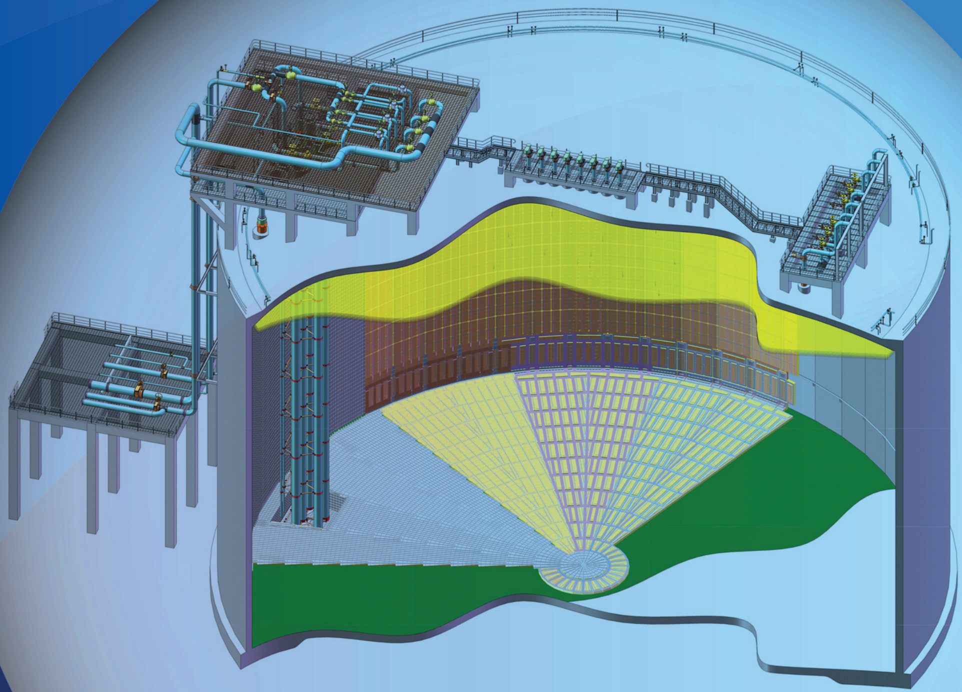

Behind the DESIGN

Adnan Ezzarhouni, Gaztransport & Technigaz (GTT), France, outlines how a sump well design can be used to increase LNG tank asset monetisation.

LNG is stored in three main areas throughout the value chain: upstream (at the LNG liquefaction plant before loading onto a carrier), on the LNG carrier, and finally at the LNG receiving terminal. Optimisation of the storage volume at each location is a key factor influencing the value of the project. In mid and large scale projects, the tanks are non-pressurised, with in-tank submerged pumps.

In-tank pumps have an intrinsic feature of imposing minimum liquid heel on the storage, avoiding cavitation. This minimum LNG volume kept in the tank to meet the minimum liquid heel is known as ‘unpumpable’ or ‘dead stock’. During shipping, dead stock can be reduced by adjusting the trim (slope) of the onboard tanks, as the onshore tanks have to take into account the unpumpable volume for the sizing.

This article will explain how the membrane sump well design can help increase LNG asset monetisation, by reducing the LNG dead stock. This allows an increased net capacity for the same given dimensions, or a reduction in tank dimensions for a given net capacity.

Membrane full integrity LNG tank

The GST® membrane full integrity system used for LNG land storage is the sister technology of the proven Mark III technology, which is currently fitted on 200 LNG tankers in operation or under construction, on a total of 850 tanks. Two GST membrane full integrity tanks are under construction in Indonesia and the Philippines, into which the cryogenic containment system is to be fitted later this year. GTT has collaborated with Strabag International – Dywidag LNG Technology, Ebara International Corp. and Thermon to create membrane LNG storage tanks that have a competitive advantage.

In comparison with the self-supporting full containment technology, the membrane full integrity concept allows for the storage of more LNG for given concrete outer tank dimensions, due to the difference in insulation thickness between the two technologies for the same required boil-off gas (BOG). This extra storage ranges from 25% for small capacity storage tanks (10 000 m^3) to 8% for large tanks (200 000 m^3).

