GTT Inside

September 2023 - N°29

Message from Karim Chapot, VP Technical Division of GTT

The LNG Industry has demonstrated more than 60 years of successful and safe operations. GTT is proud to have contributed to this success through continuous innovation in new solutions, new design proposals and efficient assistance in construction of well over 2.500 LNG tanks.

In this issue, you will discover two new developments, the first being the modular GST® concept, which offers a high degree of flexibility in onshore tank construction. The second introduces the Reduced Rectangular Combined Dome concept, for LNG fuelled ships fitted with Mark III tanks, which offers greater flexibility in tank design and containment system installation as well as cost reductions.

The third topic relates to GTT's Technical Assistance (TA). The construction of the membrane type LNG tank requires a very specific attention, rigorous control during design, material production, component pre-fabrication, and assembly.

The role of GTT is to support the shipyard and verify that the designer's requirements are met throughout the industrial process, ensuring proper execution, performing risk analyses when necessary and making recommendations to prevent potential issues during operations.

This TA during the construction phase continues after delivery. By visiting the tanks every 5 years and carrying out performance optimisation studies, GTT collects critical information to further improve the performance and the safety of the tank design.

The assistance provided over many years at all stages of the industry has enabled GTT to build a strong track record which has contributed to LNG playing a major role in the energy supply and the future transition. Enjoy your reading!

ONSHORE STORAGE: MODULAR GST® CONCEPT

Amid rising global energy prices and higher demand, new greenfield onshore projects are running into inflationary headwinds and facing significant challenges to deploy cost-effective LNG storage solutions. This is particularly true when accessing remote areas where logistics are complex and skilled manpower is difficult to deploy. Moreover, as projects become increasingly modularised, slower erection times inherent to stick-built tanks often drive overall project delivery. These observations have led GTT to re-think the conventional industrial scheme of an LNG land storage as a bespoke, fully pre-commissioned, movable asset which could reduce the unit cost of storage and enhance certainty of outcome for project developers. The answer to this question has led to the Modular GST® Membrane LNG (MML for short) storage tank concept. This article describes how membrane technology is key to developing a safe modular system for trans-oceanic transportation.

Concept presentation

The MML tank is an adaptation of stick-built GST® technology, modified with the use of a cylindrical, cryogenic steel outer tank, along with the use of a movable, carbon steel baseplate designed to make the tank light-weight (under 3,500 metric tons), and transportable over remote-controlled Self-Propelled Modular Transporters (SPMT). The idea is to complete its pre-fabrication in a controlled environment with high productivity, and finally deliver to the end user's site on a specialised, semi-submersible vessel, where the tanks are fixed on-deck using a purpose-built welded mounts with load-in capacity for up to three 45,000 m^3 MML tanks.

Main characteristics are:

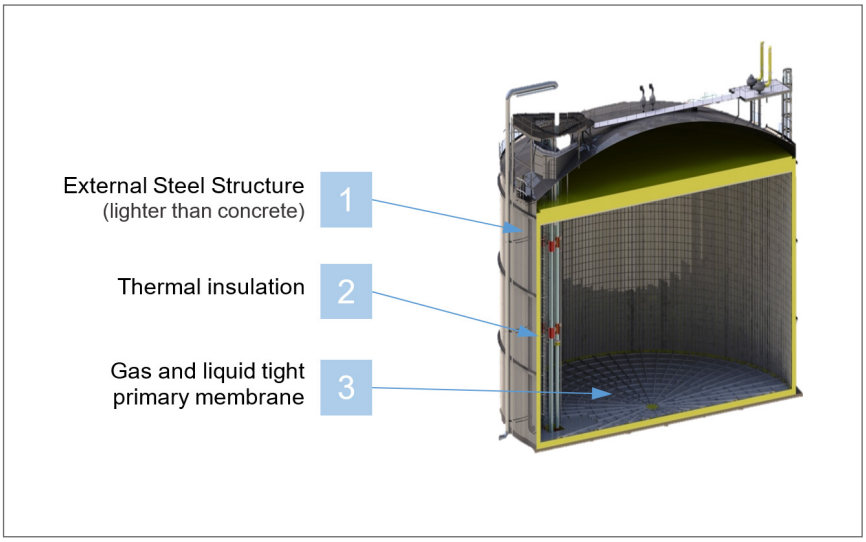

Figure 1: MML

1. **Cryogenic steel outer tank** - SS304L or 9%Ni to act as a secondary barrier.

2. **Optimised GST® containment system technology** - No thermal corner protection, adapted to cylindrical shape.

3. **Design adapted for transportation** - Dedicated membrane deflection studies and Finite Element Analysis were carried out to validate the containment system with the new carbon steel base plate design.

4. **Capacity -** Range from 10,000 to 45,000 m^3.

