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Design and Construction of the World's Largest LNG Underground Tank

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Summary

The world's largest LNG underground storage tank with the capacity of 200,000 kl will be completed in March 1998. This tank is the first to be buried completely underground, including its roof. This tank has an inner diameter of 72m and a liquid depth of 49.2m. The roof of this tank is a dome shaped structure made of reinforced concrete which supports the soil weight of about 400MN laid on it and dead weight of 150MN. The dome roof is 72.8m in diameter, 7.3m in rise and 1~2.5m in thickness. Rise-diameter ratio is 1/10 which is very small compared to 1/6 of conventional steel roof. The investigation of the buckling characteristics of the domed roof, such as experimental tests and so on, was applied to this tank and both linear and non-linear analyses were performed in order to verify the stability of the dome roof against buckling. The dome roof was constructed above temporary steel truss girders like a huge umbrella.

1. Introduction

A new liquefied natural gas (LNG) receiving terminal has been constructed on Ohgishima Island in Yokohama to meet the burgeoning demand for gas in the greater Tokyo Metropolitan area.[1] This terminal, which will be the most advanced, is scheduled to go into operation from October 1998. The first LNG underground storage tank in the world totally embedded in the ground (including its reinforced concrete roof) will be constructed in March 1998. This tank, capacity of which is 200,000 kl, is one of the biggest LNG tanks in the world. LNG is stored at the temperature of -162°C and this tank itself is like a huge thermos bottle, which has 72m in inner diameter and 49.2m in liquid depth as shown in Fig. 1. It is located in a reclaimed area facing Tokyo Bay and buried underground to achieve greater safety against fire at the adjacent oil terminal and to improve the Bay Area view. In order to build the large underground storage tank, a number of innovative technologies were developed and applied. This paper deals with the technological aspects of this tank, mainly the dome roof, in the design and construction phases.

2. Outline of the tank

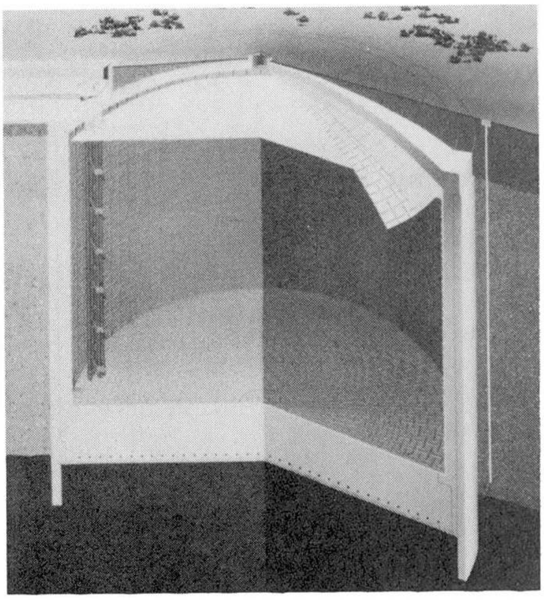


Fig. 1 General view of 200,000 kl LNG underground tank

Fig. 2 shows the ground condition and the structural configuration of the 200,000 kl LNG underground storage tank. The ground mainly consists of sandy permeable soil with an impermeable silty soft rock layer more than 58m below the surface. For tank construction, deep excavation was carried out by installation of very deep slurry walls into the soft rock as retaining and cut-off walls.

The side wall is made of reinforced concrete and features a cylindrical configuration because of a structural advantage for inground structures which retain earth and ground water pressure. The thick bottom slab is made of reinforced concrete to withstand high ground water up-lift. The dome roof is also made of reinforced concrete, which supports the weight of soil covering it. Installed inside are insulation made from rigid polyurethane foam panels (PUF), which maintains the cryogenic condition of the tank interior, and a stainless steel membrane with a thickness of 2mm for liquid/gas tightness. Surrounding the side and bottom, a heating system is provided to control ground freezing caused by the LNG's cryogenic temperature. The temperature in the side wall, the bottom slab and the dome roof are average -20~ -30°C.

