

DESIGN OF THE EVOLUTIONARY LNG CARRIER “SAYAENDO”

Koichi Sato

Mitsubishi Heavy Industries (MHI), Ltd. Japan

Henry Chung

Lloyd's Register Group Limited (LR) Yokohama Design Support Office, Japan

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ABSTRACT

MHI has completed the development and received firm orders for a new-generation LNG carrier design marking an evolutionary advance for LNG carriers adopting the Moss-Rosenberg cargo containment system well proven for robustness and reliability.

The product name SAYAENDO, or peapod in Japanese, aptly describes the continuous weather cover for the cargo tanks that is integrated with the ship's hull, constituting a visual and conceptual distinction from the ubiquitous hemispherical covers found on conventional Moss LNGCs. This new configuration benefits from greater structural efficiency thus enabling size and weight reductions, resulting in improvements in fuel consumption and operating economies.

This paper presents how state-of-the-art engineering verification methodologies were applied to validate the new design to meet the stringent technical, regulatory and safety requirements of the LNG shipping industry, as well as the design of SAYAENDO itself.

Firstly, structural design analysis using MHI-DILAM is described. MHI-DILAM is an advanced structural assessment approach developed by MHI, applied to verification of yield and buckling limit states with design waves and full stochastic analysis for fatigue strength performed on a whole ship model incorporating loads derived from first principles direct calculations.

Secondly, independent structural design verification as part of classification requirements or in support of optional enhanced notations is described, giving insight into the SAYAENDO's unique hull concept highlighting those aspects that were considered as part of the validation of the overall design and safety philosophy.

Examples of how risk assessment methods were employed to evaluate unconventional arrangements are also introduced.

Finally, the main characteristics of 155k-m³ LNGC are described, this being the finished product resulting from the development. Suitability of SAYAENDO to ice and cold operations is also briefly discussed.

INTRODUCTION

Mitsubishi Heavy Industries, Ltd., (MHI) has built forty-two LNG carriers since delivery of its first in 1983, with cooperation of the leading Classification Societies such as Lloyd's Register (LR). While safety, reliability, and economic efficiency of LNG carrier technologies are constantly being advanced through the design and construction process, the recent rise in LNG demand as well as emerging global shifts in LNG trading pattern has generated increasingly diverse customer needs for shipping and marine products in the LNG supply chain.

The cargo capacity of LNG carriers (LNGC) was about 70,000 m³ when LNG was first introduced in Japan in the late sixties. The capacity steadily progressed to 125,000 m³, 137,000 m³, and then to 147,000 m³ and larger as operational experience was gained and the need for improved economic efficiency became a priority.

LNG tankers with a capacity in excess of 200,000 m³ have now been built for specific projects. The transportation cost per unit cargo decreases with larger capacity; however, this single aspect must be balanced with design and engineering prudence and consideration for greater trading versatility.

With this as background, MHI has developed a next-generation spherical tank LNG carrier with a continuous tank cover, nicknamed SAYAENDO, meaning “peas in a pod”. Whereas a conventional spherical tank carrier is equipped with hemispherical-shaped domes above the weather deck protecting each tank as separate structures, SAYAENDO has a continuous structure protecting all tanks, and this structure is fully integrated with the main hull.

The continuous tank cover significantly contributes to the overall hull strength. It also allows more optimal layout of steel needed to maintain strength thus enabling more compact ship dimensions. Such structural characteristics made possible a reduction in the hull steel weight over a conventional design of the same cargo capacity thus achieving improved fuel consumption due to reduced displacement, better terminal compatibility, and improvements in safety, reliability and maintainability. These advantages also make the SAYAENDO design ideally suited for a large spherical tank LNG carrier. The continuous tank cover also removes the need for complex arrangements that support tank-top piping, cables and passages, thus contributing to improved maintenance. Other merits inherent to the SAYANEDO, such as reduced exposure of supporting structures and outfitting, and higher protection to maintain global strength and cargo tank integrity against ice impact loads, also make the new design uniquely suited for operating in cold regions and in ice-bound seas.

OBJECTIVE OF THE PAPER

This paper presents how state-of-the-art engineering verification methodologies were applied to validate the new design to meet the stringent technical, regulatory and safety requirements of the LNG shipping industry, as well as the design of SAYAENDO itself.

In the following sections, the motivation behind the introduction of the new design is explained. Being the key component in the development narrative, structural analysis methods of both the designers and the Classification Society are explained forming the central part of this paper.

DEVELOPMENT HISTORY

History of MHI MOSS LNGC and tank cover design

Figure 1 shows the design evolution of MHI’s spherical tank type LNG carriers.

In MHI’s history of building spherical tank type LNGCs, the development of “second generation LNG carrier concept” was considered epoch making when a lower boil-off rate (BOR) with a forcing vaporizer system and flexible type tank cover were introduced.

Spherical tank type LNG carriers have large spherical tanks (typically around 40m diameter) that project above the upper deck and are protected by large steel covers. Being such prominent structures, the design of the tank covers plays an important role in deciding the layout, performance, and overall structural design of the carriers.

In the second generation design, MHI developed a tank cover with improved structural reliability by combining a cylindrical base with a hemispherical dome. The concept of this design is to reduce the interaction force between main hull and tank cover arising primarily from hull girder response. This tank cover design has been adopted in a number of LNG carriers including those for the Australia North West Shelf Project. This flexible tank cover is considered optimum from a structural sense in case the tank cover height is not large with respect to the height of the main hull (i.e. ship’s depth).

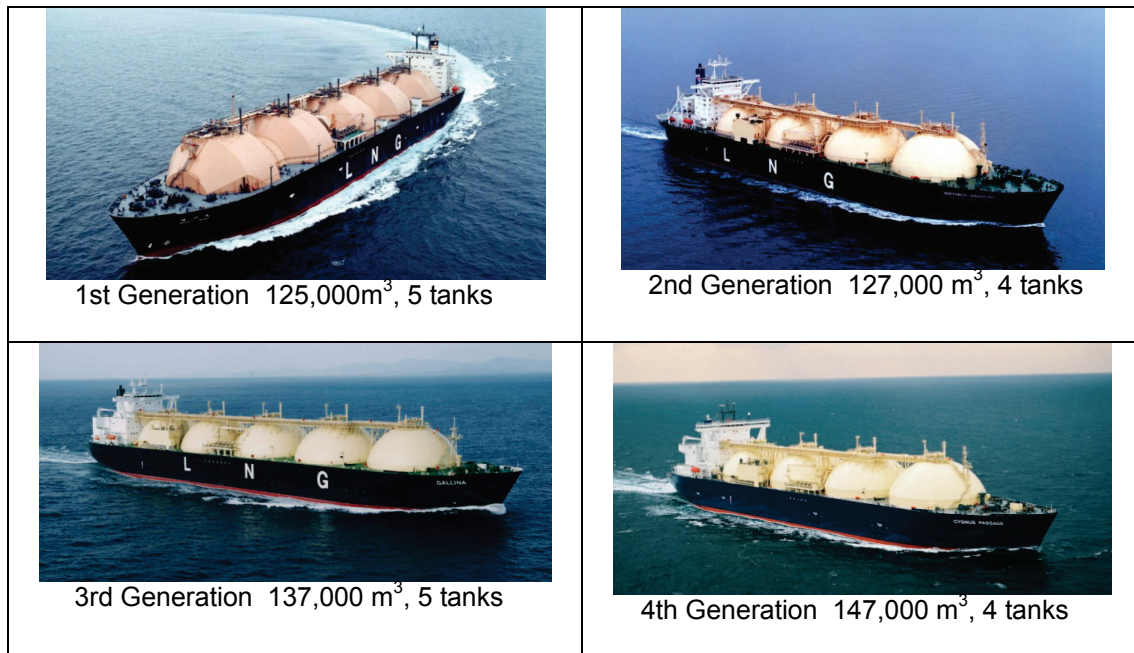


Figure 1. History of MHI MOSS LNG Carrier

Background of the development of SAYAENDO

The second generation LNGC started with 125 k-m³ capacity. On the other hand, today's standard design is 147 k-m³ or bigger. Figure 2 shows comparison between the second generation LNGC and a 155 k-m³ LNGC with conventional tank cover and stretched cargo tanks. While the ship depth (extent of main hull) is kept due to terminal compatibility, height of tank cover is increased due to increase of capacity.