5. **Schedule -** 17 to 20 months for Ex-Work delivery of 1 tank; 24 to 27 months for 6 tanks.

6. **Boil-Off Rate (BOR)** : similar to standard land storage solutions.

The insulation is composed of Reinforced Polyurethane Foam Panels and a Primary Corrugated Stainless Steel membrane as in the GST® technologies, with some adjustments to match the circular shape of the structure.

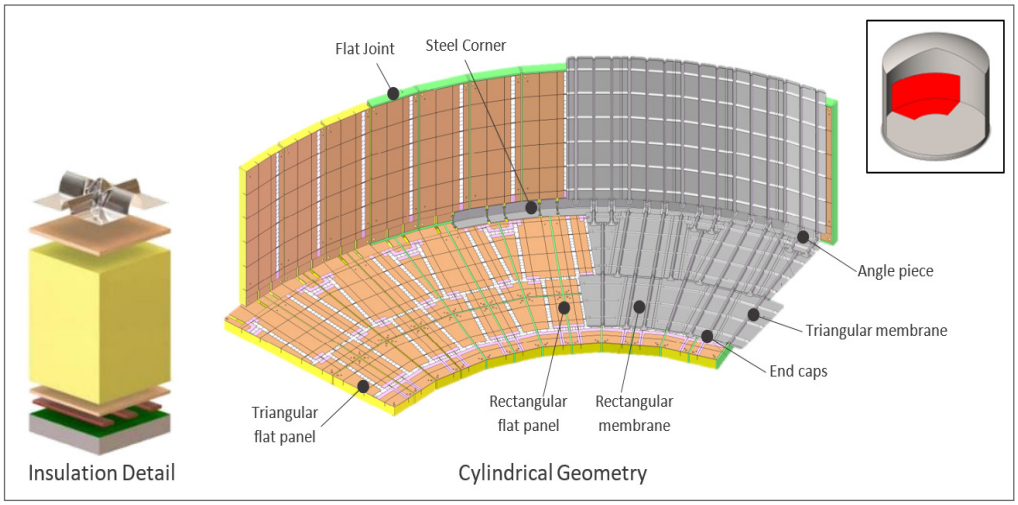

Figure 2: Containement system description

The base of the structure is composed of a lattice steel structure assembly filled with a 300mm thick layer of cryogenic rebar reinforced concrete pad, specifically developed to:

- Provide permanent on-site support for the Tank to take on all loads of the tank including operational loads and seismic loads
- Accommodate transportation of the tank as an assembly and to withstand all deflection / motion / acceleration
- Form a thermal barrier against cryogenic temperatures in case of a leak in the tank as there is no thermal corner protection in the tank design
- The concept is validated through Finite Element Analysis.

Figure 3: Transportation of MML tanks

Transport

The upper range of tank capacity is constrained to enable the manoeuvring of the prefabricated tank convoy by a heavy-haul road purposely widened to receive it. Dedicated motion analysis studies have been conducted to adapt the design of the modular tank for shipping load cases, and have confirmed feasibility for shipping the 47m diameter and 3500 ton tank structure around the world.

The main impacts of the transportation on the design were:

1. Addition of temporary anchors to avoid sliding of the tank itself on the baseplate
2. Optimisation of plate thicknesses for walls and bottom to cope with ship motion forces
3. Suspended deck is temporarily anchored to allow its installation before transportation.

This study covered the full fabrication cycle from shop fabrication to final site delivery via a combination of 4 trains of SPMTs to achieve the operation.

The transport operation considers a tank without its top maintenance platform, relief and control valves, external piping. These specific elements shall be delivered separately to be assembled on the end-user and construction site.

Considering a potential application, a transportation study assumed a Asia – North America route with a 3 to 4 weeks duration, for a single, semi-submersible ship transporting three 47m diameter tanks fixed to the ship's deck via specially designed supports. This study shows that this construction organisation is a pertinent way to proceed and take advantages of significant construction cost reduction, shorter planning and reduced man power on the end user site.

This is mainly thanks to better tank construction conditions such as personnel and supplier availability, less harsh atmospheric condition and parallelisable operation between tank construction and foundation realisation.

