Engineering of PCLNG Tank in China
— Shanghai LNG Peak Shaving Expansion Project —

中国・PCLNG タンクの設計および工事管理
— 上海 LNG ピークシェービング基地拡張工事 —


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Synopsis

Shanghai LNG Peak Shaving Expansion Project was planned in order to comply with the peak demand of Shanghai city's customers in winter season, on the background of the rapid development of Shanghai economics (**Fig.1**). Owner of this project, Shanghai Pipeline Company had supplied natural gas to 4.5 million households of Shanghai city. The previous plant had the 20,000m^3 prestressed concrete (hereinafter PC) liquefied natural gas (hereinafter LNG) tank and liquefied equipment which received natural gas carried by the pipeline from Tarim Basin in western China.
In this paper, Engineering, especially the structural design and the construction advisory services for two 50,000m^3 PCLNG Tanks, are introduced (**Fig.2**).

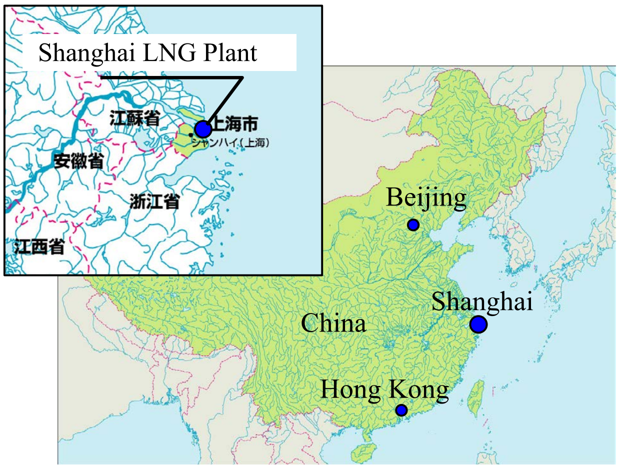


Fig.1 Location of Shanghai LNG Plant

Structural Data

Tokyo Gas Engineering Co., Ltd. was in charge of Engineering, Procurement, Construction and Management (hereinafter EPCM) of the whole LNG plant.
Project: Shanghai LNG Peak Shaving Expansion Project
Owner: Shanghai Pipeline Company
EPCM Consortium: Tokyo Gas Engineering Co., Ltd. and ACRE
Construction Company: Shanghai Electric Power Construction Co., Ltd. (Civil)
Shanghai Installation Engineering Group Co., Ltd. (Mechanical)
Engineering Company: Obayashi Corporation (Civil)
Toyo Kanetsu K.K. (Mechanical)
Project Period: June 2006 – Nov. 2008

Fig.2 50,000m^3 PCLNG Tanks

1. Design of PCLNG Tank

These PCLNG Tanks (**Fig.3**) are Full Containment Tank in accordance with BS7777[1], which has already replaced EN14620[2] in 2006.

Inner side of outer tank wall in 5.0m height from the top of base slab is covered with bottom corner protection and cellular-glass.

(1) Structural Dimension

Wall: Prestressed concrete
Inner Dia.: 54.8m, Outer Dia.: 56.1m
Wall Thickness: 0.65m

Base Slab: Reinforced concrete
Elevated Slab, Outer Dia. of Base Slab: 59.1m
Slab Thickness: 0.9m to 1.2m

Dome Roof: Reinforced concrete
Thickness: 0.4 m to 0.8m

Pile: Prestressed High-strength Concrete (PHC) pile, Dia.: 800mm, Length: 55mm, n = 328Nos/tank