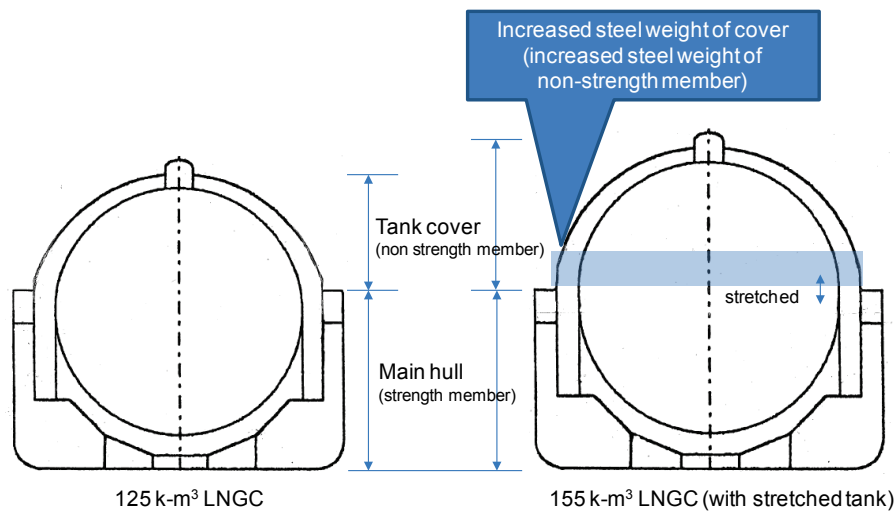


Figure 2. Proportion of Tank Cover against Main Hull

Although conventional tank cover is feasible for larger vessels with suitable design considerations, the tank covers represent a significant portion of the steel weight which does not contribute to global hull girder strength. Recognizing that conventional tank covers may not be optimally utilized as structural members when the vessel's capacity is getting larger is the key motivation behind MHI's evaluating the feasibility of integrating the tank cover with the main hull structure as shown on Figure 3.

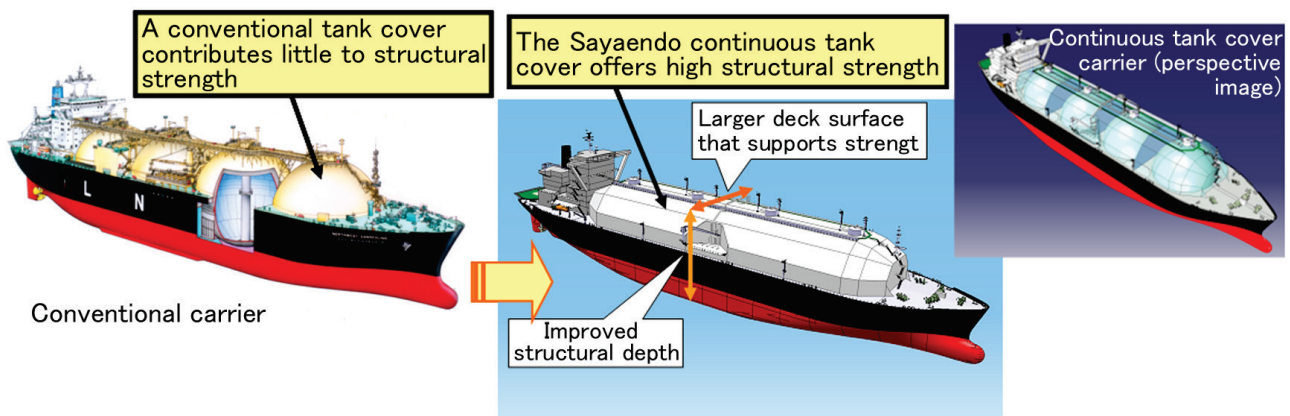


Figure 3. Conventional/Continuous Tank Cover Comparison

According to the study by MHI, for a ship of more than 147 k-m³ capacity, the integral tank cover can reduce total ship's steel weight by 5-10%, depending on particular ship dimensions.

To bring this concept of the integrated tank cover design to commercial reality, MHI and Aker Arctic Technology Inc. (AARC) concluded a patent license agreement in June 2008. MHI has now successfully developed this concept to a finished product in the SAYAENDO.

Concept and overall configuration of SAYAENDO

The name SAYAENDO, which means peas in a pod in Japanese, derives from the vessel's appearance, featuring spherical tanks ("endo" or "peas") in a continuous cover ("saya" or "pod"). In conventional LNG carriers, the upper portion of the spherical tanks above the ship's upper deck is protected by a semispherical cover and the lower portion under the upper deck is supported by a cylindrical skirt structure. In contrast, the SAYAENDO employs a continuous cover, integrated with the ship's primary strength members, to house all tanks "under one roof" while maintaining the necessary compartment divisions, thus contributing to the overall structural strength and enabling hull weight reduction.

Furthermore, in conventional LNGCs, piping, electric cables, and passages atop the tanks are supported by complex structures. The new design makes such complex supporting structures unnecessary, thus improving maintainability. The continuous cover also improves aerodynamics by substantially reducing head wind force, which serves as a drag on the ship's propulsion, contributing to reduced fuel consumption during actual operations at sea.

Figure 4 shows the overall configuration of the SAYAENDO. The characteristics of the layout are described below.

Four cargo tanks are arranged entirely under one continuous cover, with the inside consisting of four hold areas designated for each tank. Loading/unloading manifolds are placed in recessed areas made on each side of the cover between the second and third holds. Piping and electric cables are located at the flat section on the top of the continuous tank cover, improving accessibility and maintainability. Furthermore, a portion of space between the third and fourth holds integrated into the cover is designated as a cargo machinery room, thus realizing operational benefits of improved visibility, aerodynamics and navigability with the benefit of being aesthetically pleasing.

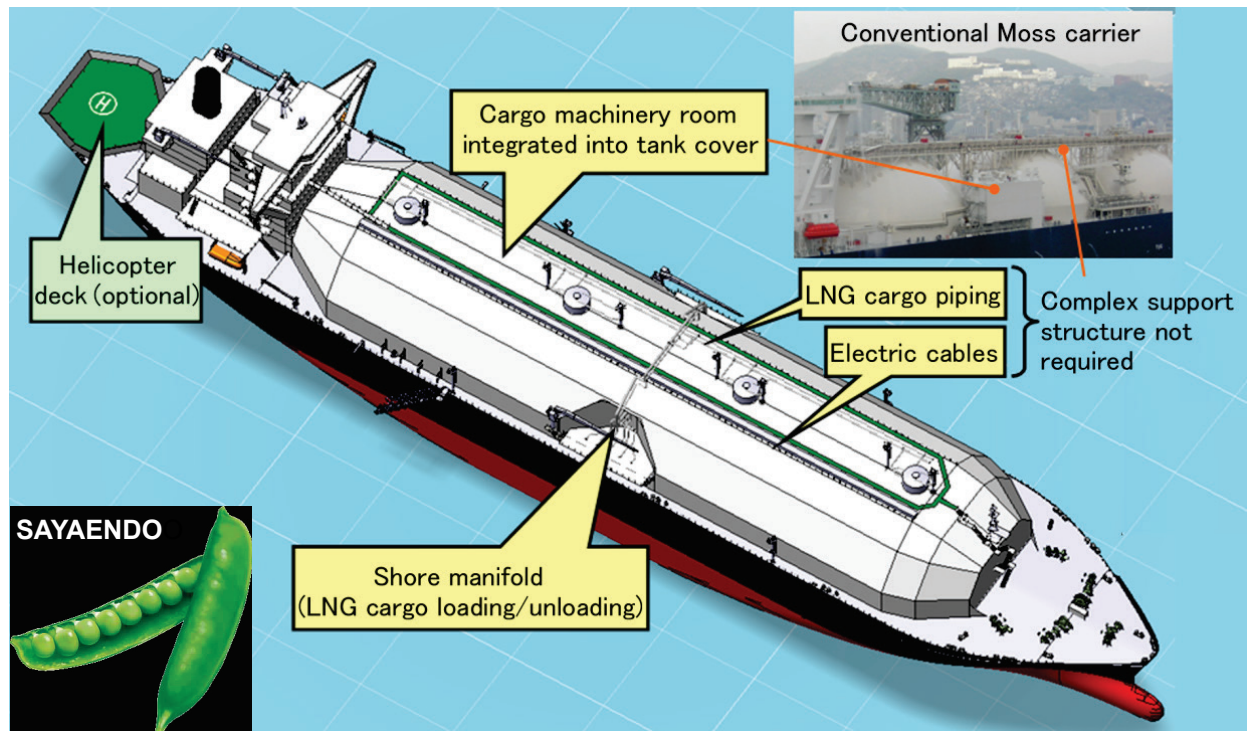


Figure 4. Overall Configuration

Key factors in development

When the concept of the integrated tank cover was being developed into a viable ship design, several key design considerations were identified and addressed as follows.