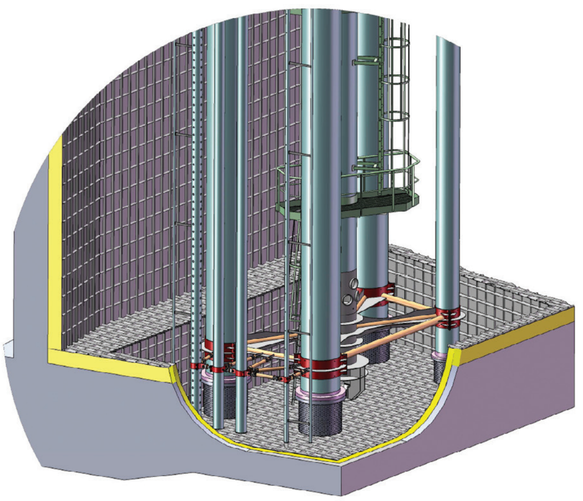

Figure 1. Sump well design arrangement.

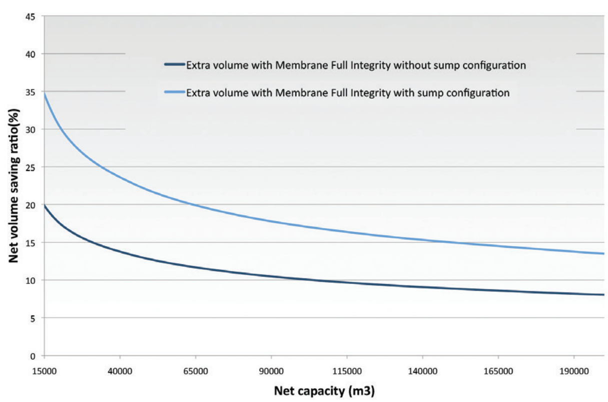

Figure 2. Percentage of extra volume gain according to LNG tank volume, with and without sump (compared to conventional self-supported tank).

How to reduce dead stock

To extend this advantage further, GTT decided to investigate the design and operational aspects of incorporating a sump for submerged pump installation, thereby decreasing the unpumpable volume and increasing the usable liquid height of the tank (Figure 1).

The membrane technology allows this concept because the bottom of the inner tank at the membrane, insulation and concrete levels is not shrinking or expanding in cold or warm conditions. The sump remains fixed, allowing safe installation and operation of submerged pumps.

Figure 2 illustrates the volume advantage realised by a sump measuring 1.5 m deep, which is in addition to the extra volume gained from insulation differences in the standard configuration.

To assess the suitability of the sump design and its operational performance, a number of technical issues needed to be studied and resolved. These included civil work design, base slab heating, submerged pumps location to preserve hydraulic efficiency, and design of the corresponding insulation and membrane components. To fully evaluate these aspects, a joint development project was formed, led by GTT. Strabag supplied the civil scope, Ebara designed the submerged pumps and Thermon provided the slab heating feasibility.

Civil scope

Strabag investigated the structural behaviour of the concrete tank structure with the incorporation of a concrete sump. The scope of this study was focused on the concrete envelope only, without consideration of membrane. Finite element modelling (FEM) analysis (Figure 3) was conducted for two sump models, under load cases selected so that horizontal loads are generated, without any rotational symmetric loads. These loads were wind and earthquake load cases.

The simulations were conducted on a case study with the following characteristics:

- Tank net capacity: 120 000 m^3.
- Wall height: 36 m.
- Inner tank diameter: 73.5 m.
- Thickness of the bottom slab: 1.2/0.8 m.
- Thickness of the wall: 0.8 m.
- Material:
  - Concrete strength C40/50.
  - Reinforcing steel grade 500.

- Seismic environment:
  - OBE: 0.15 PGA.
  - SSE: 0.3 PGA.

In the case of seismic loading, the soil and tank move more or less simultaneously, and are therefore not generating the governing horizontal forces for the design of the sump. For the wind load case, the soil is generating more resistance to the horizontal forces from wind, creating the governing forces for the design. Figure 3 illustrates the modes of deformation for the wind and earthquake loading cases.

The purpose of this analysis was to compare the necessary amount of concrete reinforcement in both configurations (with and without a sump), in order to assess the final feasibility. The calculation results show that the layout of the sump results in a higher amount of reinforcement but does not incur difficulty in the design and execution of the structure. Resistance against bending and shear, as well as crack width limitation, is also demonstrated.

Finally, Strabag suggested different arrangements of pumps in a sump, either 'in line' with independent pump wells, or assembled in a reinforced mast structure. The company concluded that from a structural point of view, there is no objection to such an arrangement.

Submerged pump design

After hydraulic analysis, Ebara was responsible for investigating the size of the pit that will surround the sump well and submerged pumps. Indeed, in a sump, an uneven distribution of flow, characterised by strong local currents, can result in the formation of surface or submerged vortices (Figure 4). This, together with certain low values of submergence, may introduce air into the pump, causing a reduction of capacity, an increase in vibration, and additional noise. Uneven flow distribution can also increase or decrease the power consumption with a change in total developed head.