3. Design [2],[3]

The tank is designed on the bases of both allowable stress design and limit state design for various loads such as dead weight (including covering soil), gas/liquid pressure, earth/water pressure, thermal load produced by LNG's low temperature, seismic load and so on. Two types of design earthquakes are taken into account in the design of the tank; one is a normal design

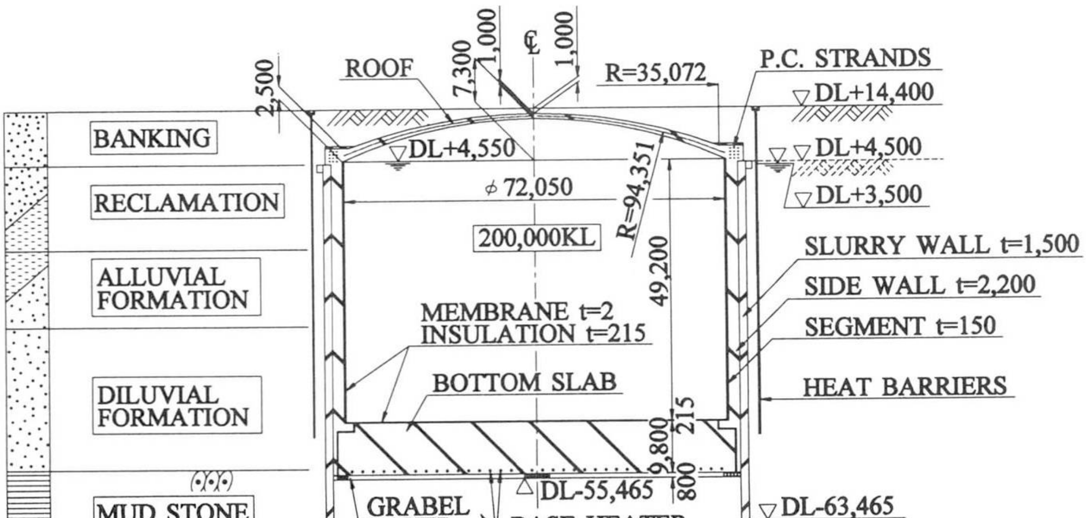


Fig. 2 Section of 200,000 kl LNG underground tank

earthquake which may occur in the life of the structure, and the other is a conceivable greater earthquake like the Great Kobe Earthquake. In the former earthquake the tank should be sound and stable enough to continue operation, while in the latter one, it is required to retain LNG safely.

High strength concrete with a design compressive strength of 59MPa was used for a side wall to reduce thickness from the conventional 4m to 2.2m. The volume of concrete and excavated soil was decreased to a considerable extent and contributed to the economical tank construction. The bottom slab was made of concrete with 24MPa strength and 9.8m thickness to withstand a high ground water pressure of 0.6MPa. A total of 14 layers of reinforcing bars (51mm in diameter) were provided in the bottom slab.

The roof of this tank is a dome shaped structure made of concrete with 29MPa strength to support the soil weight of about 400MN covered on it and dead weight of 150MN. The dome roof has a diameter of 72.8m (D), a rise of 7.3m (H), and the thickness changes from 1m at the center to 2.5m at the circumference. The rise-diameter ratio (H/D) of this tank is 1/10, which is very small compared to 1/6 of conventional steel roof of LNG inground tanks. The less the rise-diameter ratio of the dome roof becomes, the less soil excavated, and economical cost of construction is obtained. However, in the case of low rise-diameter ratio, the dome roof becomes more susceptible to buckling.

