Annex 2D

Tank Technology Study

Tank Technology Selection Study

For the

Hong Kong LNG Terminal

中華電力

CLP Power

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1.0 INTRODUCTION

1.1 Hong Kong LNG Terminal Tank Technology Selection

The Hong Kong LNG Terminal Project has selected the above-ground full containment LNG tank system for the import re-gasification terminal in Hong Kong SAR. This selection is applicable to either South Soko Island or Black Point, the two sites being considered for the LNG terminal.

1.2 Purpose

This document discusses the main reasons for selecting an above-ground full containment LNG storage tank system over an in-ground system. Specifically, our study focuses on the following main aspects of LNG tank storage systems:

- Technical drivers and industry experience
- Environmental impacts
- Economics
- Design and construction standards
- Construction, Operation and Maintenance

2.0 SUMMARY AND CONCLUSIONS

2.1 Summary

In response to questions from the Hong Kong Environmental Protection Department and the Planning Department, this document discusses the main technical reasons for selecting an above-ground LNG storage tank system.

In consideration of the environmental conditions and design drivers, design maturity, construction schedule demand, contractor availability, and cost, we have selected the above-ground full containment tank technology over an in-ground tank design. In-ground tanks would not meet our project schedule to ensure a timely and uninterruptible gas supply to CAPCO.

2.2 Conclusions

In consideration of environmental impacts, design maturity, construction schedule demand, contractor availability, and cost, we have selected the above-ground full containment tank technology over an in-ground membrane tank design for this Project.

- The Hong Kong SAR is a region of low seismic activity. Therefore, the principal design driver of having lower seismic motion amplification offered by in-ground tanks is not utilized.

- The above-ground full containment tank system employs well understood and tested technology for design, construction and commissioning that has been successfully applied world-wide.

- International tank construction contractors have over thirty years of experience of building full containment above-ground tanks. Capable and experienced full containment LNG tank contractors are available from Europe, America and Japan.

- There is a significant cost advantage for above ground full containment tanks. If in ground tanks were employed, a cost increase of at least $3.1 billion HKD is anticipated.

- There is a schedule advantage of approximately two years in constructing above-ground full containment tanks. Given CAPCO's LNG import requirement, the in-ground tank construction would not be able to meet the timely and uninterruptible gas supply schedule due to its longer construction time.

- In-ground tanks require a significant increase in energy consumptions with an associated increase in operating costs.

  - An incremental 1,500 kW would be required to provide the necessary heat freeze protection for operation of the boil off compressors.

- Environmentally, there is a significant improvement by using above-ground tanks versus in-ground tanks.

    - From a Landscape Visual perspective, there would not be a significant improvement in the overall visual impact at the South Soko terminal site if tanks were placed in-ground, as there are significant excavations to be made in either case, and the terminal process area, jetty and LNG carrier would remain visible.

    - From a Waste Management perspective, in-ground tanks would require additional excavation of at least 800,000 m^3 of rock. This represents more than a 50% increase in the total South Soko excavation quantities, and would increase the off-site disposal requirements by 400%.

    - From an Air Quality perspective, this would require the consumption of an additional 66,000 tons of natural gas over the facility life, resulting in incremental CO2 emissions of 180,000 tons.

3.0 LNG STORAGE AND RETENTION SYSTEMS

All field erected LNG storage tanks have a primary and a secondary containment system. The primary container is for normal operation and the secondary containment is for the highly unlikely event of a leak in the primary container. World wide a variety of storage tank types have been developed and constructed over the years. Those that have been successful can be categorized into the following types:

1. Single containment types have a cylindrical metal primary tank and an earthen dike or bund wall secondary containment. Single containment tanks were the first type developed and are now used mainly in remote locations.

2. Double containment types have a cylindrical metal primary tank and an independent metal or reinforced concrete, open top secondary containment outer tank. This type was developed for small sites; however few have been built because the full containment type, below, was soon developed.

3. Full containment type tanks have a cylindrical metal inner primary tank and metal or pre-stressed concrete outer secondary containment tank structurally independent but combined into one structure. Today full containment tanks are the most common type used.

4. Full containment membrane type has a cylindrical thin metal membrane primary container structurally supported by an outer pre-stressed concrete cylindrical tank. The outer concrete tank also serves as the secondary leak containment. Applications of membrane tanks have been far less than the other types of tanks except in Japan and Korea.

5. Even though all of the above listed structures can be built in-ground, only membrane tanks, type 4, have been regularly built below grade. The outer wall of an in-ground tank is not pre-stressed. The outer wall is held in compression by soil pressure which in turn also supports the LNG's hydrostatic load.