— Structural design and assessment

Different aspects were carefully reviewed and assessed by the latest structural analysis methods with the findings fed back into the design process and any resulting alterations re-validated, for example,

- Longitudinal strength assessment
- Detail connection design
- Tank cover and main hull connections including fore and aft ends
- Interaction between cargo tank and hull
- Fatigue assessment for structural detail

— Aerodynamic assessment with wind-tunnel tests

Due to the SAYAENDO's unique form, wind force analysis was required to accurately compare the operational characteristics of the SAYAENDO and a conventional carrier with semi-spherical covers. The results of wind-tunnel tests using a detailed model revealed that the wind force coefficient of the SAYAENDO was substantially reduced for headwinds due to the effect of the continuous cover, while the coefficient for side winds was comparable to that of the conventional carrier.

— Maneuverability simulation and mooring analysis

Maneuverability in harbors is an important factor in the operational safety of LNG carriers. Due to the SAYAENDO's increased lateral profile area compared with that of a conventional carrier, a detailed study was conducted to verify its maneuverability.

The maneuverability study was tasked to a specialist third-party institute. Applying the wind force characteristics confirmed by the wind-tunnel tests and the influence of tides, several simulations were conducted, including ship berthing and un-berthing exercises by an operator with a shipmaster's license using a ship simulator and computer simulated turning by tugs and course keeping in strong wind. The results confirmed that the SAYAENDO has a maneuverability equivalent to that of a ship with conventional tank covers. Furthermore, based on the analysis of the SAYAENDO's wind force characteristics, optimal mooring arrangements at terminals have been determined.

Regarding the structural design considerations, the proposed measures have been validated with state-of-the-art and benchmarked structural assessment methods as explained in the following sections.

MHI-DILAM: ADVANCED STRUCTURAL ANALYSIS METHOD

Concept of MHI-DILAM

MHI-DILAM is an advanced structural assessment approach developed by MHI, applied to verification of yield and buckling limit states with design waves and full stochastic analysis for fatigue strength performed on a whole ship model incorporating loads derived from first principles direct calculations.

Because ships and floating offshore installations are large-scale structures operating in environments with complex ocean waves, such complex loads must be efficiently processed to make possible the type of structural analysis needed for improved reliability of the design in respect of structural integrity expected by the industry and regulators today. Thus far, the structural design of ships has often been carried out using simplified "design loads". In practice, the use of the simplified design loads is established mainly as a tool where a relative comparison with existing structures can reliably be made. However, for the development of a new type of structure, or when manufacturing a product that exceeds the experience and scope of existing ones (e.g. a ship of unusually large size or different configuration), an analysis technique that can faithfully simulate the complexity of the wave loads is the preferred approach.

Although actual ocean waves are "irregular waves" with complex shapes, an irregular wave can be represented as a set of "regular waves". MHI-DILAM divides the wave cycle into 12 steps, and automatically generates an approximate total of 3,000 loads in snapshots (12 wave directions x approximately 20 wavelengths x 12 time steps) to obtain an accurate time history of the ever-changing wave loads. MHI-DILAM carries out the structural analysis of ships by processing these complex loads with the enhanced efficiency enabled by a specialized program as shown on Figure 5.

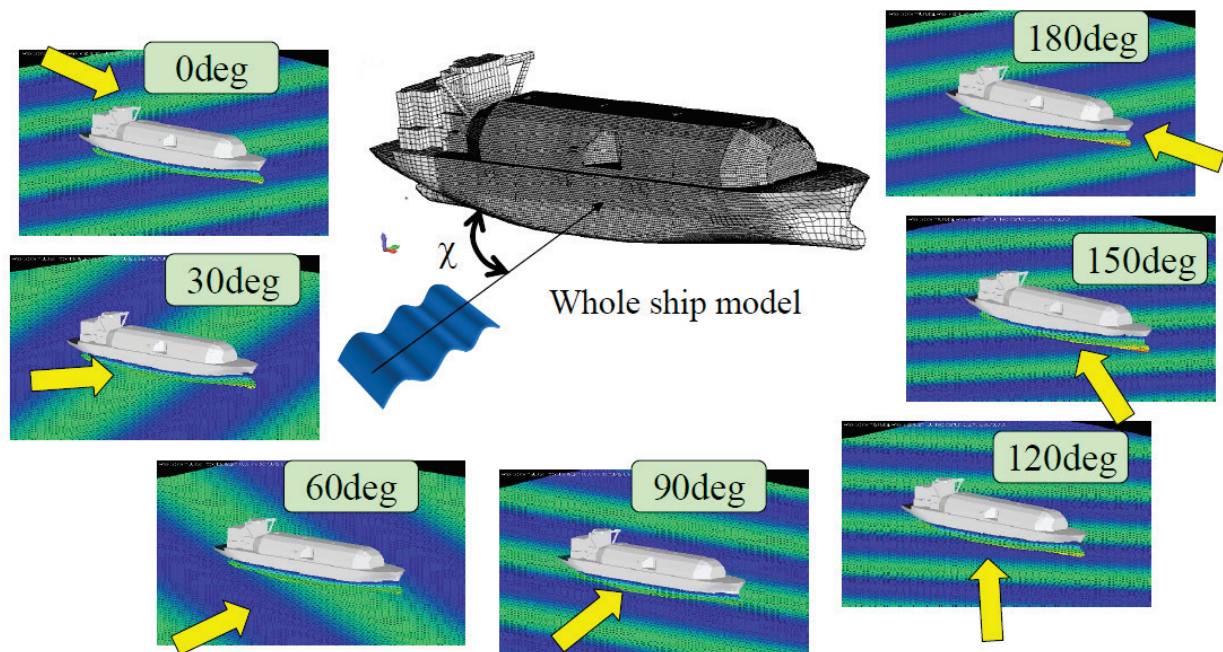


Figure 5. Combination of Regular Waves and Whole Ship FE Model

MHI-DIALM for design of SAYAENDO

For SAYAENDO, hull structural design analysis was carried out by the shipbuilder using MHI-DILAM as follows.

1. Structural analysis for yield and buckling criteria (Figure 6)
 - 35 dynamic wave load cases are applied. Examples of load cases are shown on Figure 6.
 - A whole ship FE Model is applied.
 - For wave load analysis, MHI's total system for prediction of Sea-keeping Qualities of Ships (MHI-DYNAS) is applied.
 - PULS (Panel Ultimate Limit State) buckling code is used for the buckling assessment. PULS is also incorporated in the IACS Common Structural Rules.
2. Full stochastic fatigue analysis (Figure 7)
 - 50 years of design fatigue life with wave scatter data derived from a world-wide LNG trading pattern is adopted as the design criteria of the standard design.
 - Response Amplitude Operator (RAO) of local stress is calculated by the full spectral direct analysis. A Flowchart of the fatigue analysis procedure is illustrated in Figure 7.
 - 16 kinds of representative structural details (corresponding to more than 300 locations) are selected as fatigue check points.