In order to clarify the characteristics of the buckling of the flat dome roofs, experimental 1/20 scale model tests, non-linear analysis, and a design study were carried out.[4] The rise-diameter ratio of 1/16 was adopted at these investigations, because 1/16 was considered to the least ratio of the dome roof that could be applied to the underground tanks. Fig. 3 shows the experimental model test. As a result of these investigations,

- Model structures were destroyed without buckling.
- Failure mode and ultimate strength can be estimated with the non-linear analysis of reinforced concrete (including non-linear characteristics of material and geometrical).
- The ultimate strength against buckling can be calculated by "Recommendations for Reinforced Concrete Shells and Folded Plates" by IASS (International Association for Shell and Spatial Structures).[5]

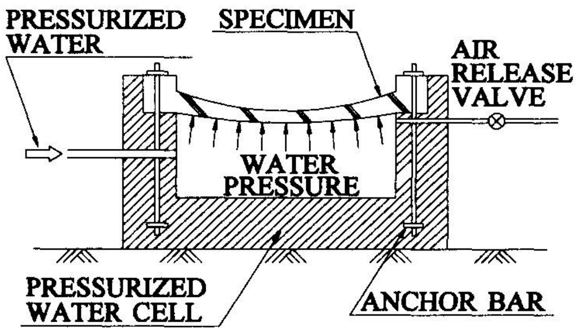


Fig. 3 Experimental model test of dome roof

The dome roof of this tank was designed by both the allowable stress design method and the limit state design method; furthermore, linear and non-linear analyses were performed in order to verify the stability of the dome roof against buckling. Various loads were taken into account, such as dead weight (including covering soil), gas pressure, thermal load, prestressed load, seismic load, loads from the side wall and so on. Concerning the linear analysis, the linear buckling load was computed by the linear finite element analysis for eigenvalue with the program code "NASTRAN". The safety factor (SF) against the buckling was calculated with the method of [IASS], in consideration of cracks and creep of reinforced concrete, and of the initial imperfection of the dome roof. As a result, SF was led to 6.8 and satisfied with SF-req. = 3.5 required on [IASS].

With regard to the non-linear finite element analysis, the non-linear buckling load was computed with the program code "ADINA". Fig. 4 shows the analytical model of the dome roof and the side wall. Concrete and reinforcing bars were modeled with solid and shell elements, respectively. The dome roof was evaluated with the non-linear characteristics of material and geometrical. Behavior of concrete under biaxial stress and tension stiffening of reinforced concrete were taken into account. After making all design load act on the structure, the load of covered soil, which is the most influential load with respect to buckling of the dome roof, was increased. At the 4.75 times the design load of covered soil, the dome roof was broken without buckling, because the member force became larger than the strength of the cross section of the reinforced concrete in the circumference of the dome roof as shown in Fig. 5, 6. By these analyses, the stability of the dome roof was confirmed.

The top of the side wall is prestressed with 24 cables like a head band to resist large thrust force of the flat dome roof and to prevent cracking of concrete with the compressive stress of 0.7N/mm^2. Though the earthquake produces cracks in concrete, cracks are controlled with the stress of the reinforcing bars within the allowable stress. This cable has the ultimate strength of 10MN and 24 cables give effective compression of 120MN to the top of the side wall. Because the temperature at the top of the side wall is very low, PC system, including PC cable, PC anchorage, reinforced concrete and so on, was confirmed by the experimental tests as shown in Fig. 7. Fig. 8 shows the arrangement of the PC cables and pilasters. 24 cables were divided into 3 groups and pulled between two pillars at an angle of 120 degrees.

