New LPG Carrier Adopting Highly Reliable Cargo Tank - IMO Tank Type B -

HIROSHI TAMURA*1 HIROTOMO OTSUKA*2

TOSHINORI ISHIDA*1 SATOSHI MIYAZAKI*3

Today, with the growing Liquefied Petroleum Gas (LPG) consumption in emerging countries and the growing production of associated gases from natural gas and shale gas, it is expected that seaborne trade of LPG will increase and its trade routes will be diversified. Mitsubishi Heavy Industries, Ltd. (MHI), which has continued to develop LPG carriers to meet the needs of the era, has focused mainly on building an 83,000m^3 type LPG carrier as a flagship model to meet large capacity demands since 2006. On the occasion of latest upgrade aimed at the improvement of fuel efficiency and environmental friendliness, we newly developed a cargo tank to realize customer benefits of high reliability and low maintenance costs. This tank has already been approved by several classification societies and the United State Coast Guard (USCG), and has been applied to an LPG carrier delivered in 2012. We will actively conduct sales activities and continue to improve further to meet customer needs.

1. Introduction

MHI has been building LPG carriers for a half century since 1962. Since building the Nichiyuh Maru in 1989, we have built VLGCs (very large gas carriers) for various customers; the 78,000m^3 series has been the de-facto standard and now the 83,000m^3 series has been included in the lineup since 2006. We have now innovated the hull form, structural designs and layouts to meet recent trends of strict environmental regulations and to enhance the performance competitiveness. In our newest innovation, we have adopted IMO Type B tanks to provide customers with further benefits.

This paper describes the features of this tank system, such as structural differences from the conventional tank system, operational advantages, etc.

2. LPG carrier tank types

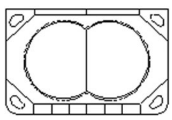
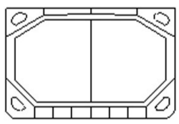
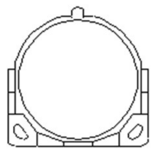
In LPG carriers, the cargo tanks which are independent from the hull structure are arranged in cargo holds and supported by tank supporting systems. **Table 1** shows a comparison of tank types for LPG carriers. Small to medium-sized LPG carriers with 20,000m^3 or smaller capacities commonly have cylindrical Type C tanks or combinations thereof and transport LPG under pressurized conditions at ambient or lower temperatures. As this Type C tank system results in a significantly thick tank skin for its large capacity, however, large LPG carriers with 30,000m^3 or larger capacities commonly apply independent prismatic tanks and carry LPG under atmospheric pressure at lower temperatures. The Type A tank, which is commonly used in the independent prismatic type, is designed based on a conventional structural design standard. In order to avoid hazard, the Type A tank requires a secondary containment structure (secondary barrier) around the tank that is sufficient to maintain the entire tank volume on the assumption of a major cargo leakage. The surrounding structure of the entire hold space is designed to serve as a secondary barrier. Large LPG carriers in service, including those built by other manufacturers, all use the Type A tank system. Meanwhile the Type B tank is designed based on fail-safe design concepts.

*1 Engineering Manager, Nagasaki Ship & Ocean Engineering Department, Shipbuilding & Ocean Development
*2 Manager, Nagasaki Ship & Ocean Engineering Department, Shipbuilding & Ocean Development
*3 Nagasaki Ship & Ocean Engineering Department, Shipbuilding & Ocean Development

Through advanced and detailed analyses, it has been proven that the Type B tanks have sufficient fatigue strength to prevent crack penetration during the design life, even if fatigue defects occur, and that the leakage should be limited during the prescribed duration, even if leakage due to penetration is detected. Hence, it is only necessary to have a partial secondary barrier to hold only the envisaged maximum leakage, which should be limited. The typical Type B tank is used in MOSS-type LNG carriers, where each tank has a drip tray as its partial secondary barrier.

We have been building both large LPG carriers and MOSS-type LNG carriers for years, and we have accumulated technological expertise in designing and building independent prismatic tanks through Type A LPG carriers, as well as in designing and analyzing Type B tank systems through MOSS-type LNG carriers. Combining this expertise, we have newly developed the independent prismatic Type B tank.