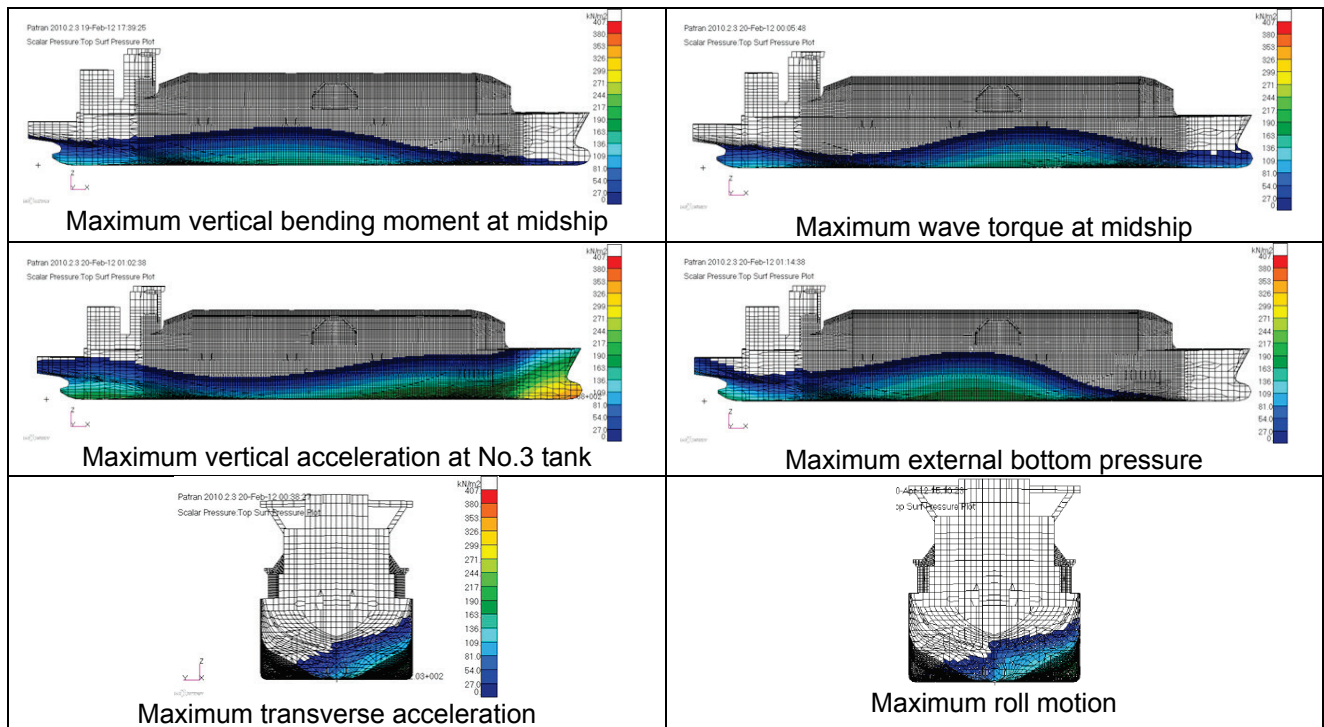


Figure 6. Yield and Buckling Analysis by MHI-DILAM
(examples of wave load cases among total 35 cases)

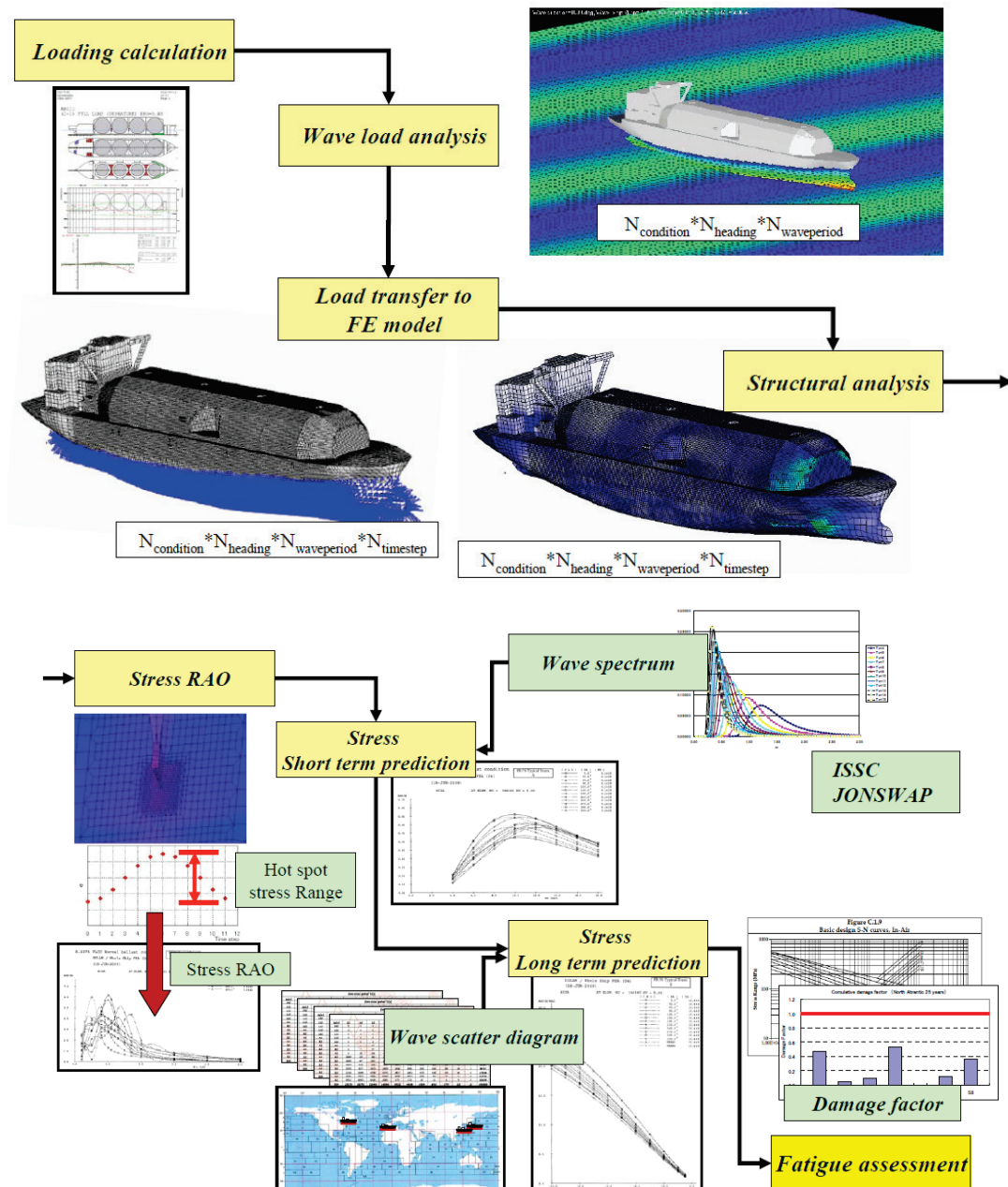


Figure 7. Full Stochastic Fatigue Analysis by MHI-DILAM

Conclusions from analysis by MHI-DILAM

Conclusions from results by MHI-DILAM can be drawn as follows;

1) Strength of tank cover and main hull

It is confirmed that the strength of the tank cover and its connection to hull is adequate for all limit states in all locations. In addition, with increased longitudinal bending strength because of the continuous cover, the stress ranges at the top of the cover and at the bottom are reduced by approximately 10% and 30-40% respectively relative to a conventional carrier, thus enhancing structural fatigue reliability of the longitudinal stiffener connections, as shown on Figure 8.

2) Comparison of hull / tank interaction force

Interaction between cargo tank system and hull structure is one of the technical key points of design of LNGC. The cargo tank support design of SAYAENDO has been derived from successive generations of MOSS LNGCs, but since there is some alteration in the structural arrangement around cargo tank system and hull girder system, interaction between cargo tank system and hull has been re-evaluated.