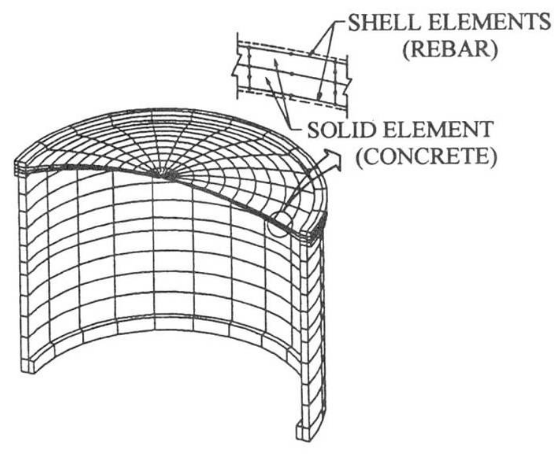


Fig. 4 Non-linear analysis model of underground tank

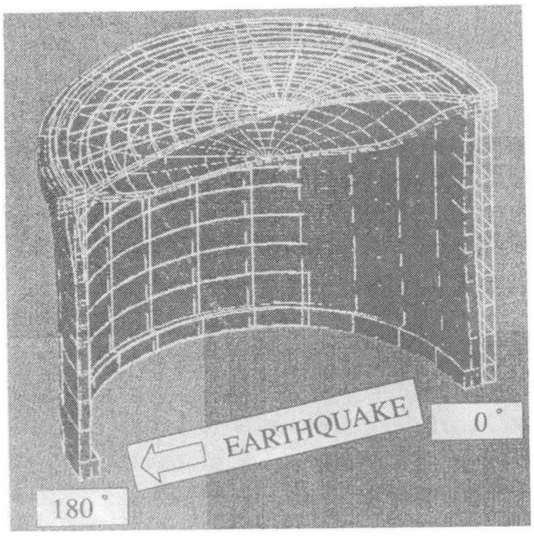
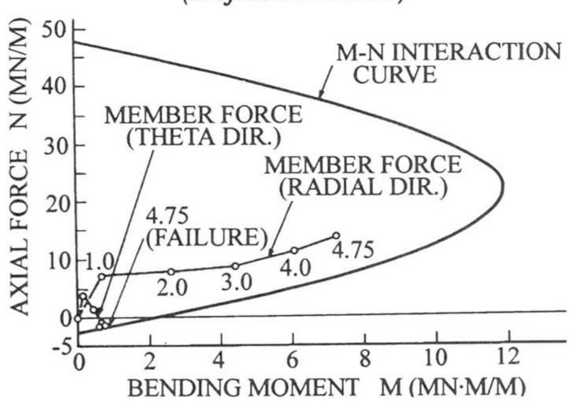


Fig. 5 Result of non-linear analysis (Deflection mode)



Values 1.0~4.75 show the magnification of the design load of covered soil

Fig. 6 Result of non-linear analysis (Interaction curve)