Table 1 Comparison of tank types

Tank type	Independent cylindrical	Independent prismatic		(Reference) MOSS-type (Independent spherical)
	Pressurized at ambient temperature or lower temperature	Fully refrigerated at atmospheric pressure		Fully refrigerated at atmospheric pressure
Structure				
IMO tank type	Type C	Type A	Type B	Type B
Secondary barrier	No requirements	Complete	Partial	Partial
Notes	For small vessels less than approx. 20,000m^3 capacity	For large vessels		For LNG carriers

3. Development of LPG carrier with Type B tanks

3.1 Features of the developed LPG carrier

The principal particulars and general arrangement of the new LPG carrier are shown in **Table 2** and **Figure 1**, respectively. The main dimensions and layout are the same as its predecessor in order to maintain compatibility with shore terminals. The main improvements from its predecessor are:

- Performance: 5% better propulsion performance is obtained by improving the hull form based on CFD and model tests;
- Layout: a simpler structure is achieved by converging fuel tanks between the cargo hold and the engine room to reduce narrow compartments in the double-hull structure, and a space for installing a ballast water treatment system is provided at the forward bottom in the engine room;
- Reliability: highly reliable Type B tanks are adopted.

Table 2 Comparison of principal particulars among LPG carriers with 83,000m^3 capacity

	Conventional	Newly developed
Length × breadth × depth	219.0m × 36.6m × 21.65m	219.0m × 36.6m × 21.65m
Draft (design/summer)	11.15m/11.60m	11.10m/11.55m
Cargo capacity	83,000m^3	83,000m^3
Tank type	Independent prismatic Tank Type A	Independent prismatic Tank Type B
Secondary barrier	Complete secondary barrier	Partial secondary barrier
Insulation	Polyurethane foam	Polyurethane foam
Service Speed	17.0kn	17.0kn
Main engine output	NR: 12,330kW NR: 11,700kW	MR: 13,700kW MR: 13,000kW

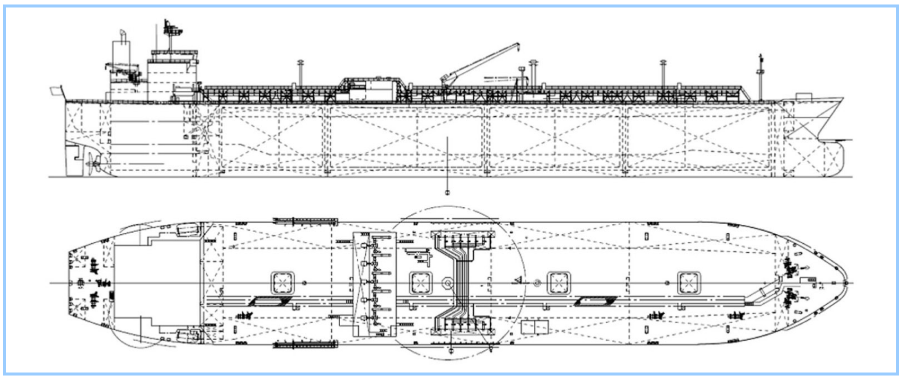


Figure 1 General arrangement of the newly developed LPG carrier with 83,000m^3 capacity

3.2 Structural design of Type B tanks

Verification of the reliability of prismatic tanks, which have to meet strict safety standards, is crucial and also entails technically difficult challenges. These challenges result from the fact that a prismatic tank with a stiffened plate structure has a much longer total weld-length than a spherical tank, the internal structure is complicated and there are many structural discontinuities and that a precise understanding of tank behavior under extreme wave conditions including the interaction between the tank and the hull is necessary because prismatic tanks are not welded on the tank support systems for thermal-contraction reasons.

The IMO Type B is one category of tank that complies with the safety requirements for liquefied gas carriers (IGC code) established by the International Maritime Organization (IMO). For this type of tank, fatigue and fracture mode analyses should be precisely conducted for the stress on each section of the structure, which can be accurately determined using an advanced analysis technique. In addition to the evaluation of fatigue crack initiation life, a safety assessment based on behavior prediction is required in the event that a crack is initiated and propagated. To meet the strict requirements, the Direct Loading Analysis Method (MHI-DILAM), which is a proprietary integrated wave load and strength analysis simulation system, is applied to the design for a highly-reliable tank structure. **Figure 2** is a flowchart of the Type B tank design process.

