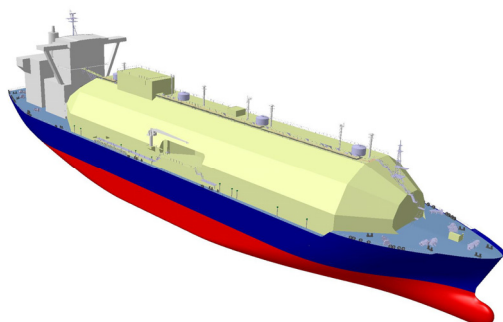


Sayaendo

- New Generation LNGC with Continuous Integrated Tank Cover -



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Spherical tank liquefied natural gas (LNG) carriers have been praised for their tank system, which has a reliable configuration and provides sloshing resistance, making it appropriate for use in areas with severe environmental conditions such as the North Sea and areas near the Arctic Ocean. This paper describes “Sayaendo”, an improved LNG carrier that has a spherical cargo containment system and a continuous tank cover integrated with the hull. Sayaendo was developed using the latest simulation technologies from Mitsubishi Heavy Industries, Ltd., (MHI), including a structural analysis system. The results indicated that the proposed carrier exhibits the level of reliability specific to spherical tank LNG carriers, and the carrier has been confirmed through various technological evaluations to be convenient for upgrading of tank volumes and implementing measures against cold environmental conditions.

1. Introduction

In recent years, gas field developments have been planned in cold regions and icefields near the North Sea. Spherical tank liquefied natural gas (LNG) carriers are attracting attention as means of transportation from these regions. Spherical tanks are very reliable because their shape is so simple, and they have been evaluated as the most appropriate tank system for use in areas with severe wave conditions such as North Atlantic and icefields. This type of LNG carrier has large spherical tanks (around 40m diameter) that project above the upper deck and are protected by covers. Therefore, the design of the tank covers plays an important role in deciding the layout, performance, and structural design of the carriers. Mitsubishi Heavy Industries (MHI) combined a cylinder and a hemisphere to develop a tank cover with high structural reliability, this is currently used in a number of carriers, including the LNG carriers of the North West Shelf Australia Project.¹

On the one hand, we evaluated the idea of integrating the tank cover with the hull for optimal distribution of hull steel weight and to increase the tank volume within the limited principal dimensions (**Figure 1**).

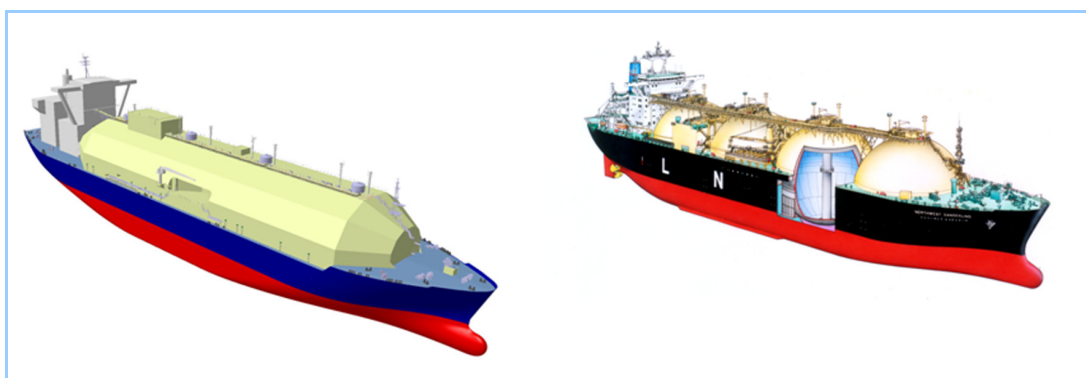


Figure 1 Comparison of a continuous tank cover and a conventional tank cover

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An integrated hull/cover structure that uses a continuous tank cover is nicknamed Sayaendo because it resembles peas in a pod, with spheres (“endo” or “peas”) in a continuous cover (“saya” or “pod”). The structure, which was developed through the technological studies explained below, yields benefits that are not possible with conventional structures and are particularly suitable for use in large LNG carriers and LNG carriers in cold environmental conditions and icefields.