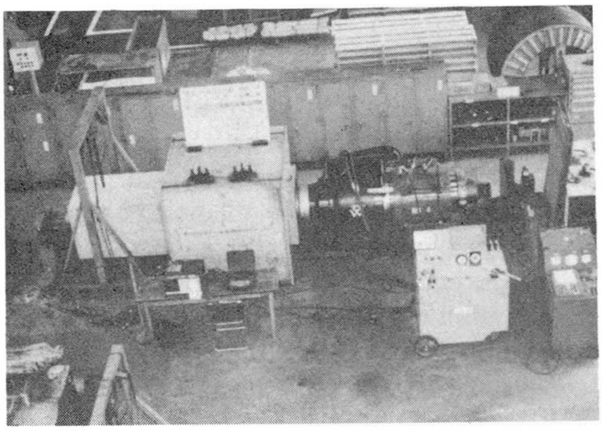


Fig. 7 Experimental test of PC system at usual temperature

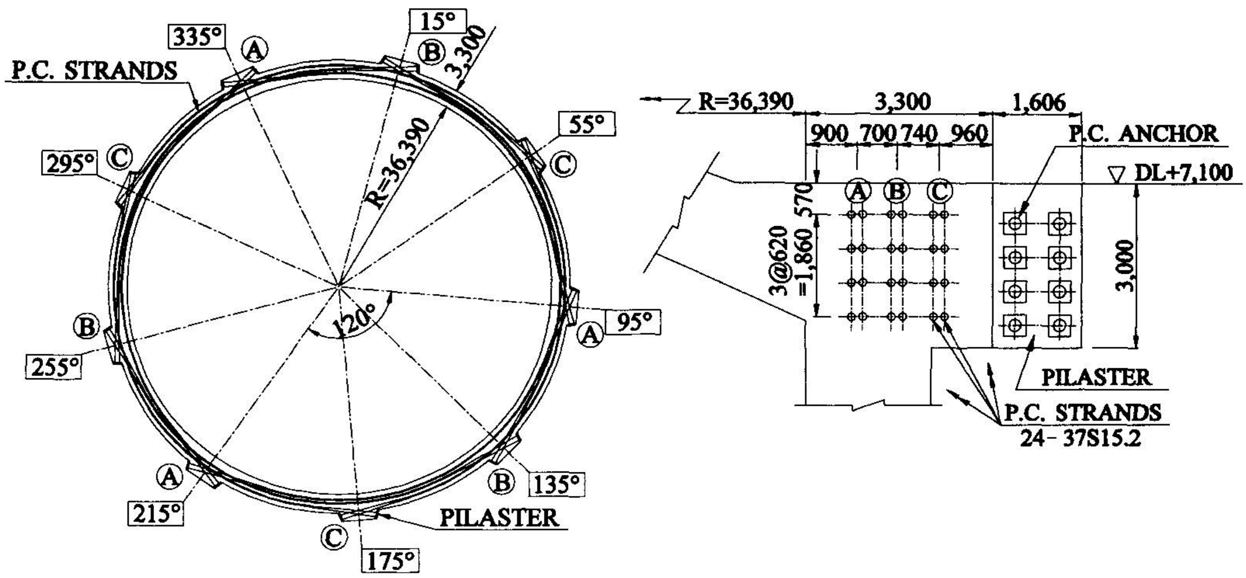


Fig. 8 Arrangement of PC tendons

4. Construction

For the construction of the tank, an accurate deep slurry wall with a high strength of 50MPa was adopted as a ground pressure retaining wall and water cut-off wall. The bottom of the wall is embedded in the impermeable silty soft rock. The depth of the slurry wall is 68m and the accuracy of excavated ditch was within 5cm with respect to absolute verticality. During excavation work, the slurry wall of only 1.5m in thickness supported earth and ground water pressure, so that a large scale underground space of 77m in diameter and 60m in depth was achieved entirely without struts.

Since the slurry wall as well as the side wall is a typical cement rich mass concrete structure, the control of cement hydration was taken into account. In order to obtain concrete strength above 50MPa, the water/cement ratio of concrete needs to be around 30%, which results in low fluidity of the fresh concrete. A water reducing agent was used as an admixture in the mix proportion of concrete to improve the cement dispersion and to ensure high fluidity as shown in Table. 1.

Placement of the bottom slab concrete with a thickness of 9.8m was divided into 2 lots. The first lot was for the lower part of 6.6m height, and the second one was for the upper part of 3.2m where 40MN of main reinforcing bars in weight were densely arranged. 30,000m^3 of the first lot concrete was poured through 70 hours continuously without stopping, and 13,000m^3 of the second lot through 30 hours.

The dome roof was constructed above the temporary steel truss girders, which were combined and made up a three dimensional truss structure like a huge umbrella as shown in Figs. 9 and

Table. 1 Mix proportion of high strength concrete for the side wall

Design strength (MPa)	Max. size coarse agg. (mm)	Slump flow (cm)	Air content (%)	Water-cement ratio (%)	Unit weight of cement (kg/m3)	Sand-aggregate ratio (%)
59	20	60±5	4.5±1	31.0	419	41.1

· Cement: Special Portland blast-furnace cement with added fly-ash for low hydration heat
· Admixture: High-range water reducing agent, Air-entrained water reducing agent, Super plasticizing agent

10. The steel truss structure with a total weight of 20 MN is very rigid in order to satisfy the severe accuracy required for the inner surface of the dome roof, where the insulation and membrane were installed. The truss structure is deflected by the dead weight of fresh concrete of the dome roof. The maximum vertical displacement of the truss structure is 35mm. After the truss structure is jacked down, the dome roof is deflected by the dead weight and creep of it, the soil weight covered on it and others. Therefore, the camber of 0~95mm was taken into consideration in the building of the truss structure. 5,500m^3 of the dome roof concrete was poured from the edge to the top with concentric circle blocks through 28 hours continuously in order to avoid construction joints which might cause harmful gaps for the assembling of the insulation and membrane. Fig. 11 shows the dome roof before being covered with soil.