The continuous cover results in the neutral axis of the hull's longitudinal bending deformation being higher than that of a conventional carrier. In the design of SAYAENDO, the effect of hull flexure on the skirt structure is minimized by positioning the location of the base of the tank skirt (skirt's lower end) near the neutral axis, as with a conventional carrier. Figure 8 shows the relation between location of hull girder neutral axis and cargo tank connection. In SAYAENDO, the interaction force between hull and cargo tank system is 30% of the conventional type due to increased hull rigidity and the optimized skirt location.

3) Fatigue strength

50 years of design fatigue life fit for world-wide LNG trading has been confirmed by MHI-DILAM for SAYAENDO LNGC. Reduced hull girder stress has favorable effect in SAYAENDO, allowing possibility of hull steel optimization to achieve the given fatigue design specification.

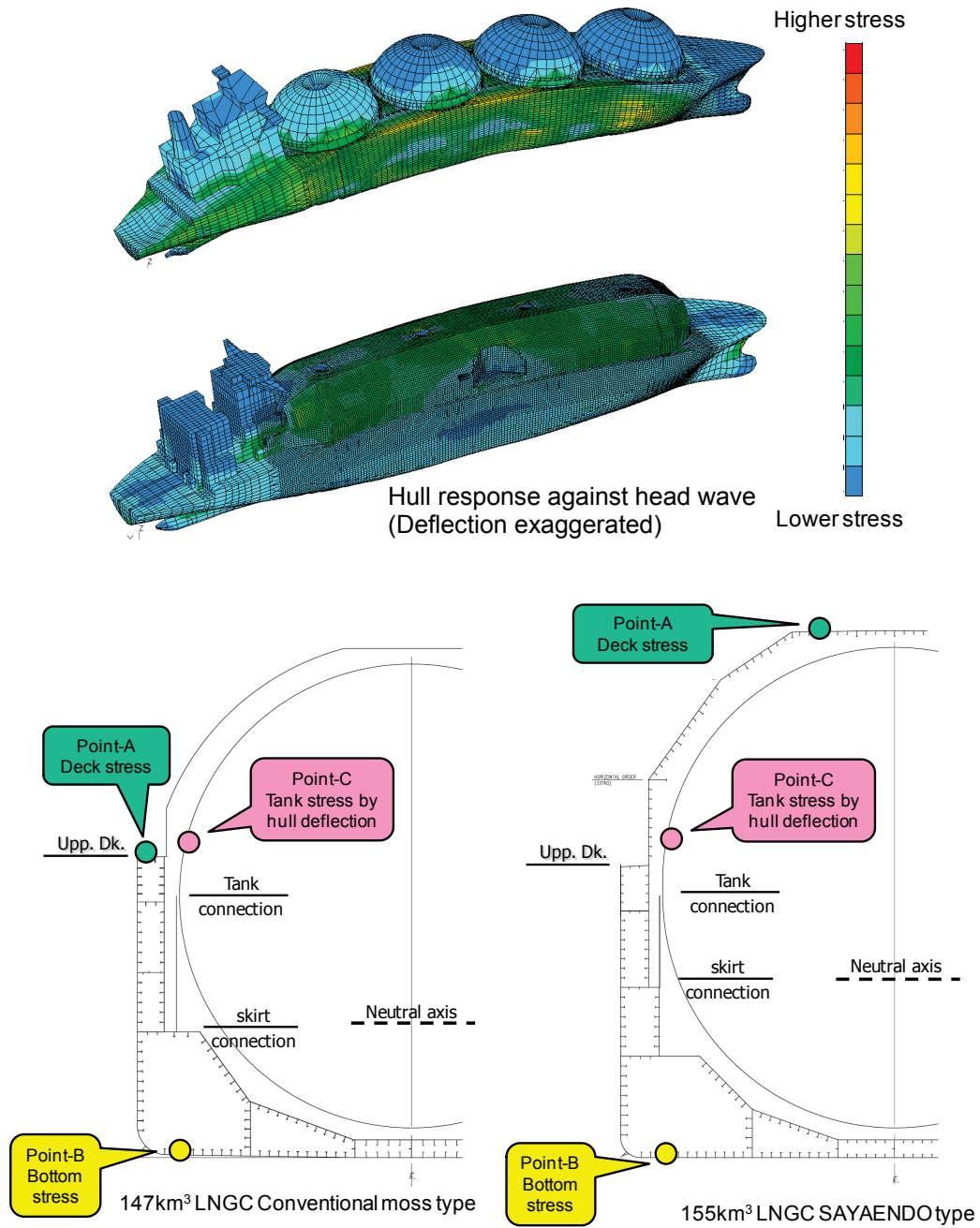


Figure 8. Comparison of Global Bending Stress

INDEPENDENT VERIFICATION BY CLASS SOCIETY

Historical Perspective on MOSS LNGC and SAYAENDO project

Lloyd's Register (LR) has been involved in the design, construction and survey of gas ships for more than 80 years. LR remains at the forefront of gas ship technology, being one of the lead class societies not only in terms of number of ships in class, but also in terms of the depth and scope of experience in gas containment systems approval and emerging technologies such as floating LNG plants.

Confining the discussion to MOSS LNGC, the following experience has a relevance to the paper subject.

- Lead Class for the LNG ships for the Australia North West Shelf project adopting a “second generation” MHI MOSS LNGC design (see Figure 1); a 6 ship series delivered between 1989 and 1994. A technical paper of the engineering appraisal of these ships was jointly published at the GASTECH 88 conference (see reference 3). In fact LR has classed a large number of MHI built MOSS LNG ships, covering the second generation 125K designs, third generation 135K designs onwards to the latest fourth generation 145K designs, ice-strengthened and winterized versions of which were adopted for the Sakhalin II LNG export project.
- Classing the earliest LNG ships adopting patented “stretched MOSS” tanks with a 4 ship series delivered from 2004.
- “Approval-in-Principle” granted in 2008 to first generation SAYAENDO design of 165,000m³ capacity.

Class Consideration focusing on the Tank Cover

With the brief introduction above of MOSS LNGC design appraisal and construction survey experience, LR is satisfied that the SAYAENDO is a product of sound engineering and well established design approaches for the cargo tanks and the supporting hull structure for these tanks, which will not be the focus in this paper. The aspect that may deserve careful scrutiny from a classification perspective remains the dual function being played by the continuous tank cover structure (1) as a protective cover for the tanks and segregation of the tank compartments and (2) as a primary hull strength member, and the paper will touch on its impact on overall arrangement. These considerations will be separately discussed below:

(1) Tank Cover as a Protective Structure for the Cargo Tanks

For conventional MOSS LNGC, the tank covers are considered as “major hull fittings” and perform the role of providing weather-tight protection to the cargo tanks and maintaining gas-tight compartments of the holds as required by the Rules and Regulations. From class perspective, the continuous tank covers shall continue to fulfill this role and the gas and weather-tight integrity of the cover shall be maintained for the SAYAENDO. While the new cover structure attracts large hull girder loads that will need to be carefully considered in assessing its integrity for this role, the conventional covers present different design challenges in that these are discontinuous structures that interact with hull girder response, thus creating some “hard spots” on the cover/deck interface that will need the careful attention of the designer and Class. By adopting a continuous structure, these “hard spots” is reduced because the structural continuity is much improved, the distortion at the main deck level is also much smaller because of greater hull stiffness and shorter distance to the neutral axis, thus mitigating the distortion induced secondary stress effects in way.

(2) Tank Cover as a Primary Hull Strength Member

This is the main focus of the discussion in this paper presented from class perspective from a primary hull strength requirement point of view, this being a new function for the cover structure. Different levels of assessment were carried out to supplement the builder's verification, which includes direct loads calculation, strength calculation, simplified fatigue assessment, screening fatigue calculations and detailed fatigue calculations.

The impact on ship arrangement by incorporating a continuous cover structure is also an important class consideration from an overall safety and Rule and Regulation compliance of point of view, and this will be discussed with some reference to using risk assessment approach as an adjunct section.

