Alexander Cooperman, Jeffrey C. Garrison, and Charles H. Venderley, CB&I, US, outline how the development of the first double steel, full containment LNG tank could shake up the LNG industry.
A full containment, refrigerated liquefied gas storage tank system consists of an inner primary container designed to store the refrigerated product during normal operation and a secondary liquid container designed to contain the product during an emergency leak from the primary liquid container. The primary container is composed of cryogenic steel suitable for the product temperature while the secondary container is composed of either the same grade cryogenic steel or reinforced and pre-stressed concrete.

Either double steel or steel-concrete full containment tank configurations are recognised by the facility design standard NFPA 59A and the refrigerated tank system design standard API 625. The examples of the acceptable full containment tank configurations are provided in Figures 8, 9, 10, and 11 of API 625.

The selection of a tank system has a significant impact on the facility siting. NFPA 59A siting requirements, including separation distances to the facility property lines, are dependent upon the selected tank system concept e.g., single, double, or full containment system. A full containment tank system allows the most compact facility siting and land utilisation, since the secondary container serves as an impoundment for both LNG liquid and vapours in case of the primary liquid container emergency leak. In accordance with NFPA 59A, full containment tank systems having a secondary liquid container composed of either pre-stressed concrete or a cryogenic grade steel are equivalent with respect to siting.

Evaluation of risks

Traditionally, full containment LNG tanks are constructed with a primary liquid container composed of 9% nickel steel and a secondary concrete liquid container which includes a pre-stressed concrete wall with a carbon steel vapour barrier attached to the inside surface. By API 625 definition, a full containment tank system shall have both the primary and the secondary liquid containers...
that are capable of independently containing the liquid product. The system shall stay vapour-tight during normal service.

The secondary liquid container from pre-stressed concrete was often selected in the past without considering a detailed risk assessment for an outer steel tank. As such, the use of a secondary liquid container composed of cryogenic steel material for a full containment LNG tank has not been considered. This is in part due to the need to assess the ability of a steel secondary container to resist external hazards such as an external explosion overpressure wave, projectile impact, or external fire.

These major external hazards are abnormal loading conditions. Therefore, while some damage to the secondary container structure due to these hazards is expected, the secondary container must still guarantee that no liquid or vapor releases would occur under the design conditions.

A secondary container wall composed of pre-stressed concrete normally provides very good resistance to the mentioned external hazards. The pre-stressed concrete secondary container is an appropriate choice if the risk assessment shows that external hazards of an extreme magnitude are credible.

However, it can also be demonstrated that a properly designed steel secondary container is capable of resisting most typical external hazards determined by the facility risk assessment.

Analyses shows that free field blast overpressures of 70 mbar or less can be generally accommodated by a secondary steel container wall already designed for roof loads and high coastal wind. It can also be demonstrated that short duration peak free field overpressures up to 250 mbar can be successfully accommodated by an appropriately designed steel secondary container. A properly designed steel secondary container can also resist perforation from industrial projectiles typically considered in a risk assessment. This includes the typically specified 50 kg flying valve or a 6 in. NB steel pipe traveling at 45 m/sec. The effects of a credible external fire on steel tanks can be controlled via appropriate fire mitigation measures, including an active fire water deluge system and a fire suppression system on pressure relief vents. Appropriate fire mitigation measures would ensure that the steel secondary container has resistance to external fire conditions similar to the concrete secondary container.

**Potential cost and schedule savings**

A secondary container from cryogenic steel presents significant cost and schedule advantages to the owner when compared to more traditional full containment tank systems with a pre-stressed concrete secondary container. Depending on the tank size and geographical location, the estimated cost savings for a double steel full containment tank can be 20 - 40% compared to a tank system with a pre-stressed concrete secondary container. This saving is achieved by eliminating some components required for a full containment concrete secondary container such as: pre-stressed concrete wall, reinforced concrete roof, and the thermal corner protection system. The steel secondary container also allows for reduced co-ordination between different trades, as well as a reduced amount of material and procedures required to perform concrete construction.

The double steel full containment configuration results in several months reduction in construction schedule as compared to a full containment pre-stressed concrete configuration. This is achieved due to elimination of certain trades, better co-ordination of activities during construction of the primary and secondary containers, and elimination of extra...
holding time required for concrete to gain sufficient strength to continue with subsequent construction activities.