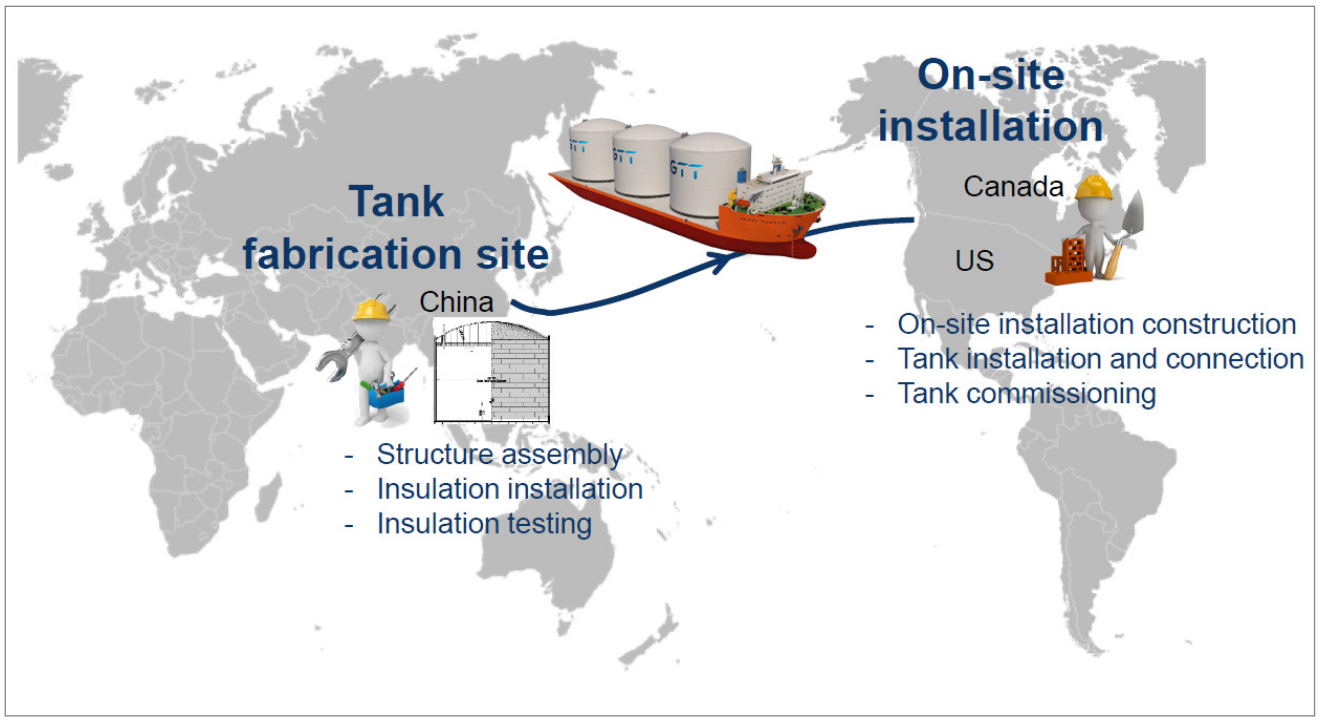

Figure 4 : MML tanks routing

Conclusion

This article summarised the feasibility analysis of a new modular, flat-bottom LNG storage tank with GST® technology. The multi-faceted development process exemplifies GTT's commitment to innovation as a key enabler to unlock challenging markets by bringing substantial benefits through the modularity, scalability, and reliability of membrane technology. While not a single modular LNG tank exists in operation today, GTT's concept will be the only fully pre-fabricated solution available; resulting in a significant speed-to-market benefit over similar, competitive offers.

Moreover, the aforementioned drive to modularisation among small and mid-scale LNG developers is precipitating a fundamental shift in the way LNG terminals will be constructed in the future, favoring a phased approach to deploy parallel trains to match growing contracted demand. Thus, the adaptation of various storage technologies in step-sized solutions could become the norm rather than the exception in the terminal of the future. This concept should enable GTT's portfolio to play a key role in future onshore LNG storage requirements.

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DEVELOPMENT OF A REDUCED COMBINED DOME FOR LNG FUELLED SHIPS (LFS)

GTT has recently developed a reduced combined dome dedicated to LNG fuelled ships fitted with Mark III tanks, taking advantage of the less challenging requirements in terms of space, for this kind of vessels compared to LNGCs. This dome and the related pump tower of reduced dimensions offer more flexibility in tank design and containment system installation as well as a cost reduction.

The domes are critical parts of an LNG tank, as they contain most of the pipes crossing the containment system while maintaining the insulating and tightness. The liquid dome is also supporting the pump tower (PT) on which the pumps are attached in order to load and discharge the LNG. Many other key components are installed on the domes such as the tank Pressure Safety Valves, the level gauges, the material passing hole and the manhole.

In the specific case of LNG fuelled ships (LFS), the LNG fuel tank has smaller dimensions than LNG carrier tanks and liquid and gaseous lines are of smaller diameter. This permits a combination of the usual gas dome and liquid dome of a LNGC into one single rectangular combined dome for LFS applications.