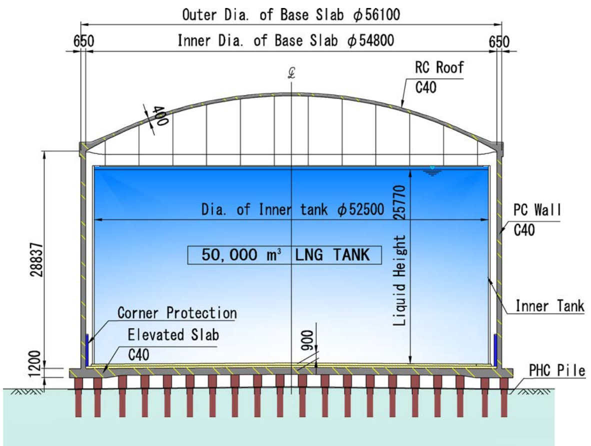


Fig.3 Dimension of 50,000m³ PCLNG Tanks

(2) Design Method

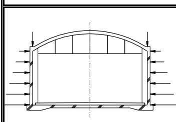
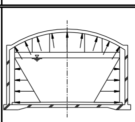
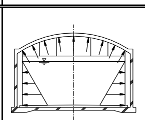
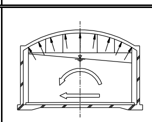
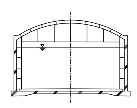
Design of concrete structure concerning PCLNG tank was based on limit state design method, which includes Ultimate Limit State (ULS) and Serviceability Limit State (SLS). Limit state design method was in accordance with BS7777 (**Table 1**). Dead load, live load, gas pressure, liquid load, wind load, temperature load, seismic load, prestressing force and concrete shrinkage were taken into consideration, adopting Finite Element Analysis (hereafter FEA). For SLS design, concrete crack width was checked for both construction and operation conditions. For ULS design, stresses in the prestressing tendons and in the reinforcing bars were limited to the yield stress. Painting on the external surface of the wall and the dome roof was required to prevent chloride penetration, on the contrary, the allowable cracking width was specified in the wall and the dome roof design.

(3) Base Slab Design

Soil layers from the ground surface to approximately 70m depth of alluvium layer are composed of the weak clay or stiff silt in LNG tank area. Pile foundation was designed to transmit all loads to suitable load bearing strata. Pile length is 55m and the bearing layer is silt of shear velocity from 200 to 280m.

Base slab design was taken into account of the nature of the soil-structure interaction and differential settlement of the foundation. The differential settlement of base slab during hydrostatic test and normal operation conditions, calculated by FEA, was less than 1/300 of base slab radius in accordance with BS7777. Since the elevated slab supported by piles was used as a base slab, the heater system was not required to prevent the icing of the ground. As secondary barrier, which was made of 9% nickel steel to prevent the leakage of LNG from inner tank, was installed on the base slab in order to hold the LNG. Therefore, base slab was not needed

Table 1 Load combinations and Limit states

Loading conditions		Construction Phase	Test	Operation	OBE SSE	Leakage
						
Serviceability Limit States	Outer tank roof	Permissible Bending Crack Widths: W≦0.3mm			——	Compression zone in wall section ≧65mm Average compression of 1.0Mpa Permissible bending crack widths of the bottom corner anchorage W ≦ 0.3mm
	Outer tank wall	Permissible Bending Crack Widths: W≦0.2mm				
	Tank foundation	Permissible Bending Crack Widths: W≦0.3mm				
Ultimate Limit States	Outer tank roof	——	○	○	○	○
	Outer tank wall	——	○	○	○	○
	Tank foundation	——	○	○	○	○

to have liquid tightness for leakage condition.

(4) Wall Design

The monolithic connections of wall-to-foundation and wall-to-roof were used. The pre-stressing force in the lower part of the wall and the peripheral part in the base slab was not needed due to bottom corner protection.

Operating basis earthquake (OBE) and Safe shutdown earthquake (SSE) was applied to seismic design in accordance with US code of NFPA 59A[4].Design seismic coefficient was calculated based on the seismic response spectrum by Chinese design consultant. The modified seismic coefficient method was carried out in seismic design. Dynamic response analysis based on three dimensional FE model including all of soil, piles and LNG tank was also carried out, and the result of seismic coefficient was compared with the above seismic coefficient calculated by response spectrum.

(5) Dome Roof Design

Concreting of dome roof was divided into two layers.

The concrete of first layer is 250mm thickness and second layer is 150mm thickness. Structural analysis was performed about both the completed layer model of LNG tank and the first layer model during construction.

(6) Material Design of wall

Specified compressive strength of concrete was 40N/mm^2 determined by cube test at 28 day which was equivalent to 32N/mm^2 by cylindrical test, for wall.

Prestressing tendons in circumferential direction were arranged in 52 circles of 12-φ15.2, which comply with the requirement of ASTM A416 Grade270, to resist the total force due to LNG leakage load and Gas pressure. Each prestressing tendon was anchored in the length of 1/2 circle at the buttress, which total number was four.

Prestressing tendons in vertical direction were anchored at the location of top part of wall, which was 29m height and had U-shape dead anchor in the base slab, induced the vertical stress of 2.0 N/mm^2 to concrete.

PC anchorage had low temperature toughness and enough experience of LNG tank. As the inner surface of wall becomes much low temperature during leakage of LNG, the reinforcing bar for cryogenic applications was applied to the inside of wall. Cryogenic rebar with 460MPa of yield strength was selected. Normal rebar with 400MPa with yield strength in accordance with GB1499-98, was applied in the location of corner protection and compression stress zone of wall.