2. Characteristics of the Sayaendo

2.1 Development concept: Advantages of Sayaendo

(1) Light and compact

In Sayaendo, spherical cargo tanks are covered by a continuous cargo tank cover. This can help minimize the main dimensions and reduce the hull steel weight by about 10% because the continuous structure allows the tank cover to be used as hull reinforcement material. Use of this tank cover can also improve the fuel economy by reducing displacement, and improved compatibility with terminals is also possible. **Table 1** compares the main dimensions, using a 165,000 m³ (165 km³) tank as an example.

Table 1 Principal dimensions of an LNG carrier with a continuous tank cover

	Sayaendo	Carriers with conventional spherical tank cover (reference)
Cargo Capacity (m ³)	165,000	
Loa (m)	290	295
Lpp (m)	277	282
B (mld.) (m)	50.4	50.8
D (mld.) (m)	23.0	27.5
d design (m)	11.5 (mld.)	11.5 (mld.)

(2) Improved compatibility with terminals

When spherical tank LNG carriers incorporating conventional tank covers are enlarged, the carrier depth must be increased to ensure structural strength, this degrades compatibility with gangways and loading arms that connect to terminals. In Sayaendo, the continuous tank cover acts as a reinforcement material and contributes to structural strength, substantially reducing the depth of the carrier. We researched the heights at which gangways and loading arms connect to major terminals in Japan and abroad, and positioned an additional gangway platform and the cargo manifold at optimal heights, which remarkably improved compatibility with terminals. **Figure 2** shows the ratios of compatibility with gangway and manifold heights at major terminals worldwide (based on data from MHI). The data revealed that for 165 km³ carriers, conventional tank cover carriers had a compatibility ratio of approximately 80%, while Sayaendo had a compatibility ratio of almost 100%.

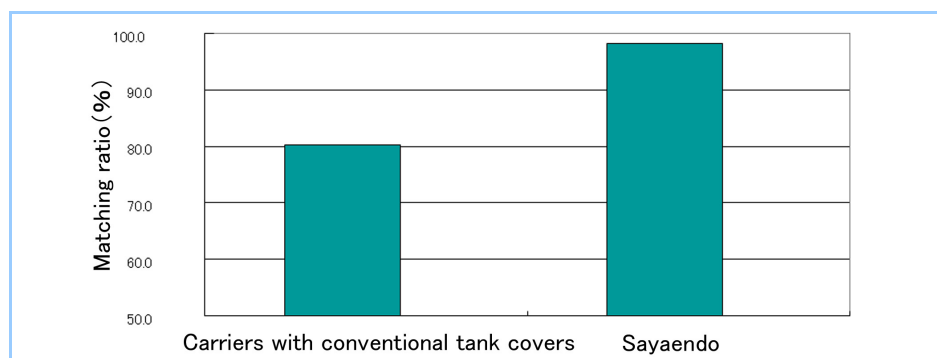


Figure 2 Comparison of compatibility with terminals: 165,000 m³ LNG carriers

(3) Improved flying passage structure

In carriers with conventional tank covers, the mechanism for running cargo and gas pipes and electrical wires (commonly called the flying passage) are located above the tank cover. The support structure for the flying passage is complicated and is generally located in a high position, so maintenance can be an issue. However, in Sayaendo, pipes and wires can be located on the continuous tank cover so support is not required, thereby improving maintainability.

2.2 Development of a prototype carrier

A 165 km³ prototype carrier (see the principal dimensions in Table 1) was developed based on the concept described above. In the first step, a hull form was developed to maximize the light and compact characteristics of Sayaendo. Next, ship model tests in an experimental tank were conducted to confirm the propulsion performance. The next step was creating primary drawings of the hull structure and then preparing general layout plans of the cargo hold part and a mooring arrangement of the fore and aft areas of the deck. CATIA (a 3D computer-aided design program) was used for this layout design and new layouts were carefully examined, an example is shown in **Figure 3**. After careful review, these layouts and communications were confirmed as appropriate for areas on the tank cover and the deck as well as areas inside the hold. The layout of the ballast tanks and main structural components on the hull are also optimized taking the characteristics of Sayaendo into account.