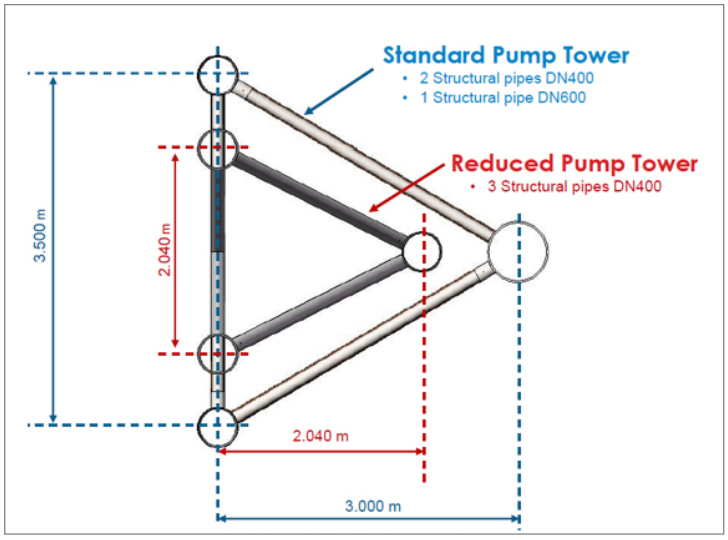

Figure 1: Size reduction of pump tower

Going further into this optimisation process for LFS, GTT has then worked on an optimised design for the pump tower and for the combined dome. The structural pipe diameter in the forward position of the PT has been changed from DN600 to DN400. The PT footprint has been reduced from 3.5m x 3m down to 2.04m x 2.04m as displayed on Figure 1. This major improvement reduces the size of the combined dome (Figure 2): -10.6m^2 less surface occupation.

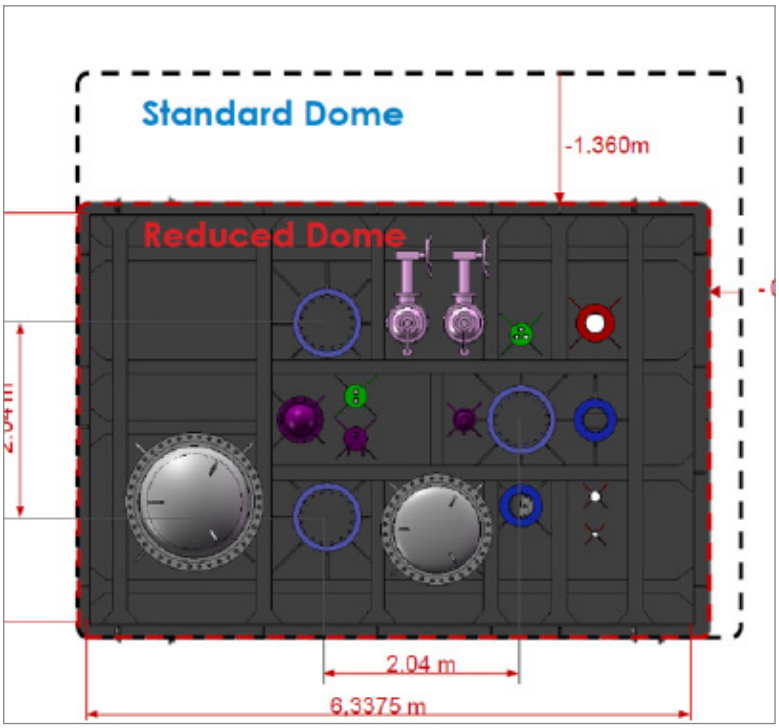

Figure 2: Size reduction of rectangular combined dome

This Reduced Rectangular Combined Dome (RRCD) has been validated by extensive numerical studies, which concluded that it can be used even for large LFS tanks of Ultra Large Container Vessels (23,000 TEUs). The application range of the RRCD for Mark III LNG fuelled ships extends from tankers and bulkers to all sizes of container vessels.

The main features of the standard dome remain available for this new RRCD: ship-owners and shipyards keep the flexibility to choose between deepwell pumps and submerged pumps and to apply a sump well in order to minimise the LNG heel level (Figure 3).