Class Notation:

LR's independent assessment has been carried out for the standard design with the following notations:

⌘ 100A1 Liquefied Gas Carrier, Ship Type 2G, Methane (LNG) in independent spherical tanks type B, Maximum vapour pressure 0.25bar, Minimum temperature –163C, ShipRight(SDA,FDA plus(50,WW),CM,ACS(B)), *IWS, LI, ⌘ LMC, UMS, NAV1, IBS, ICC with the descriptive notes ShipRight(SCM,BWMP(T)), ETA.

The standard ship is examined to comply with the LR Gas Ship Rules incorporating the IGC Code and USCG Code of Federal Regulations for gas ships trading in US waters except Alaska. This paper shall be limited to the *ShipRight* hull notations and how this may impact the design and construction of the continuous tank cover. For a general description of the ShipRight assessment approaches, please refer to documents in the reference section.

Design Verification using LR's *ShipRight* Procedures

To ensure that the tank cover structure can reliably fulfill its function as a primary hull member, the design has to fulfill three basic fitness-for-service criteria:

1. *ShipRight*(SDA)

In terms of ultimate strength verification, each class society has its own procedures and Lloyd's Register is no exception. The ShipRight Structural Design Assessment (SDA) procedures describes the methods that are to be applied to verify the yielding strength and buckling strength of the primary hull structure members, setting out the modeling approach, loading scenarios, loads and acceptance criteria. These are usually a partial model, a set of governing loading scenarios based on experience and loads obtained from simple Rule based formula to make the computation reasonably practical. In this instance, as the merit of the designer's approach especially applied to new design is manifest in the foregoing sections, with a full length model, directly calculated loads that are generally more severe than Rule loads and a design envelope covering perceivable dynamic load scenarios; DILAM findings were accepted, with yield and buckling criteria generally adhering to the ShipRight procedures. In case of conventional MOSS LNGC, the ShipRight procedures permit a slightly more generous yield acceptance criteria for the tank covers, but in this instance the criteria for strength deck members is used to reflect the changed function. LR can also derive confidence from past projects where Rule based approach and DILAM approach were carried out in parallel and the comparability of the approaches ascertained. Notable critical locations are considered to be at the forward and aft terminations of the tank cover due to the abrupt changes in hull girder section properties. The countermeasure and associated scantlings proposed by builder are verified by class from strength (and fatigue) in the form of a large scarphing structure integrated with the deck house side for the aft termination, and a more moderate scarphing structure integrated with the under-deck structure forward. See figures 9 and 10.

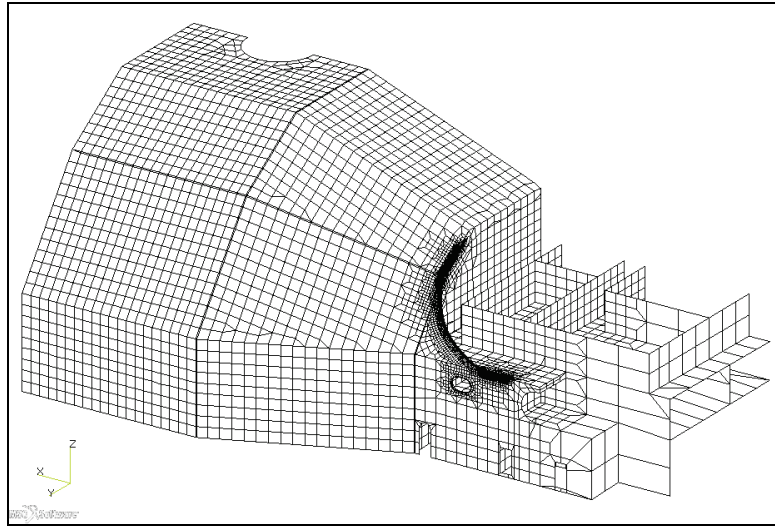


Figure 9. Scarphing Arrangement at Tank Cover Aft

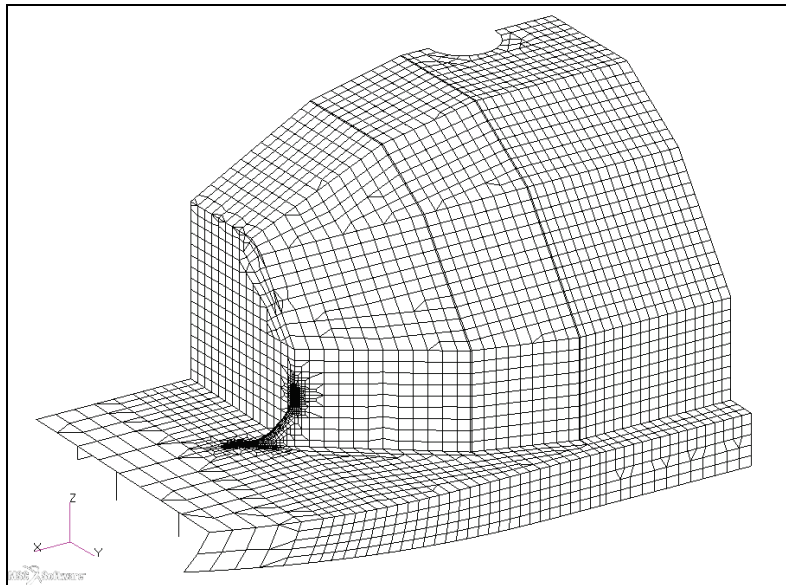


Figure 10. Scarphing Arrangement at Tank Cover Forward

2. *ShipRight*(FDA plus(50,WW))

Fatigue issues in service for conventional MOSS LNGC hull tend to affect minor structures and can often be traced to detail design considerations, and have not lead to serious concerns. The continuous tank cover structure, which now serves as a main hull girder load bearing member, falls under the scope of examination for assignment of the Fatigue Design Assessment (FDA) notation. The bracketed connections of the longitudinal stiffeners are examined by a “FDA Level 2” approach. For locations not suitable for the Level 2 approach, the critical ones are examined by a “FDA Level 3 approach” which requires very fine mesh FEM, while a hybrid “fatigue screening” approach is applied to all general locations.

The location which is considered to be of most interest is the opening on the tank cover top where the cargo tank domes protrude from the hold as shown in Figure 11. While this critical location is unique to the SAYAENDO vis-à-vis conventional MOSS LNGC for the reason that the opening is a major stress raiser and a fatigue crack has the potential to propagate under large hull girder stress at midships, it is considered that this mode of failure is not so different from other ship types, say a membrane LNG carrier, and the risk is adequately controlled by careful fatigue design and selection of material of appropriate toughness.

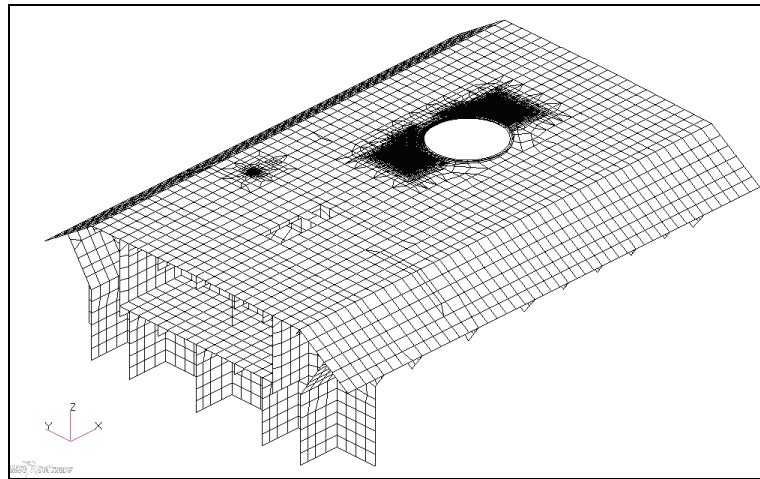


Figure 11. Tank Cover Top Opening in Way of Cargo Tank Dome

The aforementioned structures and countermeasures have been verified to exceed the project required fatigue life.

