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Development of a GTT NO96 Membrane Type 170K m^3 LNG Carrier with Ice Class IA

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Abstract

The present paper addresses development of a GTT NO96 membrane type 170K m3 LNG carrier targeted to operate in moderate ice infested seas including Baltic Sea, Sakhalin port of Sea of Okhotsk, Murmansk port of Barents Sea, etc. Critical design issues are covered in detail to meet the requirements coming from the missioned operation conditions comprising low design ambient temperature, harsh wave conditions, stringent environmental protection policies, etc.

※Keywords: LNG Carrier; GTT-NO96 membrane type; IGC, ICE-IA; Ice strengthening; DNV CSA-2; spectral fatigue analysis; sloshing; Ice Hazards; structural risk analysis; vibration and noise; winterization

1. INTRODUCTION

A liquefied natural gas (LNG) carrier, using GazTransport & Technigaz (GTT) No96 membrane type with 170K m3 capacity, has been developed to operate in ice infested seas with Ice Class IA. Trading route from Baltic Sea to east coast of North America was utilized to determine design requirements. Basic dimensions are determined considering shallow depth and design specific gravity of LNG as well as to provide sufficient energy absorbing capacity for side wing tank structure. The target trade routes are characterized by their severe requirements from environment condition, harsh sea condition, and hazards from ice features. Design has been developed through comprehensive study, where investigation was made into critical design issues – winterization and structural soundness against cold operation, sloshing impact pressure, fatigue strength, ice features, etc.

The following technical issues are discussed in the present paper:

- Basic design
- Temperature distribution analysis
- Application of first principles in

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structural design
- Sloshing
- Slamming
- Structural risk analysis against ice hazards
- Vibration and noise analysis
- Winterization

2. BASIC DESIGN

General elevation view with ice belt area and conceptual midship section of the vessel are shown in Figs. 1 and 2. The vessel has a number of special features: The double side is designed to be wider than that of conventional type of vessel to increase side structure capacity against ice loads as well as to meet shallow depth requirement; External shell in the ice belt area is reinforced with thicker plates and the longitudinal stiffeners with increased section modulus are arranged in the half space compared with the other areas. Ice belt strengthening was made to comply with Finnish Maritime Administration (FMA) Regulation. The design was done in the ice class level of ICE-IA; the forebody ice belt zone outside the body tangential line is further reinforced with additional stiffeners compared to the midship area as shown in Figs. 3 and 4.

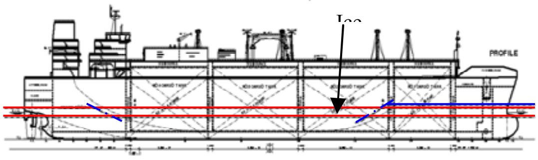

Fig.1 Target Vessel and Ice Belt for Ice Class 1A

Table 1 Principal dimension

Length O.A.	Approx. 290.0 M
Length B.P.	279.0 M
Breadth	47.0 M
Depth	26.5 M
Draft Design	11.5 M
Scant.	12.5 M