In this context, Ebara proposed a methodology to design the sump with appropriate dimensions, with regard to the flow effect on pumps. The study was based on the configuration shown in Figure 5.

The design guidelines provide all required data, such as distance between two pumps [B], wall clearance [b], submergence [S] and bottom clearance [h], required to design the pump sump arrangement to ensure that no surface or submerged vortices are formed.

The optimised dimensions of the sump are a function of [D], where [D] is the suction bell diameter. The following can be provided as an illustration:

- [B] (distance between two pump rotor axis) must be within the range [2D; 8D].

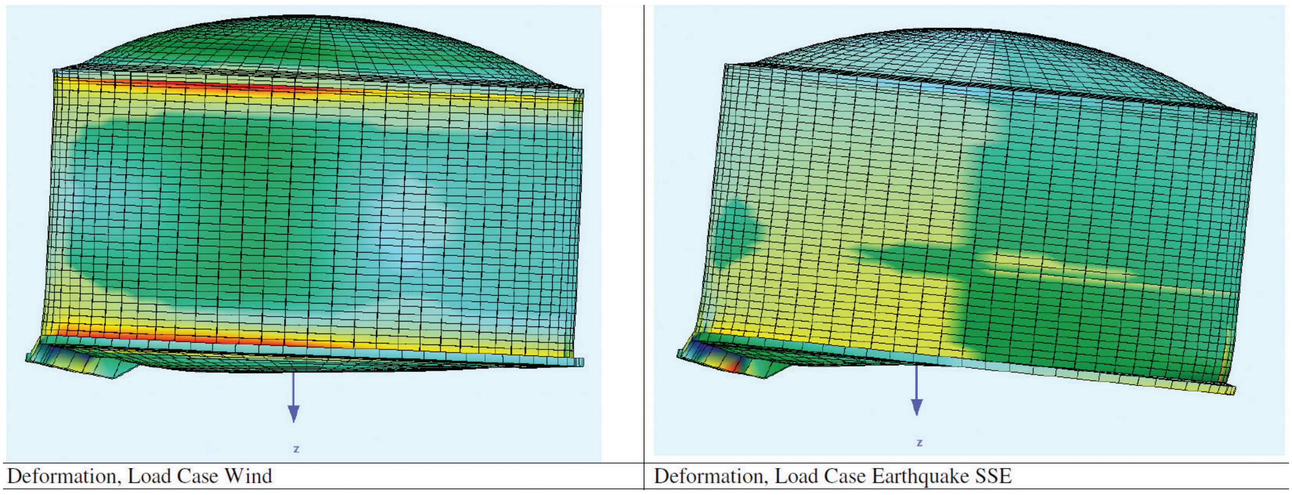

Figure 3. Modes of deformation.

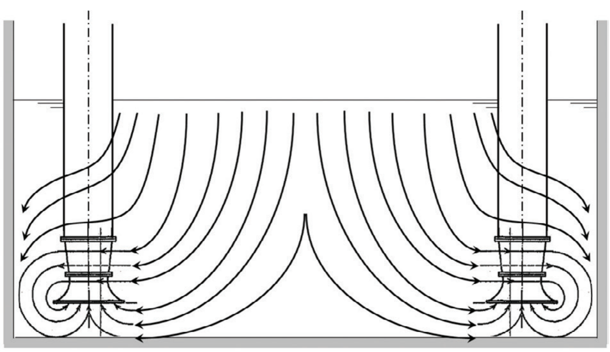

Figure 4. Main distribution of the LNG inside the pit.

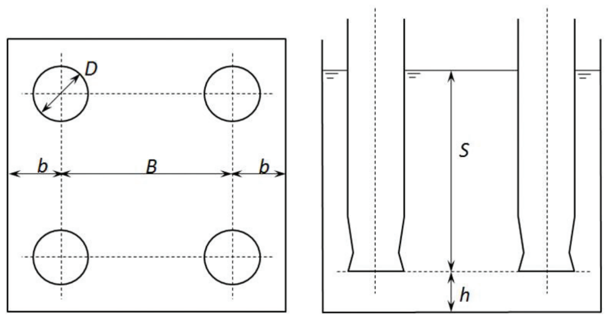

Figure 5. Design dimensioning rules of the pit.

