Development of Construction Technique of LNG Storage Tank Wall Using Precast Concrete Panels

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Abstract. The conventional LNG storage tank wall has been constructed with cast-in-place (CIP) concrete method. However, CIP method is difficult for construction management because it is significantly affected by conditions of construction site, such as climate and material supply conditions. Therefore, this construction method consumes construction time and cost. Recently, to reduce the construction time, various construction methods, such as jump-form and slip-form method [1], are being applied to the LNG storage tank wall. But, there is a limit that construction of the inner tank has to be conducted after the construction of outer tank wall is completed. Meanwhile, precast concrete (PC) method has some different characteristics compared with that of CIP method. In the PC method, structural members are previously manufactured at a factory and transported to the construction site to be assembled. There are advantages which are reduction of construction time and cost and improvement on quality control and durability. The main objectives of this paper are to introduce a new construction technique for LNG storage tank wall using PC panels to overcome the existing limitations, and discuss the benefits of the technology. In addition, to verify the applicability of the new construction technique, a mock-up test was conducted considering PC panels.

1. Introduction
As the demand for LNG, which accounts for a large share of the world's energy consumption, increases, construction demand for LNG storage tanks is also increasing. Accordingly, a number of researches on construction method have been developed to reduce the costs and period of construction of LNG storage tanks [2]. LNG storage tanks are containment structure to liquefy and store natural gas below -160 °C, with single containment tanks and double containment tanks had been used in the past. In recent years, full containment tanks have been mainly used. The full containment tanks basically consist of an inner tank and an outer tank [3, 4]. Inner tank is made of 9% Nickel steel plate with physical properties for cryogenic to safely store LNG and prevent gas and liquid leakage [5]. Outer tank is constructed by applying the cast-in-place (CIP) method using concrete with the formability of material to ensure the safety of the LNG storage tanks system. However, it is difficult to control the construction because the CIP method is affected by construction site conditions, such as weather conditions and materials supply conditions. Since it is also absolutely necessary to install and dismantle the temporary form, the construction time and costs may increase. When the CIP method
with these characteristics is applied to LNG storage tanks, then inner tank must be constructed after the construction of outer tank and roof is completed first.

Therefore, in this paper, a new construction method to rapidly construct an LNG storage tanks will be proposed by applying a precast concrete (PC) method that satisfies economy and construction simultaneously to the outer tank with considering the problems of construction and improvement of existing LNG storage tanks [6]. This construction method has the advantage of replacing the temporary form used in the existing LNG storage tanks with the PC panels to reduce the time to dismantle the form, and to simultaneously construct the inner tank and the outer tank. In order to verify the construction method proposed in this paper, a part of real-scale LNG storage tanks was installed for a mock-up test and strain sensors were used to monitor the behaviour of mock-up during construction in real time. Then, constructability and structural safety evaluation were discussed.

2. Components of LNG storage tanks
The LNG storage tank is a cylindrical containment for storage of liquefied natural gas below -160°C and reducing the volume to 1/600. The LNG storage tanks consist of an inner tank and an outer tank, and the inner tank is made of 9% nickel steel to safely store cryogenic LNG and prevent leakage. The outer tank is composed of reinforced concrete (RC) and pre-stressed concrete (PSC) to safely protect the inside of the storage tank and disconnect from the ambient temperature. In order to prevent direct contact with the outer tank and leakage to the outside when an accident occurs in which an inner tank is defective and leakage of LNG occurs, a wall liner made of a thin steel plate serving as a vapour barrier on the inner surface of the outer tank should be installed. The construction of the wall liner is carried out inside the outer tank after completion of the outer tank in most LNG storage tanks construction using the CIP method. Then the construction of the inner tank can be constructed. Figure 1 shows the overall shape and cross section of the LNG storage tanks.

![Figure 1. LNG storage tank components.](image)

3. Application of precast concrete panels
In this chapter, the construction cases of the PC panels will be discussed and the construction method proposed in this paper is compared with the existing construction method of LNG storage tanks.

3.1. Construction cases
As the structure of buildings is becoming high-rise, enlargement, and diversification in the whole world, the existing CIP method has limitations in not only shortening of construction time but also ensuring quality of concrete. The PC method is a way to modularize the structure by manufacturing large amounts of members such as columns, walls, beams and floors at the factory. Then, the member is transported to the site and assembled using the temporary equipment. Construction cases of
applying the PC method are shown in Figure 2 and 3. PC panels applied in each case have the advantage of being able to be used as permanent form by replacing temporary form, also the continuity of reinforced bars can be ensured.

![Figure 2](image1.png)

**Figure 2.** Construction case of bridge slab using PC panels.

![Figure 3](image2.png)

**Figure 3.** Construction case of bridge pier using PC panels: (a) Inner PC installation, (b) Reinforcement, (c) Outer PC installation, (d) Joint sealing, and (e) Construction of bridge pier.