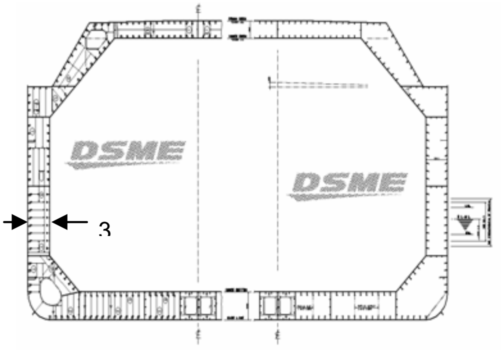

Fig. 2 Conceptual midship drawing

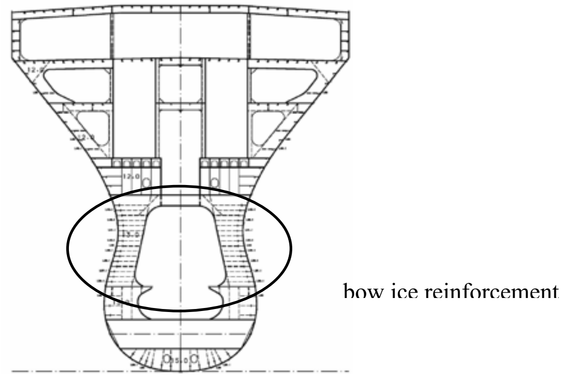

Fig. 3 Bow area section

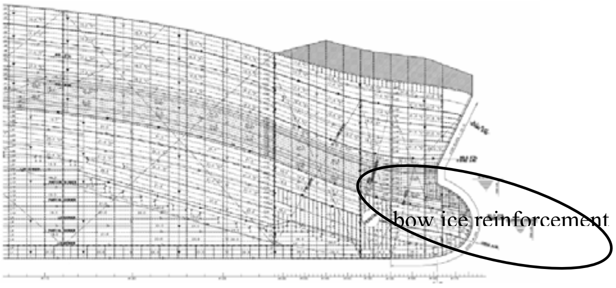

Fig. 4 Shell expansion in the bow area

3. TEMPERATURE DISTRIBUTION ANALYSIS

Determination of steel grade is one of the main issues of LNG carriers due to the cold temperature of LNG but the use of low temperature grade has been minimized so far in the conventional LNG carriers operating at benign ambient temperature. Operation in the cold environment, however, imposes more stringent requirement to the selection of steel grade.

The subject vessel is designed with the notation of DAT(−30), according to which hull should be designed to withstand −30°C. In addition, two conventional requirements – International Gas Carrier (IGC) Code and Unite States Coast Guard (USCG) regulations – are to be practiced. There is difference in the application of these regulations. IGC and USCG regulations specify that temperature distribution be calculated on a damage condition where primary insulation is damaged to lose its insulation function. The notation of design air temperature (DAT) does not impose any additional requirement for calculation condition; therefore, DAT is found not to be dominant in the determination of steel grade.

Ambient conditions for determining material grades of structures are considered with following cases based on the worldwide service including Alaskan waters:

- DNV's Notation : DAT (−30) for outer hull structure.
- IGC Condition for inner hull Structure.
  - ✓ 5°C air at 5 knots.
  - ✓ 0°C Still Water.
- USCG Condition including Alaskan for inner hull Structure.
  - ✓ −29°C air at 5 knots.
  - ✓ −2°C Still Water.

DAT notation of Det Norske Veritas (DNV) does not cover the primary barrier damage case like USCG or IGC case. IGC code determines the steel grade selection of outer hull structures. USCG requirement dominates the steel grade selection of inner contiguous hull structures.

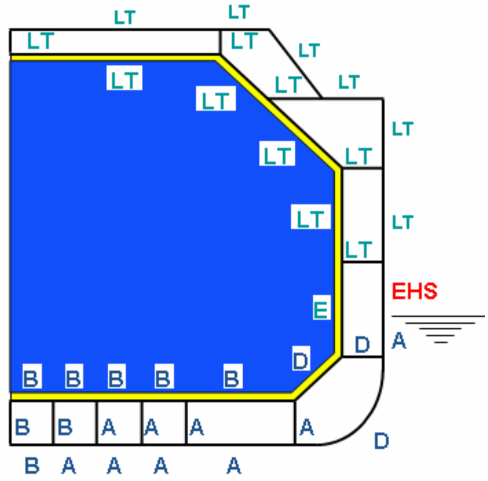

Fig. 5 Hull material selection

Temperature distribution result is used to determine steel grade in accordance with IGC recommendation. Without any winterization inside ballast and cofferdam area, the application of IGC and USCG regulations would result in low temperature (LT) grade for the large area above the draft as shown in Fig. 5. This is one of the areas that need optimization in economical aspect, considering whether to implement additional heating measures to lessen the steel grade from LT to grades E or D.

