self-climbing scaffolding was used outside the outer tank for civil works (**Fig. 9**).

Construction of the outer tank with the precast method was completed in 6 months from mid-January 2019 to mid-July of the same year. Consequently, it was possible to have the machinery contractor's independent operation carried out when the hoisting operation by the machinery contractor was at its peak, and this improved the efficiency of the machinery work. The parallel operations of the civil and machinery contractors were kept completely separate, which also resulted in more-efficient construction (**Fig. 10**).

Fig. 10 Separate construction: civil and machinery, inside and outside outer tank

Compared with about 40 months by the conventional method, the overall construction period of the No. 2 tank was only 29 months (1 month less than the initially planned 30 months, thanks to further ingenuity), and the tank construction was completed in December 2020. The total amount of skilled construction work in the field would have amounted to 14000 person-days with the conventional method, whereas it was only 8500 person-days with the precast method, a reduction of 40%. In this way, saving of labor and workers was achieved by using the precast method, and improved productivity was also realized.

7. Conclusion

Realizing drastically shorter construction time and improved productivity simultaneously, the precast method for constructing a PC LNG tank was applied for the first time in Japan to the No. 2 tank, one of the largest in the country. The following effects were confirmed.

[Shortening of construction period] The overall construction period was 29 months, whereas it would have been about 40 months with the conventional method.

[Improvement of productivity] The total number of person-days for skilled construction work was reduced by 40% compared with the conventional method.

In this way, the precast method contributed greatly, given the concurrent operations of the civil and machinery contractors when constructing a PC LNG tank. In addition, the required joint structure was devised, and the construction performance, procedure, and progress were assessed by preliminary performance tests of the precast panel joints by means of a mock-up test and other investigations.

Knowledge obtained from developing the precast method for constructing PC LNG tanks and its application to the construction of the No. 2 tank will be effective for not only the outer tanks of PC LNG tanks but also shortening the construction periods and improving the productivity of general large-scale concrete civil engineering structures constructed by the precast method.

Reference

[1] Okubo, K., Ichinomiya, T., Yokota, Y., Yamanobe, S.: *Study on the Rational Joint for Precast Member*, Proceedings of 5th International fib Congress 2018, October 2018.