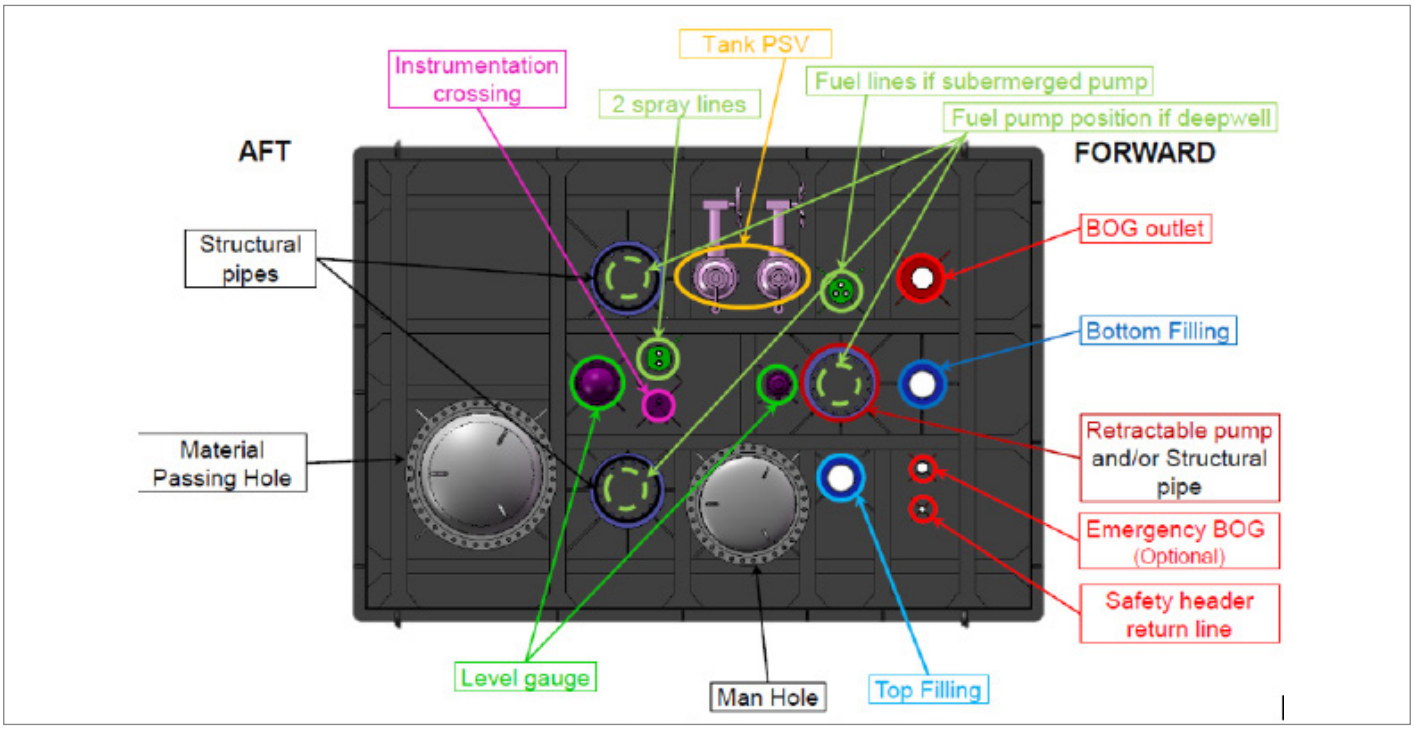

Figure 3: Overview of pipes crossing the RRCD

Applying the RRCD brings several significant advantages:

- Limited footprint makes it particularly interesting for narrow tanks. In case of Very Large Crude Carriers (VLCCs) for instance, the Mark III LNG fuel tank can be fitted in the cargo area, between the two internal longitudinal bulkheads (Figure 4). The reduced width of the new dome fits then perfectly with the narrow ceiling.
- Reducing the size of the dome and of the PT obviously comes with savings on raw materials, with around **10T of stainless steel saved**[1].

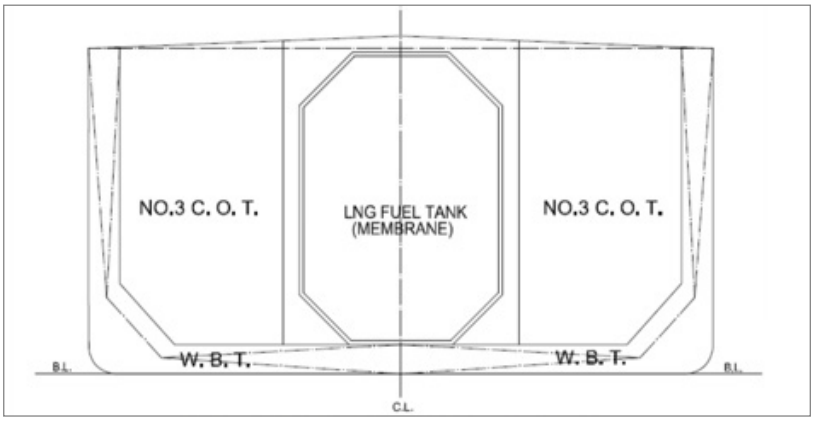

Figure 4: Mark III tank solution for VLCC

- It provides more flexibility at construction stage, giving more space for scaffolding inside the tank for installing the containment system.

Material passing hole and manhole are fitted with standard circular flanges. The upgrade for increased maximum pressure to 1 barg (instead of typical 700 mbarg as stated by IGF Code[2]) is then simplified and is currently under study.