### 3.2. Construction procedure

The existing construction method of the LNG storage tanks has the process of constructing the outer tank after construction of foundation and bottom slab. Here, the outer tank is constructed by applying the climbing-form using the temporary form into the site. During the construction of the outer tank, the roof of the tank is built at the same time. The roof is constructed on the bottom slab. After the construction of the outer tank is finished, if the concrete becomes hard enough, air pressure is injected into the inside of the outer tank to lift the roof up to the top of the outer tank. When the roof is structurally integrated with the outer tank at the top, the wall liner is installed on the inside of the outer tank, which serves as the vapor barrier of the LNG. Finally, once the inner tank is constructed, the wall liner should be constructed to stand along with roof by using the jack-up method [7]. The wall liner should be constructed with sufficient thickness to ensure structural stability when self-erection. Once the self-erection of the wall liner along with the roof is completed, the outer tank and the inner tank can be constructed at the same time, which can shorten the construction time considerably. In addition, since the dismantlement of the temporary form required in the existing construction method is excluded when constructing Outer tank in this study, the erected wall liner and the PC panels can be used as permanent form for more economical construction. In the proposed construction method, The PC panels used as permanent form should be connected to each other using a sealant between adjacent panels, and fabricated by inserting loop shear connectors on the surface that is in contact with the fresh concrete to bond with the CIP concrete. Also since the wall liner has to withstand the lateral pressure...
generated when the concrete is poured, so, 9mm thicker than the conventional 5mm thickness was used in accordance with the design standard [8]. In the process of concrete curing, wet curing is easier than conventional methods because PC panels and wall liner used as permanent forms can block the ambient temperature. Figure 4 shows the comparison between the procedures of the existing construction method and the proposed construction method. The PC panels and wall liner serve as permanent molds for pouring concrete as shown in Figure 5. The tie-rod shown in Figure 5 serves to tie up the wall liner and the PC panels to prevent the PC panels from falling during the concrete casting.

**Figure 4.** Comparison of conventional and suggested method: (a) Conventional method, (b) Suggested method.

**Figure 5.** Conceptual construction procedure using precast concrete panels: (a) Reinforcement, (b) Assembling PC panels, (c) Installation of worktable, and (d) Completed.

4. Mock-up test

4.1. Manufacture of mock-up
In order to verify the constructability and structural safety of the construction method proposed in this thesis, a full-scale mock-up was constructed and tested considering the PC panels and wall liner. Mock-up is designed based on LNG storage tank with a capacity of 200,000 k㎘ among the ground-operated full containment tanks considering with design standard [9]. The design strength (f_{ck}) of the PC panels is 40 MPa. The mock-up, which is applied to PC panels, has a height of 10 m considering the reasonable size for determining the constructability and structural safety evaluation, and twelve PC panels were manufactured in total of 3 layers with 4 panels in each layer. Also, the height of one layer was designed to be 3.75 m, which is the same height as that of the existing LNG storage tanks.

Figure 6. Mock-up with PC panels.

Figure 7. Construction procedure of mock-up with PC panels: (a) Erection of wall liner, (b) Assembling PC panels, (c) Tie-rod installation, (d) Concrete casting, (e) Concrete curing, and (f) Completed mock-up.
4.2. Experiments for verification of constructability

To verify the constructability and structural safety of the proposed construction method through the mock-up test, strain sensors were attached to the second and third layers of wall Liner, which are most concerned during the construction. Then, strain data of the wall liner was collected while monitoring the behaviour of the wall liner in real time during the concrete casting. The position of the strain sensors was selected based on the location of the tie-rod as shown in Figure 8, and the strain sensors were attached in vertical and horizontal direction as shown in Figure 9.

![Figure 8. Measurement location of strain sensors.](image)

![Figure 9. Strain sensors attached on the wall liner.](image)

4.3. Experimental results

During the mock-up test, the measurement test using strain sensors measured the strains of the wall liner on the lateral pressure that occurs when casting concrete. The measured strains were converted into the stresses considering the material properties of the structural material, and based on this, the structural safety was evaluated for the proposed construction method in comparison with the allowable stress of the wall liner specified in the design standard. The wall liner used for the LNG storage tanks was ASTM A516 Grade 60 steel plate and the allowable stress is estimated to be 147 MPa [4]. Figure 10 shows the stresses of the wall liner subjected to the lateral pressure of the concrete during the construction of the second and third layers. The stress distribution obtained from the strain
measurement experiment is shown in Fig. 10, and it can be confirmed that the maximum stress generated at the second layer of concrete casting is 122 MPa, and the maximum stress generated at the third layer is 136 MPa. In other words, structural safety is considered ensured since it does not exceed the allowable stress range of the wall liner.

5. Conclusions
The purpose of this paper is to introduce a new construction method of LNG storage tanks using PC panels and to discuss the advantages of this technology to overcome the limitations of existing construction methods. In summary, this new construction method using the PC panels has the advantage that the independent wall liner and PC panels can be used as permanent form for the construction of outer tank, allowing both inner and outer tanks to be constructed at the same time. In addition, mock-ups were manufactured in order to evaluate the structural safety in the construction steps, and experimental measurement was implemented by using strain sensors. The conclusions of this study are as follows:
(1) By applying precast concrete panels to LNG storage tanks, it is possible to shorten the construction period since the dismantlement of the temporary form is excluded in the existing construction method.

(2) Also, because PC panels and wall liners serve as permanent form, the continuity of the reinforced rebar inside the outer tank wall can be secured during the construction of the outer tank.

(3) In the proposed method, an additional process for self-erection of the wall liner is necessary. As a result of monitoring the behaviour of the wall liner through the mock-up test, the structural safety is secured because it does not exceed the allowable stress range.

(4) As the wall liner became independent in the construction of the mock-up, it was required to carry out the installation of the reinforcement from one position, but it was found that there were no significant difficulties in reinforcing bar arrangement.

(5) Economically, additionally structural members (PC panels) are generated compared to conventional method, but the construction costs are expected to be similar due to the elimination of installation and dismantling of temporary forms used in existing construction method.

(6) Since PC panels are lifted and installed with cranes during the construction, safety countermeasures must be taken to prevent falling the PC panels.

In conclusion, the construction method of LNG storage tanks using PC panels can significantly reduce the construction period and can be widely applied to various storage tanks regardless of the capacity of the storage tanks. However, it is desirable to carefully examine each construction step and apply it to actual construction of LNG storage tanks.

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