SUCCESS THROUGH PLANNING AND RISK MITIGATION: PART TWO

In part two of a two-part article, **Mark Butts and Yogesh Meher, CB&I**, address key early inputs and their impact on the selection of the optimal tank configuration.

A comprehensive storage EPC execution plan, coupled with early engagement between the EPC contractor and the owner during project development, allows for the identification of key inputs and risks, thereby optimising and de-risking the project from its outset. This proactive approach enhances project efficiency, minimises uncertainties, and ultimately improves the likelihood of successful project delivery.

Operational integrity of LNG facilities relies on the foundation set in codes and standards that dictate engineering designs and material specifications for constructing storage tanks and related equipment. These guidelines serve as a crucial layer of protection, ensuring facilities maintain safe containment of LNG, thus allowing companies to mitigate risks, safeguard personnel, and maximise reliable operations.

In the final part of this two-part series, this article will outline key early inputs and their impact on the selection of the optimal tank configuration, as well as considering risk detection and mitigation measures which help provide additional safeguards.

Key early inputs and their impact

Key inputs from early planning and risk assessment have a direct impact on selecting the optimal configuration, sizing, layout, and level of integrity for complex storage structures, such as LNG tanks. These inputs often help drive the decision on selection of the LNG storage concept and configuration to make sure the necessary safeguards are built into the design of the tank.

Soil conditions

Early geotechnical investigations play a crucial role in LNG tank projects by providing essential soil properties and performance characteristics. These investigations establish the foundation type required for the tank and help determine

seismic design criteria for structures on the foundation, such as the storage tank and tank topside platforms and piping. By assessing soil conditions and seismic hazards, geotechnical investigations enable engineers to design foundations that can withstand anticipated loads and seismic forces, thus contributing to the structural integrity and safety of the entire LNG facility. Additionally, these investigations inform construction planning and cost estimation, mitigating risks associated with foundation failure and seismic events, and ultimately supporting the successful execution of the project.

Lack of sufficient soil information can result in critical conditions being overlooked. Voids, soft soils, or buried debris can delay the construction schedule.

It is important that a thorough soil investigation guideline is prepared by a storage tank EPC contractor before performing any investigation. The investigation guideline will help identify the number of soil borings and their distribution to adequately cover the footprint of the LNG tank.

The input from the geotechnical report helps define the type of foundation selected for the LNG tank based not just on loading, but also on settlement criteria defined from the tank design. The foundation selected for the LNG tank not only serves to support the inner and outer tanks, but also assists in preventing detrimental effects of freezing of the soil underneath. Ring wall and slab on grade type foundations typically require foundation heating systems to prevent the soil freezing, while an elevated pile cap has the necessary air gap to avoid a risk of soil freezing.

Site seismicity

The geotechnical investigation for the tank site also needs to address the probability of earthquakes and the magnitude of the ground motions from seismic activity and the influence of the soil. The seismicity study defines the ground motion hazard for the project location, and is determined by analysing many variables, including but not limited to: regional seismicity, subsurface soil conditions, and proximity to known seismic faults. Additionally, the study provides information to quantify the soil liquefaction potential of the site, or the ability of the soil to shift and consolidate due to seismic activities.

Storage tanks are designed for two levels of seismic events: the operating basis earthquake (OBE) and the safe shutdown earthquake (SSE). The OBE is the maximum earthquake for which the structure sustains no permanent damage, and restart and safe operation can resume after the earthquake. The SSE is the maximum earthquake for which the structures may sustain some permanent damage, but there is no loss of overall structural integrity and containment of contents.

The seismic loading on the LNG tank has a direct impact on the dimensions of the LNG tank (proportioning diameter and height), liquid sloshing height, and need for anchorage.

In locations with high seismic, it can be beneficial to add base isolation to the tank system in the form of friction pendulum isolators. Use of seismic isolation often results in an economical tank design with a reduced footprint, while providing the most reliable mechanism for accommodating the large seismic displacements that occur during an earthquake. The implementation of a base isolation system allows a significant reduction of the earthquake forces on the tank by approximately 80%.