4. APPLICATION OF FIRST PRINCIPLES IN STRUCTURAL DESIGN

Hull structure has been designed based on first principles to take into account harsh wave conditions as the design requirement. The application of first principles in the present design was guided by the requirements of DNV computational ship analysis (CSA-2), which also specifies how to calculate wave loads with reasonably sufficient safety margin.

The application of rational based design concept followed conventional design procedure complying with rule requirements and finite elements (FE) analysis with a part model. Basic rule scantling was made for longitudinal members and cargo hold FE analysis for transverse and longitudinal members. These processes provided first level of structural design, which were further investigated by whole ship analysis and spectral fatigue analysis, details of which are addressed hereafter.

Critical wave conditions are selected associated with various loading conditions depending on locations and loading components. Two limit states - Ultimate limit state (ULS) and Fatigue limit state (FLS) - are referred to in the determination of load cases. The total number of load cases is ten (10) composed of eight for ULS and two for FLS.

Hydrodynamic load is obtained from 3-dimension (3-D) diffraction theory. This wave load analysis should be performed with sufficient care to roll damping, static balance, and environmental parameters. The following responses were calculated:

- Motions in 6-degree of freedom (DOF)
- Sectional loads at specified sections
- Pressure distribution at wetted hull surface
- Pressure distribution at cargo tanks

Pressure distribution at cargo tanks is defined as the function of acceleration and motion. Special care was taken in the application of hydrodynamic load to a whole ship FE model, since the secondary effects accumulated along the hull - global shear force and bending moment - can not be neglected. It should be noted that global loading components in FE analysis are differently calculated from the wave load analysis since the hydrodynamic analysis does not consider the effect of cargo pressure variation.

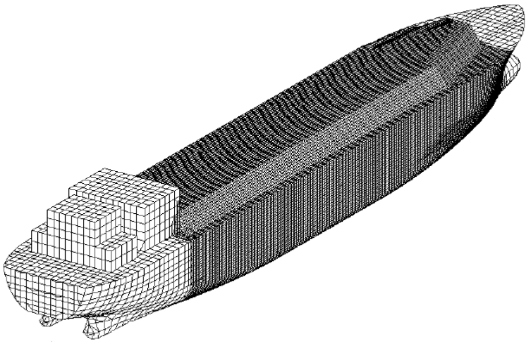

Fig. 6 Whole ship FE model

Some comments are made herein on the difference in wave load between ULS and FLS. Non-linear effects coming from wave elevation and ship motion are to be fully included in ULS analysis; however, FLS analysis is not necessarily carried out with strict definition of nonlinearities. Non-linear effects are estimated to reduce during the calculation of stress range for fatigue evaluation. There is another notable difference in the selection of loading condition between ULS and FLS. ULS loading conditions are selected artificially in some sense to find a most critical condition for a specific location and loading component. FLS loading conditions, however, should be selected with the consideration of the implemented time span. Yielding and buckling check was made in ULS analysis for the results, which guarantee structural adequacy with the vessel. Careful structural improvements were made to have applied stress level below the allowable limits.

Special consideration to accidental limit states (ALS) was also made through the check of ultimate hull girder capacity. The hull was assumed to be intact or damaged by collision or grounding. The damage extent was determined according to the DNV CSA-2 regulation.

Design has been made to provide sufficient fatigue strength considering the fact that the mission of the developed ship includes the operation across the North Atlantic. It has been rare for LNG carriers to operate in the North Atlantic and designers were challenged to develop local details complying with 40 year fatigue life for the trade route.

Rule based approach had been taken for the scantling for the connections of longitudinal and transverse members, which gave sufficient level of confidence. Calculation was made using a DNV software of NAUTICUS HULL helping the application of regulations in accordance with DNV CN30.7. Reinforcements were made by increasing the size of longitudinal stiffeners or by improving connection details. Resultant fatigue lives are summarized in Fig. 7 and Table 2.