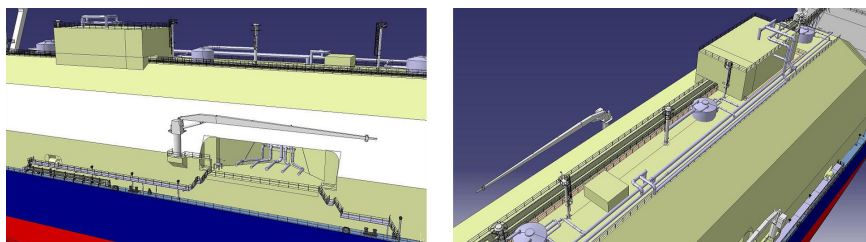


Figure 3 Example of a layout review using 3-D model

2.3 Application to cold regions/icebreaking LNG carriers

Sayaendo appears to be suitable for use in cold regions and icefields because it is based on an independent tank system, in which shell plates are susceptible to deformation caused by contact with ice blocks, etc. It also reduces the exposure of supports and equipments, and its overall strength is effective in resisting ice impact loads.

Figure 4 shows an icebreaking LNG carrier. Calculations were carried out to simulate a collision with an iceberg to confirm the safety of the tanks (**Figure 5**).



Figure 4 An icebreaking LNG carrier

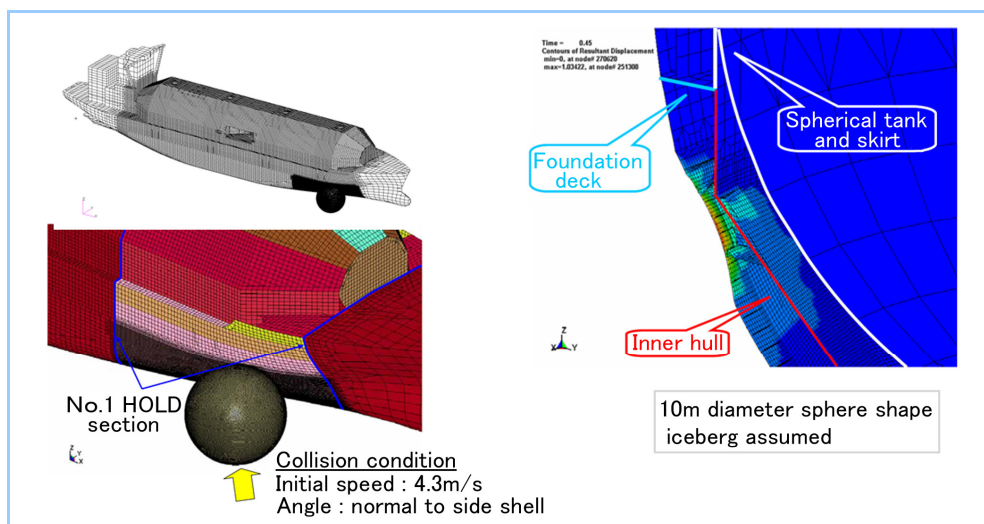


Figure 5 Tank safety assessment against iceberg collision

3. Technological Evaluation

3.1 Evaluation of structural strength

The conventional tank cover used by MHI is a combination of a cylinder and a hemisphere. This shape was developed to minimize the interaction force between the cover and the hull, utilizing the cover's flexibility to improve reliability.¹ In this kind of conventional structure, the structural design is simple and reasonable, but the cover weight contributes only a little to the overall strength (although it contributes greatly to torsion rigidity).

In Sayaendo, the cover is integrated with the hull, and the steel weight can be reduced by optimizing the steel layout of the hull and the cover as a whole. Due to its novel design, we carried out the following evaluations:

- (1) Whole ship FE (Finite Element) analysis using direct wave load calculations, and
- (2) Strength analysis of tank covers itself.