The Reduced Rectangular Combined Dome should become the standard dome for the Mark III LNG fuel tank, reducing the cost of the fuel tank and easing its construction.

[1] Best estimate based on standard project configuration.

[2] More details on increased maximum pressure for Mark III LNG fuel tank can be found in our dedicated webinar: WEBINAR SUBSCRIPTION CENTER & ON-DEMAND REPLAY | GTT.

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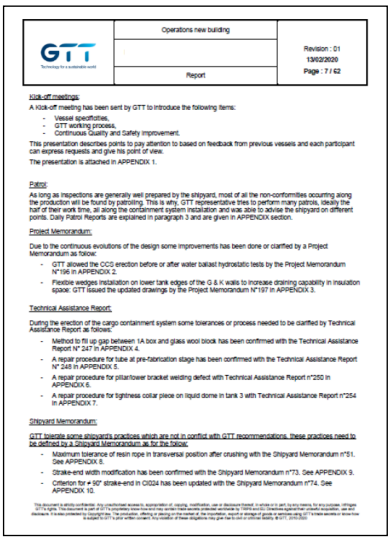
ENSURING SAFETY AND PERFORMANCE OF LNGCs
GTT SUPPORT DURING CONSTRUCTION

Throughout over 60 years of experience in designing patented LNG membrane containment technologies, GTT has not only developed thorough engineering and design capabilities on its systems, but also specific on-site know-how that may be deployed during the construction process to the benefit of its clients, and industry stakeholders.

Benefiting from more than 10,600 cumulated tank-years for Mark III and more than 11,400 cumulated tank-years for NO96, GTT has also attended more than 1,100 refits where it was required to thoroughly scrutinize the cargo tanks. GTT is thus ready to mobilize an experienced team of surveyors to support the shipyard teams to ensure that the GTT systems are properly installed on board, and that the design specifications, drawings, studies, and any other requirements defined during the engineering phase are accurately realized.

The quality of implementation of the designs is critical in ensuring the safety and performance of the membrane containment systems. Yet, as the technology is complex, this implementation can often raise unexpected issues or concerns:

- Design deviations always occur during construction: some have an acceptable or minor impact, while others, more significant, require rectification. It is key that an independent third party be in a position to assess them and define an acceptable action plan, as need be, in order to satisfy all the stakeholders' constraints ensuring that the technology is preserved: those of the shipyard of course, but also of the ship-owner and the classification society.
- Gas trials are always a truth test: GTT may also provide technical assistance during this key phase where the different equipment (compressors, heater, insulation, etc.) are tested, by performing all the standard operations the vessel will realize during her lifetime (cooling down of the insulation, tank loading/ unloading, cargo transfers between tanks, etc).



Operations new building

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Report

Kick-off meetings

A kick-off meeting has been sent by GTT to introduce the following items:

- Vessel specificities,
- GTT working process,
- Continuous Quality and Safety improvement.

This presentation describes points to pay attention to based on feedback from previous vessels and each participant can express requests and give his point of view.
The presentation is attached in APPENDIX 1.

Patrol

As long as inspections are generally well prepared by the shipyard, most of all the non-conformities occurring along the production will be found by patrolling. This is why, GTT representative tries to perform many patrols, ideally the half of their work time, all along the containment system installation and was able to advise the shipyard on different points. Daily Patrol Reports are explained in paragraph 3 and are given in APPENDIX section.

Project Memorandum:

Due to the continuous evolutions of the design some improvements has been done or clarified by a Project Memorandum as follow:

- GTT allowed the CCG erection before or after water ballast hydrostatic tests by the Project Memorandum N°196 in APPENDIX 2.
- Flexible wedges installation on lower tank edges of the G & K walls to increase draining capability in insulation space. GTT issued the updated drawings by the Project Memorandum N°197 in APPENDIX 3.

Technical Assistance Report:

During the erection of the cargo containment system some tolerances or process needed to be clarified by Technical Assistance Report as follows:

- Method to fit up gap between 1A box and glass wool block has been confirmed with the Technical Assistance Report N° 247 in APPENDIX 4.
- A repair procedure for tube at pre-fabrication stage has been confirmed with the Technical Assistance Report N° 248 in APPENDIX 5.
- A repair procedure for pillar/tower bracket welding defect with Technical Assistance Report n°250 in APPENDIX 6.
- A repair procedure for tightness collar piece on liquid dome in tank 3 with Technical Assistance Report n°254 in APPENDIX 7.