The approximate number of field erected LNG tanks operating worldwide is summarized in the following list[1]:

Single Containment Type	320
Double Containment Type	15
Full Containment Type	110
Membrane Containment Type	30
Membrane In-ground Containment Type	50

[1] The World LNG Source Book, 2004, Gas Technology Institute.

3.1 International LNG Standards

There are two standards normally used to build LNG facilities in the world: the North American standard of NFPA 59A (Incorporates an LNG tank standard of API 620 Appendix Q) and the European standard of EN 1473 (Incorporates an LNG tank standard of BS 7777). The HK LNG facility has elected the European standard (EN 1473 and BS 7777) for it's LNG design standard.

A description of LNG storage tank categories can be found in the European Standard for LNG Facilities (EN1473).

British Standard BS 7777 provides rules for the design, construction and testing of above ground tank types 1 through 3 above. Above ground and in-ground membrane tanks are presently built to proprietary company standards, and are not included in either the European LNG tank standard BS 7777 or the American tank standard API 620Q. It is anticipated that a new European Standard EN 14620 replace BS 7777 and may contain design, construction and testing rules for in-ground and membrane tanks. The Hong Kong Terminal LNG tanks are based on BS 7777, which is a proven standard around the world, available to all LNG tank contractors and has an excellent performance record.

For illustration purpose, we highlight the design characteristics of a full containment tank system, which have been adopted by most recent LNG projects world-wide. Full containment tanks have been selected for this project.

3.2 Full Containment Tank

A tank designed and constructed so that the self-supporting inner tank, which is constructed of 9% Ni steel, contains the LNG. The secondary reinforced and pre-stressed concrete outer tank is capable of containing the LNG and vapor. The inner tank contains LNG under normal operating conditions of near ambient pressure and minus 162^{O}C. The outer tank is capable of both containing any leakage of LNG and controlled venting of vapor created from any LNG leakage. A full containment tank does not require a dike or bund wall to contain any leakage, resulting in saving of space. It is noted that EN1473 does not recognize any failure mode for the full containment LNG tank storage system. Full design, construction and testing requirements for full containment tanks are covered in BS 7777.

4.0 COMPARISON OF FULL CONTAINMENT AND IN-GROUND TANKS

4.1 Environmental

- Being mostly below grade, in-ground tanks have lower visual impact than an above-ground full containment tank. However, in the case of the South Soko Island site, the only visually sensitive receivers are recreational, Tin Hau temple, and grave descendant's visitors to the site. There would not be a significant improvement in the overall visual impact because: 1) there are significant excavations to be made to the site, affecting the visual character, in either case, and 2) the terminal process area, jetty and LNG carrier have a greater degree of visual exposure to the recreational visitor than the tanks.

- The construction of three 180,000 m^3 in-ground LNG tanks requires the removal and disposal of between 800,000 and 1,350,000 m^3 of rock and soil. This represents a 50% to 100% increase in the blasting and excavation required, and would increase rock disposal requirements between 5 and 9 times.

- Construction of in-ground tanks requires over three times as much concrete to construct.

- Because the wall insulation system on a membrane tank is also a structural component it's efficiency is only about one-half of the wall insulation on a full containment tank. Lower thermal efficiency creates boil-off gas that must be removed by compressors. The additional boil-off gas flow increases power consumption by about 750 kW. Therefore, over the 25 year life of the tanks approximately 33,000 tons of additional fuel gas will be consumed generating 90,000 tons of carbon dioxide.

- The storage of LNG in tanks removes small but significant quantities of heat from adjacent surroundings. For in-ground LNG storage systems, electric heating cables are required to eliminate the formation of ice in the surrounding soil. Ice formation can create huge frost heave loads capable of damaging tank foundations and walls. These heaters are in continuous operation.

  Above-ground tanks only require a base heating system, which operates intermittently. Heat from solar gain assists in providing replacement energy. The three 180,000 m^3 in-ground tanks will consume about 680 kW more electrical heating power. Power generation will require approximately 27,000 tons of natural gas and produce about 75,000 tons of $CO2$ over a 25 year tank life.

- In most cases, in-ground LNG tanks penetrate natural ground water levels. Ground water can be detrimental to the construction and operation of in-ground LNG tanks. In this regard dewatering wells will be spaced around the tank to lower ground water levels. These well points will operate for the life of the tanks constantly discharging water at the surface. Before in-ground tanks can be utilized, a ground water investigation and a study on the impacts of long term ground water pumping and disposal need to be conducted.