In summary, early geotechnical investigations, guided by comprehensive site-specific soil investigations guidelines, are indispensable for de-risking LNG storage EPC projects, as they provide critical data to inform foundation design, mitigate seismic risks, and ensure the technical integrity and safety of the facility.

Process design parameters

Completion of the facility process design during the FEED phase is important to help define the process parameters required to complete the LNG tank design. These typically include pressure, flow, boil-off, and product composition required to help optimise the LNG tank design.

The early completion of the facility process hydraulics, simulations and flow diagrams provide the key information that feeds into development of the tank piping and instrumentation diagrams (P&IDs). Current LNG tanks, irrespective of the containment type, are installed with in-tank pumps to further enhance the integrity by avoiding any nozzles or penetrations through the tank wall. The tank topsides include a very complex arrangement of process piping, safety devices, electrical instrumentation devices, and platforming, with key focus on operability, accessibility, and maintainability. The early issuing of tank P&IDs helps bring certainty to the tank top arrangement and addresses the key interfaces to further de-risk the project.

As part of FEED design, a 3D model is generated to provide an excellent visual representation of the planned facility. Often 3D model reviews take place during this FEED phase and provide a very important planning tool for constructability. The progression of the 3D model continues from FEED all the way through the EPC phase, as the level of maturity develops.

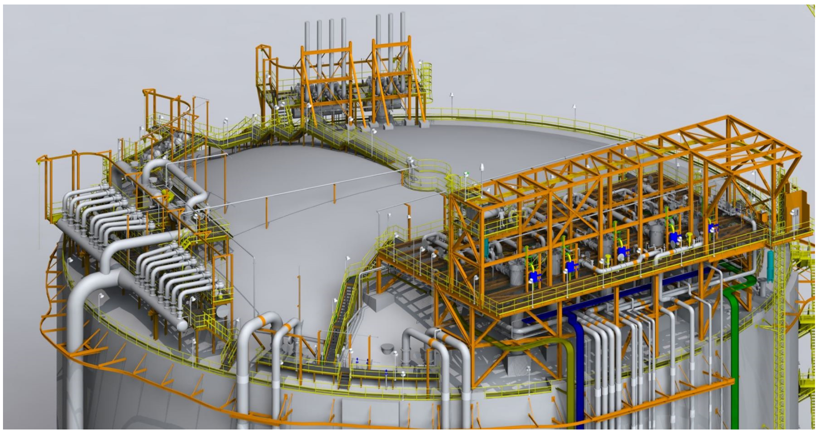

Figure 1. 3D model rendering during FEED.

External hazards

External hazards play a significant role in the selection of the tank containment system and materials of construction. Major external hazards, such as external fire, external explosion, and projectile impact should always be included in the facility risk assessment performed by the facility owner. The risk assessment determines credibility of these hazards and magnitude of external loads and effects these hazards apply to tank systems. While the storage system's outer tank is often constructed of pre-stressed concrete to mitigate these external hazards, in some cases an outer steel tank may be adequate.

External fires and radiation

An early risk assessment based on the facility layout will help identify fire exposure and radiation loading on the LNG storage tank. The key input parameters include thermal radiation intensity and fire duration. Full containment concrete tanks are typically able to withstand short duration high intensity fires or low intensity long duration fires. This ability to resist an external fire radiation as high as 32 KW/m^2 for a long duration is a built-in safeguard in a concrete tank. Steel tanks are also able to resist significant thermal radiation without any mitigation, but only for a relatively short time period due to the concern with reduction in steel strength. Longer exposures to sustained radiation require a proper engineering evaluation and may require mitigation measures.

External blast/explosion

As part of the plant risk assessment, the potential for, and design size of, a vapour cloud explosion (deflagration) for a gas processing plant needs to be determined during early engagement. The magnitude of the pressure wave approaching the LNG tank is based on:

- Possible locations of ignition.
- Congestion in each potential area.
- Size of vapour cloud ignited.

Blast loading has a major impact on the design of the tank. Since the cost to mitigate all risk can be very expensive, it is important to define the blast design basis for each tank.