Shipyard Memorandum:

GTT tolerate some shipyard's practices which are not in conflict with GTT recommendations, these practices need to be clarified by a Shipyard Memorandum as for the below:

- Maximum tolerance of resin rope in transversal position after crushing with the Shipyard Memorandum n°51. See APPENDIX 8.
- Strake-end width modification has been confirmed with the Shipyard Memorandum n°73. See APPENDIX 9.
- Criterion for + 20° strake-end in CIG04 has been updated with the Shipyard Memorandum n°74. See APPENDIX 10.

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GTT assistance during construction

GTT's support during construction is intended to assist the shipyard quality and construction teams to ensure that the containment system is erected properly. Training of the shipyard's bonding and welding teams, regular patrols, random controls, and specific inspections are typical of the type of service GTT may provide during all the execution phases from the prefabrication stages, to the erection and testing steps of the containment system until the cargo tank commissioning; they are defined with the shipyard in order to maximize the efficiency of the quality control.

Support to quality management

GTT assists the shipyard teams to ensure that the highest quality standards are met during the erection phase.

GTT surveyors' findings during patrols are systematically shared with the shipyard by way of Daily Patrol Reports (DPR). Regular meetings are also regularly organized with the yard production and quality teams to follow-up on the erection, and on corrective action plans, if any. GTT may even deliver upon request a construction report confirming the suitability of the containment system at delivery.

DAILY PATROL REPORT

Year 2023
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Owner: ---- Ship Name: -----

Techno : NO96 GW GTT Representative :

17/01/2023

Subject N°1: Automatic welding defects found during Helium Test.	Type Defect	Criticality High	Location Tk4	Zone Secondary Membrane

GTT OBSERVATIONS

Dear Sirs,

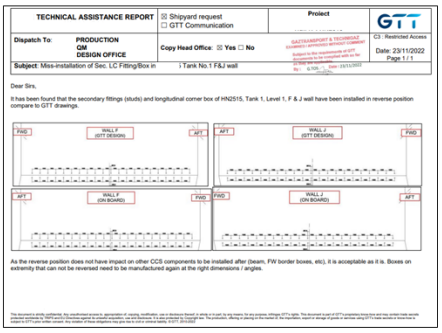
After helium test in tank 4, we found a lot of leak obvious (4 out of 5).

All these defects are on automatic welding process (MG2, MG3).
Same kind of obvious defect (seam welding omission) was already found in tank 3.
As automatic process are important to ensure the system reliability, please maintain an acceptable level of self-checking and quality control.

Risk assessment

GTT, as technology provider, benefits from its expert knowledge of the design and the technology to provide independent technical judgements on any issue raised during installation and may also advise on mitigation plans, where available. Depending on the issue at stake, those analyses may be documented through:

- Technical assistance report (TAR) where one specific hull is concerned
- Project Memorandun (PM) where hull series of the same project are concerned
- Shipyard Memorandum (SM) where all hulls in the shipyard are concerned.



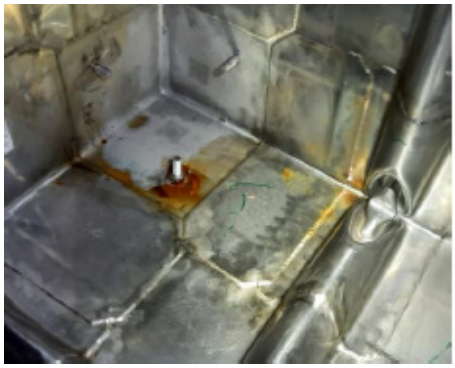
Typical deliverables (TAR, PM, SM) issued by GTT site teams during construction

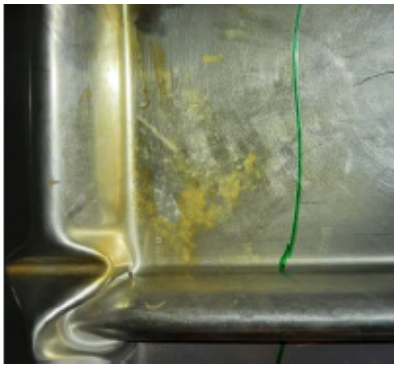
Where a serious matter arises, potentially affecting the integrity of the tank during construction, GTT may also conduct studies and provide engineering support to define the best technical solution. Such matters may vary from a fire to an electric shutdown, but also over-pressure in the insulation spaces during vacuum tests, or defects of prefabricated CCS components.