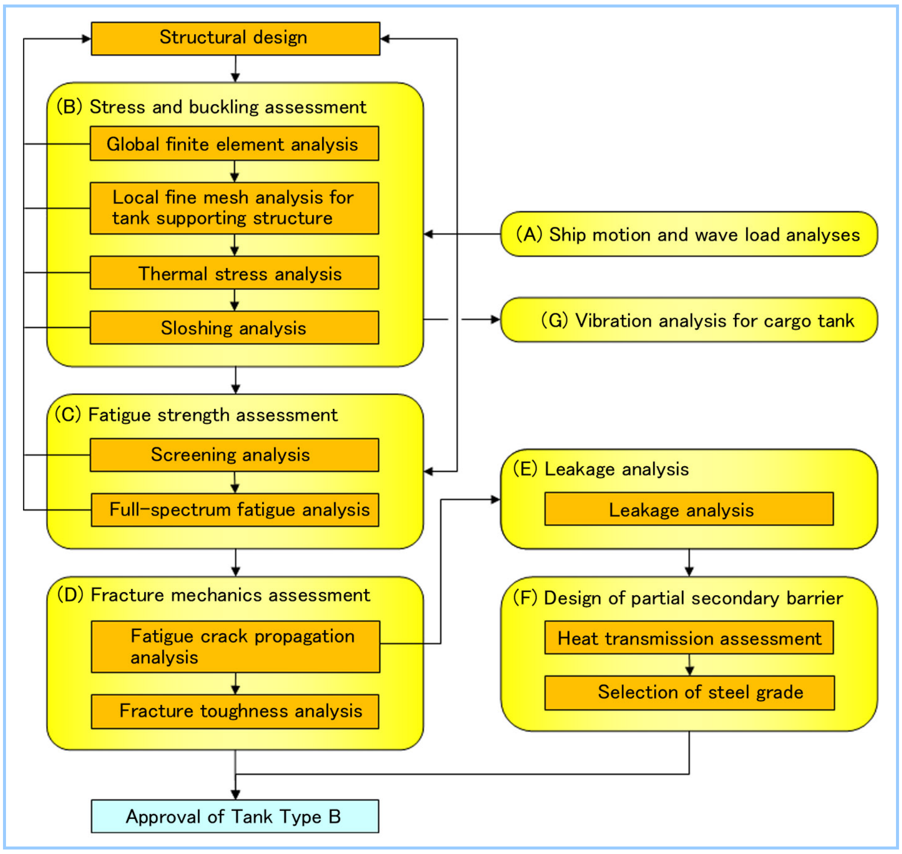


Figure 2 Design flow chart of Type B cargo containment system

Further to ship motion and wave load analyses, which are essential for direct loading analysis, a stress and buckling assessment is performed. Here, MHI-DILAM reproduces the extreme conditions that occur roughly once every 25 years in the North Atlantic Ocean regarded as the world's most severe marine meteorological condition. The Finite Element Analysis Method (FEM) is used to evaluate the structural response under the extreme conditions (**Figure 3**). It is noteworthy that MHI-DILAM sufficiently evaluates the complicated behavior of the tank supporting structure (which sandwiches resin blocks between the hull and tank) of a prismatic tank. In the structural design process of an independent prismatic tank, it is essential to know the complicated interaction between the tank and the hull. In that process, non-linear effects such as the reaction forces of the supporting system or the frictional forces on the resin blocks, which vary with the contact conditions, have to be taken into account. Non-linear FEM analysis using MHI-DILAM enables the faithful simulation of the behavior, and allows the design of highly rational and reliable tank structures.

Fatigue strength assessment with MHI-DILAM uses a two-phased approach, "screening analysis" and "hotspot analysis." The former uses a large-scale full ship FEM model, and the latter uses a local fine mesh FEM model. This approach verifies many of the structural discontinuities of a prismatic tank without omission, and correctly identifies the critical locations among structural members. Then, the fatigue life is accurately evaluated by full spectrum analysis (**Figure 4**).

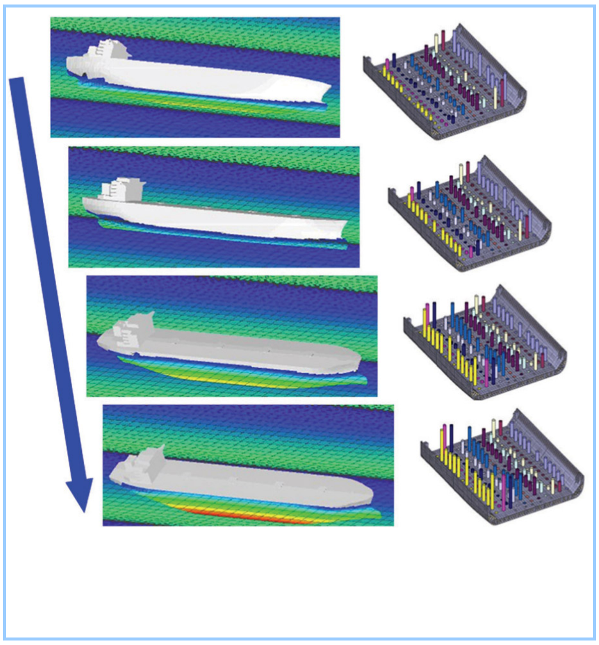


Figure 3 Simulation of ship motion and structure response under extreme conditions