When it is determined (from the plant risk assessment) that the tank design should include blast as a credible event, it is important to determine the design parameters and magnitudes. The nature of blast pressure waves creates a dynamic response from the structure that could magnify the impact on the structure significantly. Explosion loads are generally defined by the peak free field overpressure, the positive pressure pulse duration and the shape of the pressure vs time curve.

The dynamic response of the structure can be determined either with a pseudo-static method or with a transient dynamic analysis. Generally, the acceptance criteria are established to maintain product and vapour containment to allow safe shutdown of the tank.

Projectile impact

Impact due to both wind-borne and other flying projectiles is often considered in the facility risk assessment. Projectile shapes and sizes are required to evaluate their impact from the risk assessments. Commonly seen projectiles are based on wind-borne small objects or airborne valves that impact the outer tank.

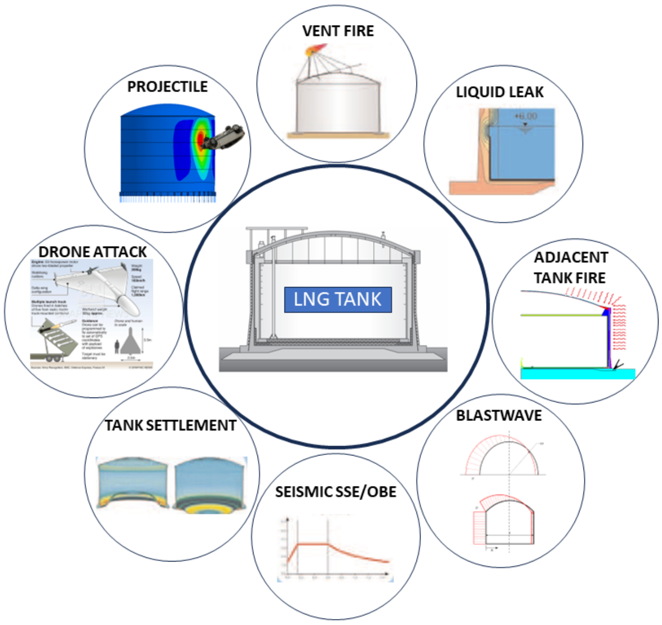

Figure 2. Identifying key hazards and their impacts.

Less commonly seen projectiles considered in the facility risk assessment based on geographic locations and local jurisdictions include:

- Small aircraft impacts – this is mainly considered as both horizontal and inclined impacts.
- Helicopter crashes – this is mainly considered as a vertical impact.
- Missile impacts – an intentional missile attack is sometimes considered as part of the risk assessment by some facilities.

For these impacts, it is important to define the impact mass, diameter, and velocity to help with the evaluation. It is important to agree on acceptance criteria, as these impacts can lead to either deformation, penetration or perforation of the outer tank. While built-in design safeguards may be able to accommodate impacts from commonly seen small airborne projectiles, large projectile impacts often require additional mitigation measures to meet the acceptance criteria. The mitigation measures may include changing the tank configuration from steel to concrete, which further reinforces the importance of defining the risk of projectile impacts during early engineering.

More recently, due to increased external threats, some facilities are requiring evaluating resistance of the LNG tank structure to attack by a munitions drone. The mass of the munitions drone will need to be specified, along with the mass of the explosive load that causes the detonation on the surface of the outer tank wall. This evaluation requires development of a direct contact surface explosion analysis model with capability to evaluate surface detonation. A thorough drone attack evaluation may be completed as part of the facility risk assessment, as accommodation of such loading requires a more robust outer concrete containment wall to be able to meet a reasonable acceptance criterion for safe shutdown.

Risk detection and mitigation provide additional safeguards

Early Hazard Risk Assessment through HAZOP and HAZID studies may reveal additional detection and mitigation measures that need to be implemented as additional layers of protection. It is very important that any risks be detected and mitigated before they become issues and have an impact on the structural integrity of the LNG tank.

For LNG tanks, potential leaks, overpressure, rollover, overfilling, and radiation concerns often require additional mitigation measures to help preserve their integrity through additional safeguards.