2. Construction of PCLNG Tank

Construction periods were approximately 27 months from project contract to completion of cool-down work. Construction procedure of PCLNG tank was in the following, 1) Piling work, 2) Columns and Base slab construction, 3) Wall construction and Steel roof installation, 4) Raising of steel roof by air pressure, 5) Tensioning for circumferential PC cables in the ring beam part of wall, 6) Dome roof construction, 7) Outer steel tank, base insulation and inner tank work, 8) Hydrostatic test of inner tank, 9) Closing of temporary openings of wall, 10) Tensioning for vertical and circumferential PC cables in wall, 11) Side insulation work and Painting work of outer surface of wall.

(1) Control for Thermal Crack of Concrete

Thermal crack was occurred in the previous PCLNG tank. Therefore, the crack controlling measures were required by the authorities for concrete structure of the client side.

The following countermeasures were performed,

1) Both member thickness and design concrete strength were reduced to be less than the previous LNG tank
2) Reinforcement ratio was more than 0.5% in the lower part of PC wall in order to control the crack width.
3) Since the age for determination of the specified compressive concrete was increased from 28 days to 56 days, cement quantity could be decreased.
4) Moisture curing was carried out immediately after concreting of base slab during winter season.

(2) Base Slab Concreting

Concrete of base slab was installed by four concrete pump vehicles as a joint-less member. (**Fig.4**)

Fig.4 Concrete casting of Base Slab

(3) Wall Construction

Concrete placing of wall was divided into 10 lifts by using the concrete pump vehicles. The average height of the lifts was planned to be 3.6m. The concrete placing of each lift was divided into 2 parts, which were 2.4m at first day and 1.2m at second day. The timber was used as the form material. The lower form of 1.2m was removed after concreting of first day and was used as the 1.2m form of second day by assembling at the same day. Scaffolds were assembled simply by using

Fig.5 Jumping form method of wall

steel pipes and H-steel. The Jumping form method was adopted to lift up by tower cranes (**Fig.5**).

(4) Dome roof Concreting

Concrete placing of Dome Roof was divided into two layers. The concrete of first layer was placed on steel roof directly, which was supported by the air pressure of 0.008N/mm^2 (800mmAq) inside the steel roof and wall. The concrete of second layer was placed on first layer concrete, which was supported by air pressure until the placed concrete had achieved the 70% of the specified concrete strength. As the edge part of dome roof inclines 30 degrees, the mesh bar was arranged circumferentially in 1.0m pitch to prevent the fresh concrete from flowing down by concrete vibration. Although concrete of the outer parts in dome roof was placed by the concrete pump vehicles (**Fig.6**), concrete of the inner part was placed by three buckets and tower cranes (**Fig.7**), because the boom length of concrete pump vehicles was shorter than roof top height.

Fig.6 Outer part placing of dome roof

Fig.7 Inner part placing of dome roof

(5) Prestressing Work

Prestressing work of wall was carried out in the following sequences.

1) Tensioning of circumferential prestressing tendons before concreting of dome roof

2) Tensioning of vertical and circumferential prestressing tendons after closing temporary openings (**Fig.8**).

For specification of PC grout material, the strict quality control was adopted, which was satisfied with both GB code, i.e. GB50204-2002, and fib code. Pre-mixed type grout with low bleeding was used. The grouting system having the container was adopted by the local constructor, which can add the grout automatically after grouting work.

(6) Paint Work

Allowable crack width was permitted under the conditions that outer surface of wall is coated (**Fig.9**). Since PCLNG tanks are located near Yangtze River, outer surface of concrete was judged to be severe condition for durability design. Acrylic resin was applied to prevent chloride penetration.

Fig.8 Vertical prestressing work

Fig.9 Painting work

3. Conclusion

Construction of this project was finished in Nov. 2008, and LNG was carried by ship from Malaysia and received on time. China government said that natural gas is important energy to control supply of oil and coal and to improve air pollutions. As the results, there are many construction plans of LNG plant along the coast in China now. The experienced Japanese companies will be hoped to cooperate for the entire LNG plant project not only EPCM but also construction, technical support of operation in the world.

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[3] Recommended Practice for LNG Aboveground Storage, Japan Gas Association, 2002 (in Japanese) (latest version published in 2012)

[4]Technical Committee on Liquefied Natural Gas and acted on by the National Fire Protection Association, Inc., Standard for the Production, Storage, and handling of Liquefied Natural Gas(LNG), NFPA59A,2001 (Latest version published in 2013)

概 要

経済発展によりガス需要が急増している中華人民共和国上海市において長江の河口である長江口に位置する液化天然ガス (LNG) ピークシェービング基地に LNG タンクを含む LNG 設備を増設するものである。このうち，LNG タンクは中国側が施工を担当し，設計を含むエンジニアリング業務とコンストラクションマネージメントを日本側が実施した。本報文は，プレストレストコンクリート製 LNG タンク 2 基の増設のうち構造設計および工事管理について報告するものである。