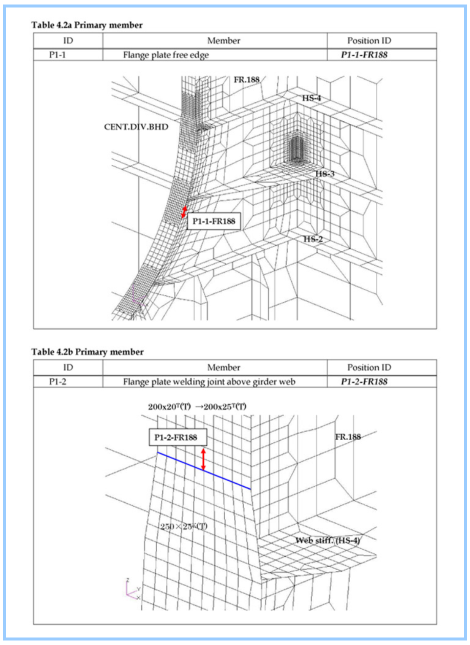


Figure 4 Example of hot spot analysis

In the fracture mode analysis, the stress field around a crack tip was calculated based on detailed analysis results obtained from MHI-DILAM, and the propagation was simulated by predicting its path and growth rate (**Figure 5**). In the leak analysis, leakage from a micro crack is estimated from the stress fluctuation around the crack in order to verify that LPG leakage can be detected and the gas can be stored safely over 15 days as required by the IGC code. These analyses enable the design of highly-reliable tanks that meet the IGC code requirements in all locations inside the cargo tanks.

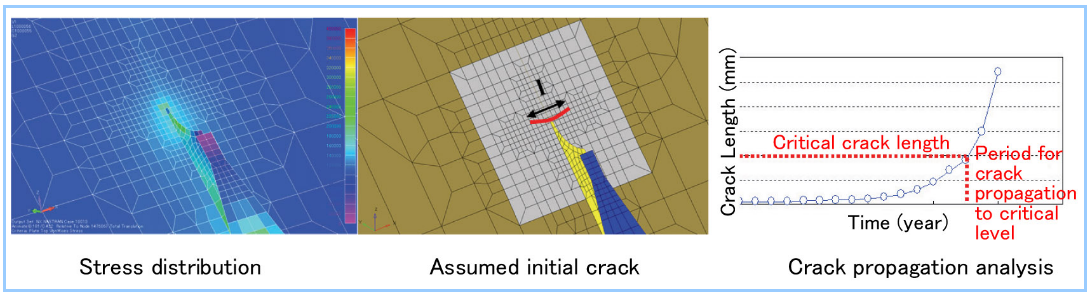


Figure 5 Simulation of fatigue crack propagation

Through the fatigue analysis, etc., the detailed structural design of the new LPG carrier was improved based on a tank structure with a proven and trusted experience. For example, it has softer girder ends, better bracket shapes of the tank supporting structure and a lower stress concentration at the end connections of the longitudinals than its predecessors.

In addition, we quantitatively evaluated the damage risk of the structural members based on extensive and detailed reliability assessments through the screening and hotspot analyses described above. Based on the evaluation, we provide customers with guidelines describing priority inspection points. The installation of inspection platforms at such points ensures effective maintenance and inspection.

3.3 Secondary barrier

A Type A tank system has a complete secondary barrier covering the entire cargo hold, but a Type B tank system has a partial secondary barrier that is sufficient to contain only the envisaged cargo leakage. This newly developed LPG carrier has a partial secondary barrier covering the entire inner bottom plate and lower part of the hopper/stool plate to fulfill its functions under trim and heel conditions. The extent of the secondary barrier is determined based on quantitative evaluation considering liquid vaporization by heat ingress and the liquid storage capacity (15 days) with safety margin calculated as the ratio between the allowable leak rate and the design leak rate from the fracture mode analysis. Where the hold bottom is trapezoidal in shape at the forward and aft end of the cargo hold, the secondary barrier is designed assuming that the leakage will accumulate there under heel condition. The secondary barrier of this newly developed tank is made of low temperature steel in accordance with the IGC code, and the extent of the secondary barrier is much smaller than a conventional complete secondary barrier. **Figure 6** is an outline view of the partial secondary barrier.