Leak and spill detection

LNG terminals are designed to detect any vapour leaks, as well as detect and capture liquid leaks from the primary container. While the secondary containment offers the required safeguard, an additional leak detection system is normally required to provide a form of early detection. Additionally, safety relief devices provide the measures for controlled release of vapour generated from a spill/leak in a full containment tank.

Rollover protection

Rollover occurs due to stratification of two distinct layers of varying density as a result of filling LNG of different densities when compared to the contents in the tank. The phenomenon of rollover occurs when the interface between the layers becomes unstable, leading to rapid mixing of the two layers. As the superheated liquid from the lower layer rises to the surface, it gives off large amounts of vapour leading to potential overpressure of the tank. Rollover is mainly a concern for import facilities, where the product composition can vary from different cargos. Peak shavers, where the product is stored inside the tank for a long duration, need to address the risk of rollover as well. This is usually not a concern for export terminals, where the product density does not vary sufficiently to cause any concerns with stratification within the tank. When risk assessment identifies rollover as a potential hazard, several mitigation measures can be implemented, including:

- Providing options to fill from either the top or bottom of the tank depending on relative density of cargo and tank contents.
- Provision for mixing the tank contents using re-circulation system by operating in-tank pump.
- Installation of level temperature density (LTD) gauge to help monitor for density stratification.

Radiation mitigation

Risk assessment may identify the need for radiation mitigation from either external fire or from a relief stack fire. As previously mentioned, steel tanks are able to resist thermal radiation without any mitigation, but only for a relatively short period due to the concern with reduction in steel strength. For longer durations or higher heat fluxes, mitigation measures will need to be implemented.

For radiation exposure to outer tank steel wall and roof, active fire protection may offer the best solution.

Radiation from relief vent stack fires can be mitigated by one of several measures including adjusting the height of relief stacks, using fire suppression system on vent stacks, or applying active or passive fire protection on exposed tank top platforms.

Overfill protection

Tank overfilling of the inner tank may lead to overflow into the annular space between the inner tank and the outer tank. Full containment tanks can contain the liquid in the annular space while the relief valves release the vapour generated in a controlled manner. Tank overfilling can be mitigated by implementing safeguards including continuous level measurement using a tank gauging system consisting of several level gauges of different technologies (servo and radar). Additionally, level alarms (high and high-high) provide operators with the necessary warnings. These alarms allow for at least a 10 – 15 minute alert before overfill at the filling rate. Automatic emergency shut down (ESD) valve trips are required beyond the high-high alarm, thus stopping the flow into the tank.

Hazardous area

A potential for liquid and gas leaks on the tank topsides can create an explosive environment. This concern is often mitigated by specifying a hazardous area classification for the area around and on top of the LNG tank. Electrical equipment installed within this area needs to be appropriate for this hazardous area classification. Non-sparking or arcing features of the electrical equipment help reduce the possibility of explosion from gas leaks.

Fire and gas detection

A detailed fire and gas study is conducted to help quantify and locate the fire and gas devices on the LNG tank topside. Strategic location of these devices helps quick detection of fire or gas so other mitigations can be implemented. Prevailing wind needs to be factored for gas detection.

Conclusions

CB&I's project delivery model ensures high-quality and cost-effective solutions for projects. Many customers draw on the company's deep knowledge and extensive LNG experience early in a project's development, allowing CB&I to provide input, recommendations, and project-specific solutions that enhance the long-term value of the facility. The company's integrated EPC resources enable the company to self-perform all aspects of the project, from conceptual design to tank commissioning. This translates into low-risk and high-value LNG storage solutions for its customers.

Early planning, thorough risk assessment, and mitigation are vital to the overall success of the project. It is essential to identify key inputs from early planning and risk assessment that have a direct impact on selecting the optimal configuration, sizing, layout, and level of integrity for these complex storage structures. In addition to enabling a safe and robust design, risk assessment helps identify typically installed safety devices, which play an important role in prevention and detection, as well as appropriate mitigation measures to help preserve the structural integrity of the LNG tank. **LNG**