For the first study, we evaluated the structural reliability using MHI-DILAM, an advanced structural analysis program developed by MHI.² Figure 6 shows an example of the structural analysis using MHI-DILAM. For the second study, we evaluated the strength of the cover itself, as well as the buckling strength of the plates and members at the top of the cover, and the fatigue strength of the joints between the hull and the cover. The results indicated that the cover was sufficiently reliable.

In addition to these evaluations, we conducted structural strength assessment according to the guidelines set out by major classification societies (LR and DNV), these results also confirmed that the product is satisfactory.

3.2 Layout safety evaluation and risk assessment

Due to the novel design of Sayaendo, we held discussions about the safety of the layout with major classification societies, and obtained an approval in principle (AIP) from LR, DNV, NK, and ABS. We also conducted a risk assessment of the layout around manifolds to ensure safety of the new layout. In Sayaendo, parts of the manifolds and related pipes are located under the cover (Figure 7), this is preferable for operation in cold regions, but the layout requires careful evaluation with regard to adequate ventilation, gas detection, firefighting capability, etc. The safety of these new arrangements required an objective evaluation, and we carried out a brainstorming session using the hazard identification (HAZID) method under the supervision and instruction of Lloyd's Register (LR). Based on the accidents under consideration, the results indicated that the structural safety of Sayaendo is equivalent to or better than that of conventional designs.

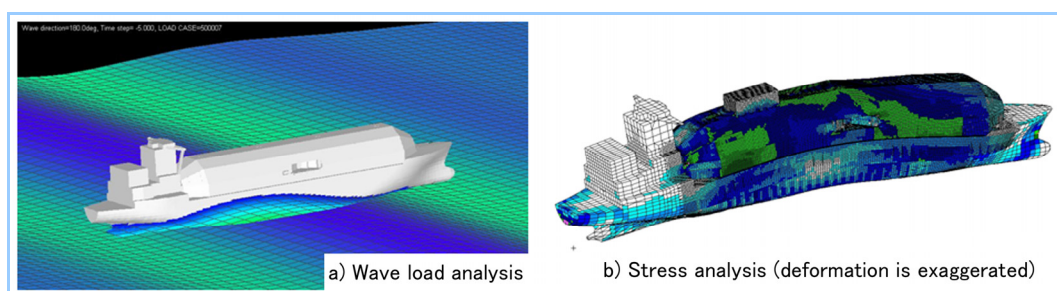


Figure 6 Stress analysis with direct wave load using MHI-DILAM

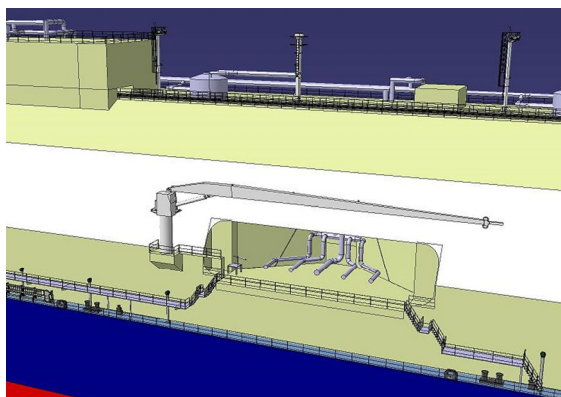


Figure 7 Manifold layout in Sayaendo

3.3 Maneuverability simulation

Maneuverability in harbors is an important aspect of LNG carrier performance, because insufficient controllability could cause serious damage to the terminal facility, possibly even leading to closure of the terminal. When carriers are enlarged, maneuverability in harbors generally worsens due to the increased wind pressure. Detailed validation was required for Sayaendo in particular, because the windage area is wider compared to carriers with conventional spherical tank covers. Therefore, wind-tunnel tests were conducted using a detailed model. The results revealed that the wind pressure coefficient was substantially reduced for head-on winds ($\beta = 0^\circ$) due to the effect of the continuous cover, and the coefficient for cross-winds ($\beta = 90^\circ$) was approximately the same as that for carriers with conventional covers.