Furthermore, in certain geographical locations, either climate conditions or concrete constituent material availability may impede construction of the secondary container from pre-stressed concrete. Availability of appropriate concrete constituent materials may affect the ability to efficiently construct a concrete secondary container. Project site weather conditions may significantly reduce the concrete construction window, extending the concrete secondary container overall construction duration. Under these circumstances, if a full containment tank concept is required, a full containment tank system with a secondary container from cryogenic grade steel may be the most appropriate and economical option.

The first project of its kind
In 2021, CB&I was selected to design and construct the world’s first double steel full containment LNG tank in the province of Batangas, the Philippines. The full containment tank system, with both primary and secondary liquid containers constructed from cryogenic grade 9% nickel steel, achieved optimal facility siting, a cost-effective tank configuration, and accommodated an aggressive construction schedule, with full mechanical completion ready for commissioning expected within 19 months of site handover to CB&I.

The 60,000 m³ LNG tank is designed as a full containment tank system that is fully compliant with NFPA 59A, API 625, API 620, and local regulations. The tank has an open top, primary liquid container with an aluminium suspended deck located above the primary container, and a secondary liquid container with a fixed dome roof. The primary and secondary liquid container walls and bottoms have no piping or nozzle penetrations. All nozzles for process piping, instrumentation, and pressure/vacuum relieving vents are located in the dome roof. Submersible LNG withdrawal pumps are located in the pump columns fabricated from stainless steel which are supported on the primary tank bottom and braced from the secondary container compression bar. The roof platform is sized to locate all necessary equipment, instrumentation, piping, and a luffing jib crane provided for equipment maintenance. The dome roof, secondary containment wall, and top platform are protected by an active fire protection water deluge system.

The tank insulation system consists of several layers of load bearing insulation between the primary and secondary container bottoms, loose fill insulation between the primary and secondary container walls, and fiberglass insulation on the suspended deck. Additional insulation is provided beneath the secondary container 9% nickel steel bottom to protect the upper base slab from exposure to cold temperature in case of an emergency product leak from the primary liquid container.

The general configuration of the tank is depicted in Figures 1 and 2.

High seismic considerations
The facility is located in one of the highest seismicity regions of the Philippines with the maximum spectral horizontal ground acceleration exceeding 1 g. To accommodate the extreme seismic conditions, the LNG tank foundation is seismically isolated using a double slab foundation system consisting of seismic isolators installed between the upper and lower base slabs.

The seismic isolation system was required to reduce horizontal seismic acceleration applied to the tank. Both operating base earthquake (OBE) and safe shutdown earthquake (SSE) seismic events having the respective return periods of 475 and 2475 years were considered. The non-linear response-history analysis was performed for both OBE and SSE seismic events considering the site-specific seismic parameters provided by the local geotechnical consultant based upon a site-specific seismic study as required by NFPA 59A.

Careful selection of the isolator configuration was used to reduce horizontal seismic accelerations to the acceptable level and to control lateral displacements of the isolated tank. The tank piping system is designed with sufficient flexibility to accommodate lateral tank movements that will occur during the OBE and SSE seismic events.

Conclusions
- Selection of the most appropriate material for a full containment LNG tank secondary container should be based on the detailed evaluation of the risks due to internal and external hazards as well as economics and schedule considerations.
- If a risk assessment shows that external hazards can be accommodated by a steel secondary container, the steel secondary container would allow the owner to realise savings in both cost and schedule while meeting the code siting requirements, as well as maintaining overall safety and operability of the full containment tank system.
- The estimated reduction in overall tank system cost for a double steel full containment tank may be in the range of 20 - 40% compared to a full containment tank with pre-stressed concrete secondary liquid container. The actual cost savings is dependent upon tank size and geographical location.
- Selection of the double steel full containment tank configuration vs. the full containment configuration with pre-stressed concrete outer container may result in several months overall schedule reduction.

The tank system owner and operator are always responsible for selecting the most appropriate full containment tank configuration based on a thorough assessment of the project risks and economics. The world’s first full containment steel LNG tank designed and constructed by CB&I now provides this option to owners and operators.

References