Unlike ultimate limit state (ULS) which is determined by extreme events e.g. largest nominal wave event in a lifetime, fatigue limit state (FLS) is generally considered a fitness-for-service criteria governed by the stress history generated by “average” events and not extreme events. While all LNG ships under LR class has to satisfy a minimum requirement of 20 years fatigue life based on a world-wide trading pattern specific to LNG ships, a higher fatigue strength requirement in terms of trading routes and target fatigue life is often part of the project requirement, such as a trading pattern with Atlantic Basin bias with a 50 years target fatigue life. In this context, one unique feature of the ShipRight FDA procedures is the ease of allowing the fatigue strength to be investigated using different user-defined trading routes. This feature has particular utility for the design assessment of ships contemplating a North American LNG export scenario where the fatigue demand transiting the North Pacific to and from, say, North East Asia can be severer than that experienced on most existing LNG trade routes.

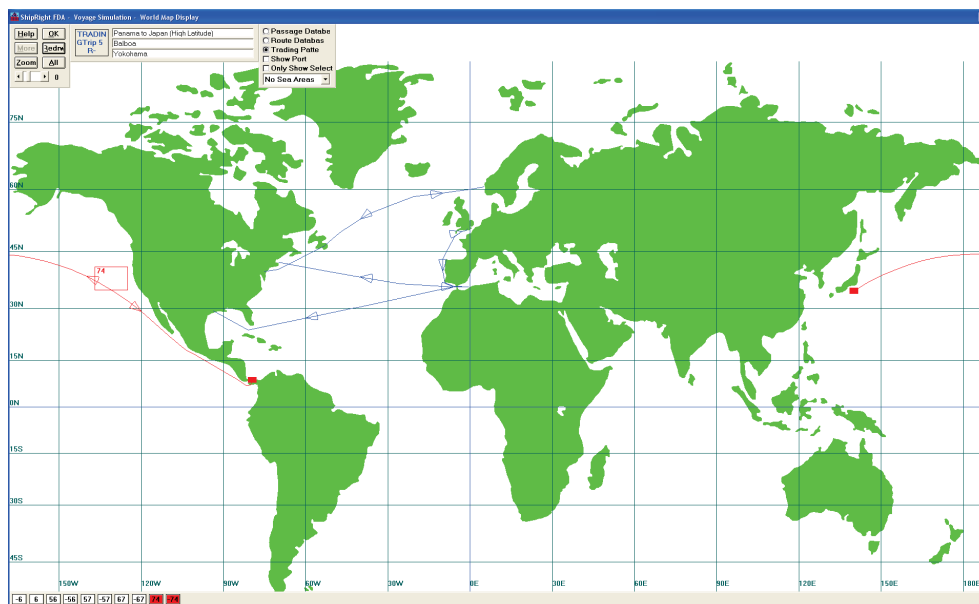


Figure 12. Nominal “Atlantic Basin” and Trans Pacific LNG Trade Routes

Class Consideration of Overall Ship Arrangement

As touched on earlier, conventional tank covers, being such large prominent structures, dictate the layout of equipment and compartments on the LNGC deck area. The general layout of these equipment and compartments has more or less remained unchanged despite the gradual increase in ship size and evolution in tank cover designs. So it could be said that these are optimally arranged from functionality and regulatory compliance purposes. However, by incorporation of a continuous cover, it necessitates the layout to undergo a re-design. To depart from well established arrangements can present challenges even to experienced designers and regulators and some aspects are touched on here.

Class was involved while at the Approval-in-Principle stage to review designer's proposals from a regulatory as well as from an overall safety consideration, identifying any gaps and clarifying any conflicts with industry practice. While it would not be appropriate to discuss details which are proprietary, some of the matters that were reviewed include a novel LNG cargo manifold system as well as the arrangement of the cargo machinery room, and these are briefly described in this paper.

1. Novel LNG cargo manifold system

In order to optimize the arrangement of the piping and associated fittings on the cargo manifold and the tank cover from the view of production efficiency and minimizing their exposure to the elements thus enhancing maintainability, MHI designers investigated several design proposals with the help of formal risk assessment. The following are some of the tasks that were undertaken:

- Compliancy Review (generic Gap Analysis) in order to identify any Class Rule/IGC non-compliances of the proposed piping design.
- Hazard Identification Study (HAZID) in order to enable identification of potential hazards related with the proposed design layout and cargo transfer operations.
- Identify critical systems/equipment related to the potential hazards and prioritize mitigation measures based on Risk Class levels.

While the novel system was not incorporated in the commercial product, the study has been valuable in that it very clearly focuses the designer's and class's attention on the relevant safety issues which contributed to the success of the final design.

2. Arrangement of the cargo machinery room

A comparative safety assessment of the proposed arrangement of cargo machinery room integrated with the tank cover with the arrangement found on board existing liquefied gas carriers was carried out with the input of experienced subject matter experts (SME) from machinery and piping, electrical and control, fire safety, and hull structures. A review of historical data was carried out to support this activity. The process worked effectively thanks to a very open and transparent dialogue between the designers and the SMEs which led to a finally adopted design which is considered equivalent to existing ships in safety, but offer operational advantages and received the approval of Administration, Class and Owner.

THE 155K-M³ SAYAENDO LNG CARRIER: MAIN CHARACTERISTICS

General

The following sections describe the key features of the 155k-m³ SAYAENDO design as a total product.

The 155k-m³ SAYAENDO adopts a new-generation hull form designed to achieve significant improvements in long-haul operating economy, operational flexibility and environmental performance combined with key technologies such as the continuous cover, stretched tanks, and advanced propulsion plant.

The 155k-m³ SAYAENDO is designed with a molded depth of 26 m to support terminal compatibility and maintains the same height from the bow to the engine room as a conventional 147k-m³ carrier. The front and back ends of the continuous cover are faired into the hull with suitable scarphing structures, designed by MHI and verified independently by Class to achieve the requisite structural reliability.

For the main power plant, the SAYAENDO uses MHI-UST (Ultra Steam Turbine plant), a new turbine plant that achieves higher thermal efficiency through effective use of thermal energy by reheating steam. Together with the weight reduction and improvements in propulsion performance, the new ship is expected to be able to achieve more than a 20% reduction in fuel consumption compared with conventional ships.



Figure 13. 155 k-m³ SAYAENDO

Main characteristics of 155k-m³ SAYAENDO are as follows.

Increased cargo capacity via stretched tanks

The capacity to transport 8,000 m³ more LNG than a typical 147k-m³ carrier is achieved without increasing the beam by using vertically stretched spherical tanks that maintain the same tank diameter. Thus, the new design provides a higher cargo capacity while meeting all the New Panamax requirements including air draft.

Reduced hull weight and compact design

In conventional LNGCs, hemispherical covers provide little contribution to the overall strength, which is constituted by other hull structures. By employing a continuous cover to house the four spherical tanks, the cover is able to perform as a primary hull strength element, and the 155k-m³ SAYAENDO was able to achieve greater overall strength while achieving a reduction in steel weight. The new design also allows a reduction in the depth of the ship. Size comparisons with a conventional 147k-m³ carrier are shown in Table 1.

Table 1. Size Comparisons with a Conventional 147k-m³ Carrier

	Conventional 147k-m ³ carrier with a spherical tank cover	155k-m ³ Sayaendo with a continuous tank cover
LNG cargo tank type	4 spherical tanks	4 spherical tanks
Cargo tank capacity (m ³)	Approx. 147,200	Approx. 155,300
Loa (m)	288	288
B (mld.) (m)	49.0	48.94
D (mld.) (m)	26.8	26.0
Design draft (mld.) (m)	11.27	11.55
DW (t)	Approx. 71,300	Approx. 75,000
Speed (kt)	Approx. 19.5	Approx. 19.5
Main propulsion plant	Conventional turbine	UST

Lower fuel consumption

A significant reduction in fuel consumption is achieved through reduction in steel weight and improvements in propulsion performance, as is a reduction of head wind force with the use of the continuous tank cover and adoption of the high-efficiency UST propulsion plant. With its fuel-selection flexibility (i.e., gas and oil mixture rates), the UST plant provides cost-efficient choices in managing the effects of fuel price fluctuations.