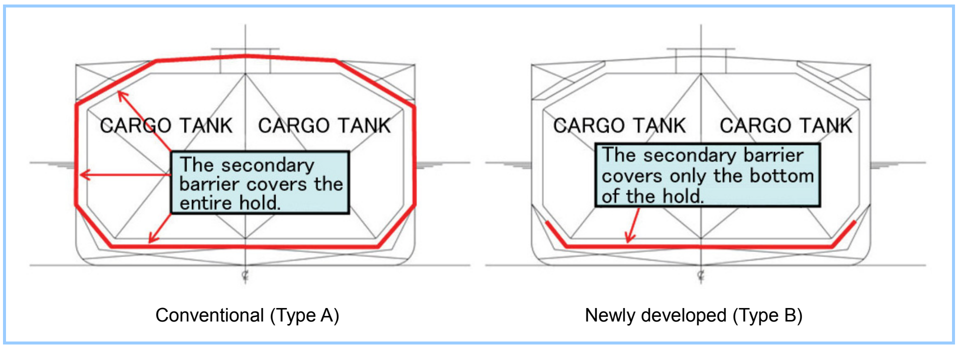


Figure 6 Comparison of secondary barriers

3.4 Thermal insulation of tanks

The thermal insulation system of the Type B tank is the same as those found in conventional Type A tanks, but some modifications have been made to its forming-in-place method. In the case of a Type B cargo containment system, it is necessary to provide a function to lead the leakage to the secondary barrier and prevent leakage from spraying (spray shield) so that the hull structure outside of the secondary barrier is not exposed to low temperatures. In the forming-in-place method, the insulation firmly bonds with the tank skin due to its self-adhesion mechanism. Hence, this method requires a mechanism to lead the leakage to the secondary barrier after cracks occur. This newly developed tank has leakage channels called “leak paths” on the surface of the tank as the mechanism. The performance of the leak paths and validation of the spray shields were tested in the presence of the classification societies. As a result of the test, it was confirmed that the insulation system satisfies the required leak rate and functions properly as a spray shield.

3.5 Approval from classification societies

During the design concept phase (2009), “Approval in Principle (AIP)” was obtained from three organizations: the American Bureau of Shipping (ABS), Lloyd's Register of Shipping (LR) and Nippon Kaiji Kyokai (NK). During the basic design phase, “General Approval” was obtained from the above three organizations in 2010, and “Concept Approval” was obtained from USCG in 2012.

4. Benefits of LPG carriers with Type B tanks

Type B tank provides the following main benefits for LPG carriers:

(1) Highly reliable tank: Detailed analyses have proven sufficient safety performance and the risk of fatigue damage is very low.

(2) Easy and effective maintenance: As the inspection guidelines showing the specific area to be checked enable effective and consistent maintenance after entering service, it is possible to sustain structural reliability during the ship lifetime.

(3) Low maintenance cost: A conventional cargo hold is entirely made of low temperature steel, but the cargo hold for a Type B tank is made of ordinary steel excluding the bottom area, which works as the partial secondary barrier. As a result, maintenance or repair is easy if the hull is damaged from contact with pier fenders or tug boats, or if the top side tanks are damaged by corrosion.

As it is considered that future trade routes will be changed from the conventional trade pattern between the Middle East and Asia to diversified transport routes due to the growing LPG consumption in emerging countries and the growing production of associated gases from natural gas and shale gas fields, high reliability in cargo systems and easy maintenance become significant benefits in selecting and arranging repair yards and materials.

While the hold space is normally filled with inert gas, dry air can be used as a substitute for Type B tank systems with certain equipment. This also leads easy inspections, low CO_2 emissions and low fuel costs for producing the inert gas during a voyage.

5. Conclusion

We have developed an LPG carrier with a Type B tank system based on our technical expertise on independent prismatic tanks accumulated through the construction of many LPG carriers over a half century, as well as design and analysis technology on Type B tanks acquired through the development of MOSS-type LNG carriers. This newly developed tank will certainly meet customer needs for a high level of safety and high economic efficiency in diversifying LPG trading styles. The tank has already been installed in an LPG carrier delivered in 2012, and further sales activities are under way. We will continue to supply high-quality LPG carriers and pursue technological development to meet various customer needs, including high environmental performance and easy maintenance.

References

1. Koichi, S. et.al, MHI-DILAM (Direct Loading Analysis Method)- An Advanced Structural Analysis Method for Ships and Offshore Structures -, Mitsubishi Heavy Industries Technical Review Vol.47 No.3(2010) pp.65-72