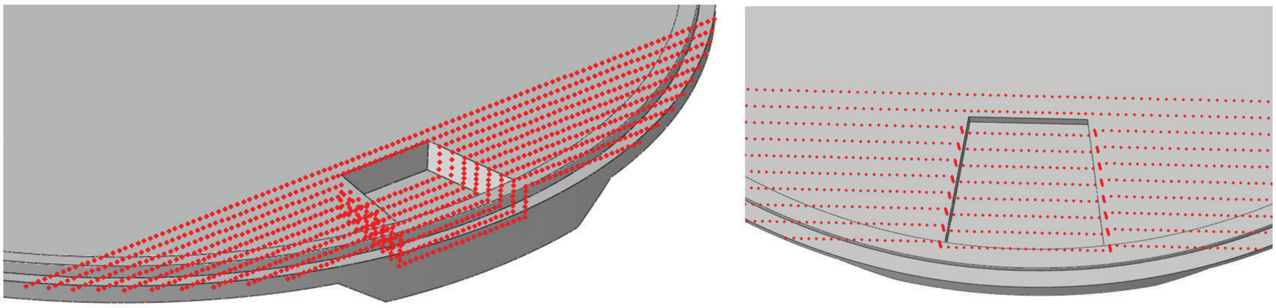

Figure 6. Heating system cable arrangement around the pit.

- [b] (the wall clearance) must be within the range [0.75D; 1.0D]. Too low a bottom clearance harbours the risk of bottom or wall vortices. Too large a clearance induces unfavourable flows around the pump body, leading to vortex streets and vortices.
- [S] (submergence) is the difference in height between the liquid level and the suction bell. The critical submergence, [Scr] is that liquid level at which the vortex just reaches the outlet opening, and [S] > [Scr] is a necessary condition for the safe operation of a pump. [Scr] is determined by the following equation:

$$S_{cr} = D + \frac{9.2Q}{\pi D^{1.5} \sqrt{g}}$$

- [h] (bottom clearance) must be within the range [0.3D; 0.75D]. Too low a bottom clearance leads to bottom vortices. Any further increase in the distance may impair the velocity distribution in the suction bell approach.

Using relevant guidelines, Ebara confirmed that the sump does not affect the hydraulic performance of the pumps. The maintenance principle of the pumping system also remains unchanged.

Slab heating feasibility

The purpose of the analysis made by Thermon was to validate the arrangement of the heating cables within the slab, which includes a pump sump. 3D finite element analysis (FEA) was performed to analyse the proposed heating system design and confirm that the foundation would not be subjected to frost heave. The analyses were based on a steady-state condition. These equilibrium steady-state solutions can represent time frames that are not normal or even occasional, and therefore may result in temperature profiles that are lower than average.

The advantage of FEA is the model flexibility, making iterations on geometry and boundary conditions easy. As an example, four scenarios were studied, based on the following assumptions:

- -10°C ambient, normal condition – the LNG tank is exposed to an ambient temperature of -10°C with a wind velocity of 25 mph. All heater circuits are on. The resistance temperature detector (RTD) sensor is located on the top surface of the slab at the centre point of the LNG tank.
- -10°C ambient, half-failed condition – the LNG tank is exposed to an ambient temperature of -10°C with a wind velocity of 25 mph. One of two heating cables failed. The RTD sensor is located on the top surface of the slab at the centre point of the LNG tank.
- 35°C ambient, normal condition – the LNG tank is exposed to an ambient temperature of 35°C with a wind velocity of 5 mph. All heater circuits are on. The RTD sensor is located on the top surface of the slab at the centre point of the LNG tank.
- 35°C ambient, half-failed condition – the LNG tank is exposed to an ambient temperature of 35°C with a wind velocity of 5 mph. One of two heating cables failed. The RTD sensor is located on the top surface of the slab at the centre point of the LNG tank.

Moreover, different heating cable configurations could be studied. The first considered a longitudinal repartition of heating cables, which required two additional cables around the sump in order to improve the heating efficiency. The second considered a transverse repartition of heating cables, offering the possibility to independently pilot the cables around the tank, as illustrated in Figure 6.

Thermon found the design to be suitable for every scenario. Temperature profiles in concrete slab and soil appeared to be acceptable as per design criteria. The installation of the cables and their maintenance capabilities in operation are identical to the original slab arrangement.

Containment system design

As for the containment system design for the sump, the existing tools in supplier workshops could facilitate the production of all required components, including the salient angle pieces. GTT developed the appropriate insulating component design to fit properly with the sump geometry.

Insulating panels were designed regardless of the shape of the sump, and checked by finite element calculation. Thermal and thermomechanical analysis was performed in order to demonstrate the suitability of these insulating components, regardless of panel thickness.

Conclusion

The positive result of this joint development project, covering every aspect of the design and constructability of the sump, offers benefits to the market. Using a sump well design can result in considerable savings in the storage tank cost for a given volume, or can add significant volume for a given dimension of the concrete outer tank. **LNG**