- The life of the facility is assumed to be about 25 years at which time the LNG tanks would be removed and the site returned to previous or other uses. The steel and concrete of a full containment tank can be removed and recycled, creating a useable level plot area. Recycling the concrete from the outer wall of an in-ground tank would be very difficult, if not impossible. Any destruction of the outer wall may cause the earth sides to collapse. Only the top portion of the wall could be reclaimed. To make the area reusable, the holes would need to be filled and compacted with approximately the same amount of rock and soil that was removed.

4.2 Economics

- The capital cost of constructing an in-ground LNG tank is over twice that of a full containment tank. The capital cost increase over full containment tanks is estimated to be greater than HKD $3.1 billion.

- In-ground tanks consume more electrical energy for increased boil-off compression, soil and foundation heating and ground water pumping. The extra power consumption is approximately a constant 1,500 kW load. Assuming the cost of power is HKD $0.88 per kw-hr, and the operating life of the in-ground tanks are 25 years there is an operating cost increase of approximately HKD $290 million over full containment tanks.

4.3 Design and Safety

- When LNG tanks are located in areas of possible aircraft impact full containment tanks have a higher chance of impact than in-ground tanks. However, the Hong Kong LNG Terminal is in a very low impact risk location.

- Structures that are built into the ground generally have reduced acceleration loads generated from seismic events. This is because motions of in-ground storage system follow the seismic ground shaking and are not amplified through the structure of the tank as is the case for an above ground storage system. In addition, sloshing responses of LNG tanks resulting from seismic activity are lower for underground tanks. This however does not mean that an in-ground tank is safer than an above ground tank. It means that an aboveground tank is designed to higher seismic loads than an in-ground tank. In all cases LNG tanks are designed to maximum seismic activity for each tank type and its location.

- Based on the seismic hazard studies, the Hong Kong region is an area of low seismic activity. For example, seismic loading is not explicitly considered for general building design in Hong Kong. Hence, the design driver for selecting underground tank system to lower seismic loads is not applicable and the above-ground storage tanks are an appropriate choice for this location.

- Ground water can be very problematic for in-ground LNG tanks. The density of LNG is less than one-half that of water. If for some reason ground water was to rise around an in-ground tank or leak into it, buoyant forces could lift the tank or displace LNG over the tank wall. However such an event is considered highly unlikely.

4.4 Construction

- From the time of contractor release for the construction of a full containment tank, approximately 36 months are required to design, manufacture, erect, test and prepare for LNG tank cool-down. Approximately 60 months are required for these same activities for in-ground tanks. Because of this two years incremental duration of construction, a facility based on in-ground LNG tanks would not meet the gas supply time line required by CAPCO's LNG import requirement.

- Whereas over 400 above ground LNG storage tanks have been constructed world-wide, about 50 in-ground storage systems have been constructed and these are principally in Japan. With this high number of above-ground LNG tank systems in operations, there is a number of international tank construction contractors proficient with all aspects related to the design, construction, and commissioning of these tanks. The technology involved is well understood and is documented in international codes and standards. As a result a relatively optimized contracting, design and construction process for the above ground tanks is available for the Hong Kong Terminal Project.

- In-ground LNG tanks were developed in Japan making Japan the only source of experienced designers and constructors. Owners outside of Japan have difficulty in locating interested contractors capable of building in-ground tanks outside of Japan.

- Construction of membrane tanks are more labor intensive and require higher skilled workers which are in short supply in Hong Kong.

- Ground water management during construction will likely be difficult at the Hong Kong Terminal site.

- The transportation, storage and use of blasting materials for in-ground hole excavation will create additional construction hazards.

- The membrane on an in-ground tank is only 1.5 mm thick which makes it more likely to be damaged during construction. The thickness of inner tank plates for a full containment tank average about 25 mm.

4.5 Operation and Maintenance

- The soil heating cables on an in-ground tank are located such that they are almost impossible to repair. Redundant heating cables will be installed to lessen the possibility of failure.

- Since most equipment and piping is located on the roof of an LNG tank, access to this equipment is generally easier for in-ground tanks.

- Above-ground LNG tanks do not require the operation and maintenance of dewatering pumps.

- Because much on an in-ground is covered with soil, tank inspection and monitoring is difficult and possible problems may go unnoticed. When problems do occur, it is much harder to repair them. For example, the in-ground tanks in Yung-An (Taiwan) have been leaking for years, but due to the difficulty in pinpointing the leak location and accessibility, have elected not to try to repair the leak.