Deformation during ship movement

Fire and smoke

Bad weather and water ingress





Lack of tank preservation

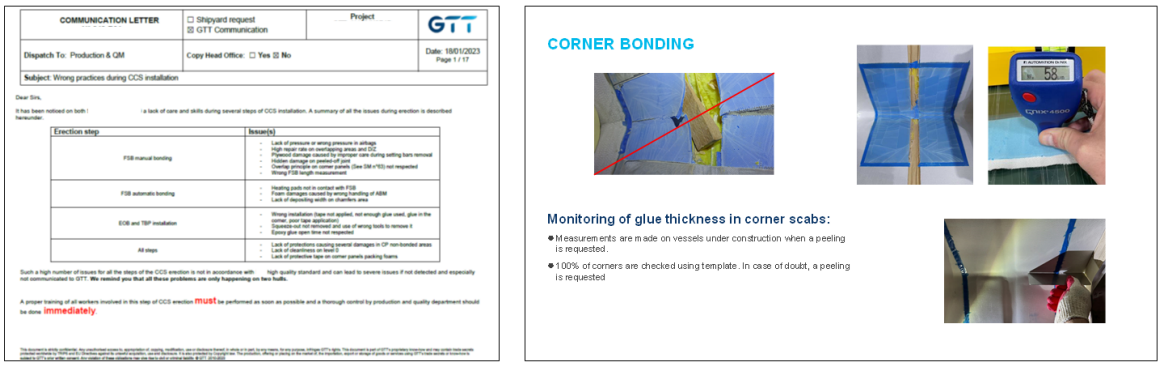
In these instances, where serious repairs cannot be avoided, GTT may rely on its large panel of expertise, including thermal, hydrodynamic, process, structure, design, operational and repair skills, to provide specific analyses to assess the acceptable areas and define tailored-made repairs to be made.

This service take the form of technical reports made available to the shipyards and sometimes the ship-owners to help them address their insurance issues and secure their respective contractual commitments.

Sharing the latest state-of-the-art on GTT technology

GTT membrane systems consist of a complex assembly of composite materials which require specific know-how to be installed in satisfactory conditions. Erection of certain areas might be sensitive, and knowledge of how the technology evolves over time is critical. Therefore, GTT regularly improves its know-how, based both on the evolution of its designs, and its knowledge of the technology overtime, as evidenced by return of experience from vessels in operation.

GTT surveyors therefore are able to provide regular training to the teams of the builder, ship-owner and classification societies and systematically update each party prior to the beginning of construction with the latest learnings and standards available at GTT. This expertise may be shared with shipyards through communication letters.



Communication letters and kick-off meeting at construction delivered by GTT site teams

GTT assistance after delivery

GTT assistance remains available after delivery of the vessel, where unexpected concerns related to the cargo containment systems may arise during ship operations and require further analyses. GTT may provide a wide range of technical advice and support to secure the tank during ship activities, from the monitoring of the tank situation to the issuance of recommendations and to conduct investigations to be performed during first special survey.

Thanks to its wide panel of expertise on its technologies, GTT is able to provide services that maximize ship safety and performance while minimizing the potential impacts on commercial operations or ships downtime for maintenance activities. In particular, if defects are reported during the ship operation, GTT is able to carry out the proper investigations with a holistic approach that leads to a root cause analysis (RCA) report. Each possible cause is systematically analysed based on testing, calculation campaigns and observations. Such assessment is essential for the appropriate understanding of the most probable defect origin to identify the most appropriate mitigation measures, and define recommendations to avoid defect re-occurrence in future constructions. These reports are often required for insurance purposes.

The observations, as well as the outcome of these RCA, with recommended improvements and mitigation measures are transparently shared to the LNG industry in order to secure all the future constructions and vessels in operation. The analyses of all observations are shared through detailed presentations to the relevant parties and where useful, to the industry during the LNG membrane owners forum. Whenever safety of the cargo tanks is at stake, GTT may share its technical analyses to recognized professional associations (SIGTTO, SGMF, etc.) and regulatory authorities (IACS, Flag states, Coast Guards, etc.).

An assistance based on an unrivalled knowledge of GTT technologies

GTT has gradually developed a unique database containing full records from all of its interventions and observations of its systems' behaviour on vessels in operation. This database fuels mathematical and experimental models, subsequently used to predict likely operation conditions, enabling GTT to anticipate the possible risks of failure, assess their likelihood and justify the technical choices with classification societies.

Thanks to its detailed database, GTT is able to work remotely, identifying and precisely defining the solutions to be implemented, without necessarily involving any alterations to the tank in order to minimize the idle time of the vessel (any intervention involving the tank will put that ship out of service for a minimum of five days).

The maintenance operations are all supervised by GTT's teams in order to ensure that the quality of the work comply with designer's requirements and hypothesis and further incorporate the latest maintenance procedures.

GTT continuously upgrades its membrane systems on the basis of the return of experience.

The unmatched track record obtained during the last 60 years is the fruit of constant improvements gathered all along the lifecycle of the vessels starting from the design phase up to scrapping activities. It requires a detailed knowledge of the design of each vessel, a deep involvement in the construction of each cargo containment system layer that only allow to assess very accurately the safety margins and to understand the consequences of each decision on the GTT systems.