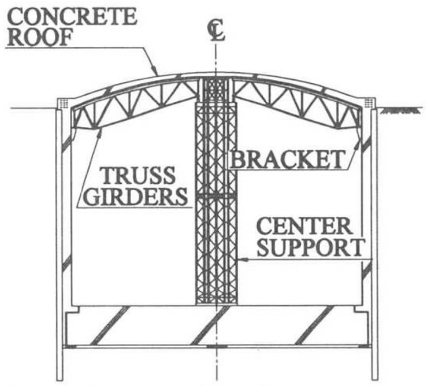


Fig. 9 Section of steel truss structure

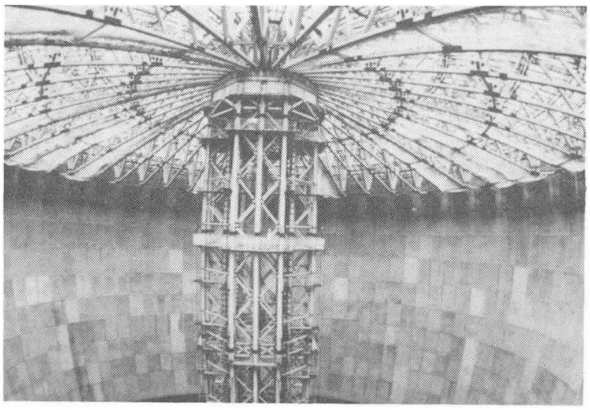


Fig. 10 View of steel truss structure

5. Conclusion

Construction of the 200,000 kl LNG underground storage tank has been successfully proceeding at the Ohgishima LNG terminal. After completion of the tank, it is totally embedded in the ground and cannot be seen. In the construction of this tank, the newest and most advanced technologies were applied. The Ohgishima LNG terminal starts operation in October 1998, moving rapidly into the 21st century.

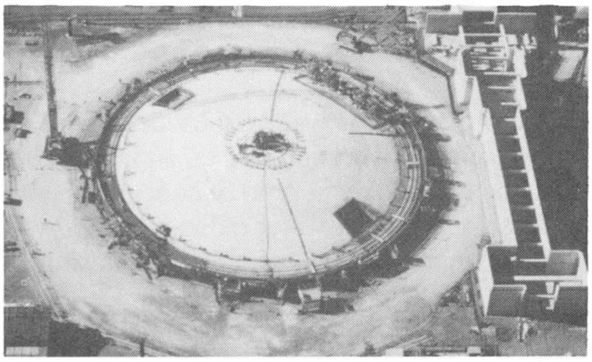


Fig. 11 Over-view of concrete dome roof

References

[1] Umemura J., Goto S., Sakata K. and Nakano M., "Technological Challenges for the Construction of the Ohgishima LNG Terminal ", 12th International Conference on Liquefied Natural Gas, 1998.

[2] Goto S., Nakano M., Nakazawa A. and Kuroda M., "R&D and Construction of the World's First LNG Underground Tank ", Concrete Journal, Vol. 35, No.2, Feb. 1997. (in Japanese)

[3] Nemoto M., Kawamura Y., Sugino F. and Kuroda M., "Design and Construction of the Prestressed Concrete in the World's first LNG Underground Tank ", Prestressed Concrete Journal, Vol.38, No.6, Nov. 1996. (in Japanese)

[4] Okamoto K., Minegishi K, Kuroda M. and Watanabe M., "Structural Stability of Reinforced Concrete Dome Roof " Proceedings of JSCE (under contribution in Japanese)

[5] Dulacska E., "Explanation of the Chapter on Stability of the < Recommendations for Reinforced Concrete Shell and Folded Plates > and a Proposal to its Improvement ", IASS Bulletin, No. 77, 1981, [Translated into Japanese by Hangai. H. et al., Column Journal, No.101, 1986.]