The maneuverability simulation was outsourced to a third party, Japan Marine Science, Inc. The simulation was carried out by a shipmaster license holder using a maneuver simulator that incorporated the wind pressure characteristics confirmed by the wind-tunnel tests and the influence of tides. The simulation confirmed that the carrier had a maneuverability equivalent to that of carriers with conventional tank covers. The simulation was based on a 177-km³ LNG carrier, which is the largest of the expected spherical tank LNG carriers. **Figure 8** illustrates the simulation.

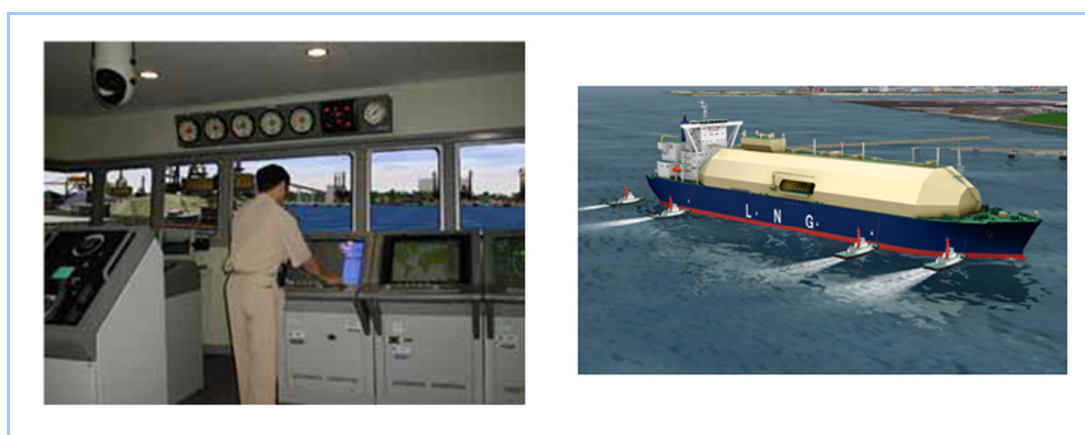


Figure 8 Maneuvering simulation

3.4 Evaluation of environmental performance

Sayaendo is expected to produce less CO₂ emissions compared to carriers with conventional tank covers, due to its reduced use of materials and fuel. We have also developed a plan for the next-generation carrier, which is based on Sayaendo but is mounted with an energy-saving ultra steam turbine plant. At our request, the National Maritime Research Institute (NMRI) carried out a life cycle assessment (LCA) to determine the CO₂ emissions generated by the carrier throughout its lifetime, including its construction, navigation, and demolition. This evaluation was done using the NMRI's "LCA software for ships," and incorporated the propulsion performance during navigation and energy consumption during each operation mode, including cargo handling, as well as the energy consumption during BOG treatment, shipbuilding, and demolition. **Table 2** lists the preconditions and evaluation results, CO₂ emissions from a 165 km³ Sayaendo would be approximately 24% less than emissions from a 147-km³ carrier with conventional tank covers.

Table 2 LCA conditions and evaluation results

Operation period	30 years			
Course	Japan – Western Australia			
Service speed	19.5 kt			
Dock period	25 days / 2.5 years			
Non-operational days	Not specified			
Cargo capacity	147,000 m ³	165,000 m ³	165,000 m ³	165,000 m ³
Tank cover shape	Conventional tank cover	Conventional tank cover	Conventional tank cover	Sayaendo
Main engine	Conventional steam turbine	Conventional steam turbine	Ultra steam turbine	Ultra steam turbine
CO ₂ emission index	100	84	80	76

4. Conclusion

This paper described Sayaendo, a new type of carrier that features a continuous cover integrated with the hull and a reliable spherical tank system, which can be suitable for enlargement and is appropriate for use in cold regions. The advantages of Sayaendo were confirmed through various technological evaluations. Sayaendo was developed using MHI's advanced simulation technologies, including whole ship FE analysis using direct wave load calculation technology, safety evaluation technology, and performance evaluation technology, and it exhibits good environmental performance. We will continue to develop and improve the system, responding to the diverse needs of LNG transportation, and we plan to promote commercialization of the product.

References

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