Low boil-off rate (BOR)

Thanks to the characteristics of the spherical tank system, the rates of naturally generated boil off gas (BOG), which is caused by heat ingress into LNG storage tanks, can be readily optimized according to operational requirements by altering the thickness of the thermal insulation. Instead of a typical BOR of 0.15%/d achieved in conventional LNG carriers, the SAYAENDO is capable of 0.08%/d, which is even lower than the 0.10%/d adopted recently as the definition of low boil-off rate.

Lower maintenance costs

In conventional hemispherical tank cover ships, piping, electric cables, and passages atop the covers are supported by complex structures. The continuous tank cover makes such supporting structures unnecessary, thus significantly improving maintainability.

Highly versatile cargo capacity

A larger cargo capacity increases economic competitiveness by lowering the unit cost of operation; however, due to limitations on LNG storage capacity at receiving terminals, LNG carriers that are too large may pose operational difficulties. A total tank capacity of 155k-m³ offers highly versatile terminal compatibility worldwide.

Compact design, comparable to a typical 147k-m³ carrier

A compact design comparable to a typical 147k-m³ carrier is achieved through use of the continuous tank cover and stretched tanks, ensuring versatile terminal compatibility. The SAYAENDO is also compatible with the size limits for traveling through the Panama Canal after its planned expansion is completed in 2014 (366 m in LOA, 49 m in width, and 15.2 m in draft and 57.91m in air draft). These dimensions make it ideally suited for the emerging North America LNG export scenario.

Environmental performance

With improvements in propulsion performance, a reduction of head wind force, and lowered fuel consumption via adoption of the UST plant, the SAYAENDO is expected to achieve a CO₂ reduction of approximately 25% per cargo unit during actual operations compared with a conventional 147k-m³ carrier (Figure 14). The UST propulsion system also features very low emission of NO_x and SO_x, which makes it ideally suited to visiting North America where Emissions Control came into force from August 2012.



Figure 14. CO2 Reductions per Cargo Unit

FURTHER APPLICATION: COLD CLIMATE

Meanwhile, gas field developments in Arctic and sub-Arctic regions, such as Norway and northern Russia, are gathering great interest as new exporters of LNG, which is currently being sourced primarily from South East Asia, Australia, and the Middle East, as well as around the Atlantic Basin. LNG carriers operating in such cold climate zones require special considerations for the hull strength for ice-navigation as well as equipment and outfitting for low temperature.

Through participation in northern gas field shipping projects, such as Snohvit (Norway) and Sakhalin (Russia), MHI has considerable expertise in developing practical designs and specifications for building LNG carriers for use in cold climates. Based on such designs and solid experience in shipbuilding, new development of LNG carriers able to navigate in even more extreme temperature and harsher environments is fully underway. For these new LNG trade routes, specifically to address potential situations where icebreaking is needed for year-round navigation, MHI has so far conducted propulsion plant reviews, simulation of iceberg collisions and global strength evaluations during ice-breaking operations. With respect to the tank type, a self-supporting tank, spherically-shaped and attached to the hull in such a manner that is highly tolerant of deformation effects in the outer shell is regarded as the most suitable for LNG carriers for Arctic conditions, and a spherical tank LNG carrier with a continuous tank cover is being selected for on-going developments.

SAYAENDO is considered to be uniquely suitable for use in cold regions and ice infested waters because it is based on an independent tank system which is inherently tolerant to a loading scenario in which the shell plates are susceptible to deformation caused by contact with sea ice. It also reduces the exposure of equipments and their supports to the effect of low temperature and atmospheric icing, and its overall hull girder strength is highly effective in resisting ice impact loads.

Figure 15 shows an icebreaking LNG carrier. Structural analyses were carried out to simulate impact with an ice sheet to confirm the integrity of the hull and cargo tanks.

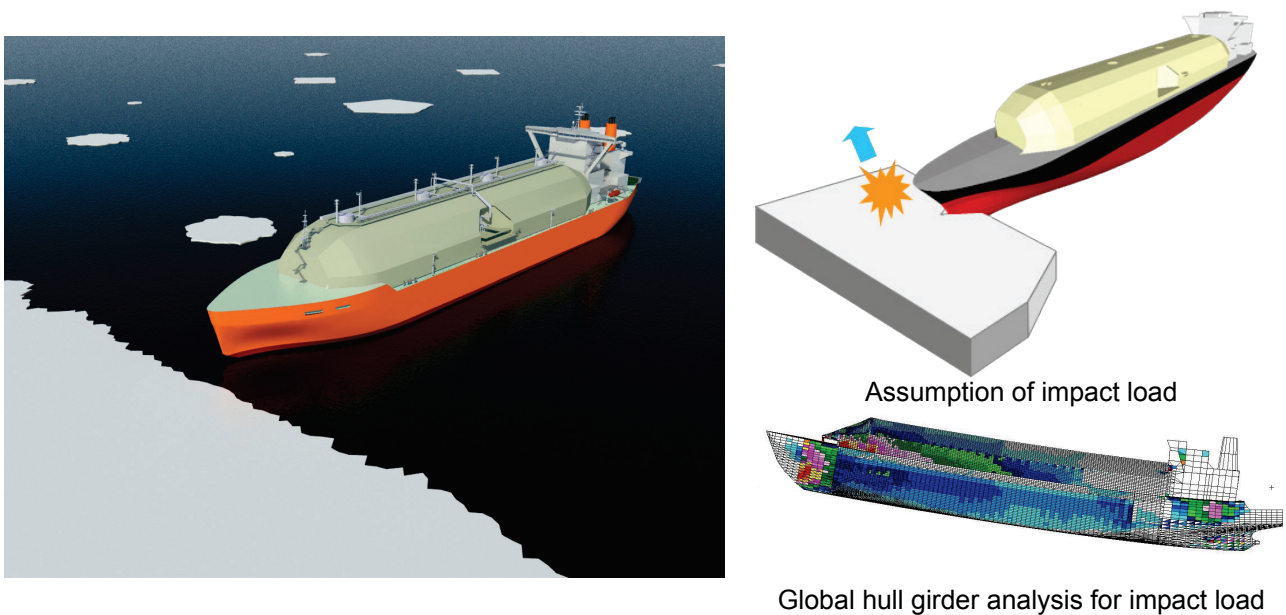


Figure 15. An Icebreaking LNG Carrier (image) and Example of Structural Analysis

CONCLUSIONS

Presently, as part of efforts to minimize carbon footprint and fuel costs, improvements in energy efficiency are being vigorously sought in the marine transportation industry. In response, MHI is actively developing products with improved environmental performance and the SAYAENDO is born of this effort.

By integrating a continuous tank cover with a hull that maximizes the structural reliability of spherical tanks, the SAYAENDO was developed with the following advantages.

- Optimized hull structure offering more rigidity with less light weight
- Compact design, especially in ship's depth
- Lower maintenance cost, due to omission of flying passage
- Suitability for navigation in cold region

As described in this paper, state-of-the-art engineering verification methodologies by the shipyard and the classification society were applied to validate the new design to meet the stringent technical, regulatory and safety requirements of the LNG shipping industry.

Positioning eco-ships as one of the key high-value-added products in the company's Shipbuilding and Ocean Development business sector, MHI aims to expand its product line and to further its pursuit of eco-ship development and customer expansion. MHI will continue to work with its partners and customers to develop innovative products that not only meet the changing needs of the shipping and LNG industries but also fulfill our commitments to corporate social responsibility as global citizens.

Lloyd's Register, in her 253RD year of operation, has in her mission statement the words "secure for the benefit of the community the safety of life and property at sea". While these words underpin the business ethos in 2013 as they did in 1760, LR is also committed to supporting industry in the development of products that are not only safe and robust, but also make a direct contribution to reduced environmental impact. In this respect, LR is honored to have played a role in the development of the SAYAENDO not only in respect of the validation of

the structural concept as described in the paper, but also in the approval of the Ultra Steam Turbine plant; which together make a promising contribution to minimizing environmental impact while maintaining the requisite level of safety.

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