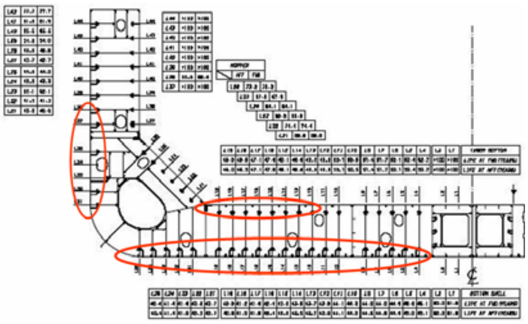

Fig. 7 Fatigue check for longitudinal connection

Table 2 Summary of fatigue lives for longitudinal connection

Location	Fatigue Life
Bottom (L4-L25)	Min. 40 years
Inner Bottom (L1-L19)	
Side (L31-L38)	
Other Areas	More than 50 years

For the longitudinal connections, the rule based approach – mainly based on local scantling concept – is considered sufficient; however, the main knuckle areas need to be carefully designed since stresses applied at knuckle areas are dominated not by the primary loading component such as local pressure, but by secondary effect such as girder bending. This secondary effect can not be reasonably assessed by rule based approaches, where the amplitude of loading components is the main parameter and a large degree of ambiguity exists in the phase of loadings.

Spectral fatigue analysis has been carried out for the main knuckle areas to overcome the weakness of the rule based approach. Direct wave loads are applied to the whole ship FE model to build stress response amplitude operations (RAO) for check locations. The whole ship FE model and local fine meshed models are used for the following check areas:

- Lower hopper connection
- No.2 stringer connections
- Main girder connections at cofferdam bulkhead

DSME spectral fatigue analysis system (D-SFAS) was used for the spectral fatigue analysis. Figs. 8, 9 and 10 shows the locations and local fine model used in the analysis. Welding details were carefully controlled to have low stress concentration at fatigue-prone spots. Offshore standards were also utilized to assess effects of post-welding treatments on fatigue life improvement.

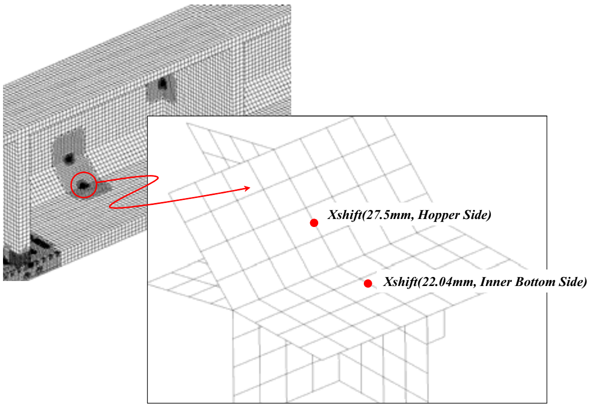

Fig. 8 Spectral fatigue analysis(Lower hopper connection)

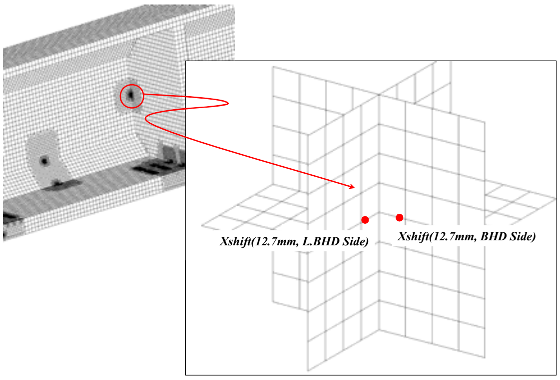

Fig. 9 Spectral fatigue analysis(No.2 Stringer connection)

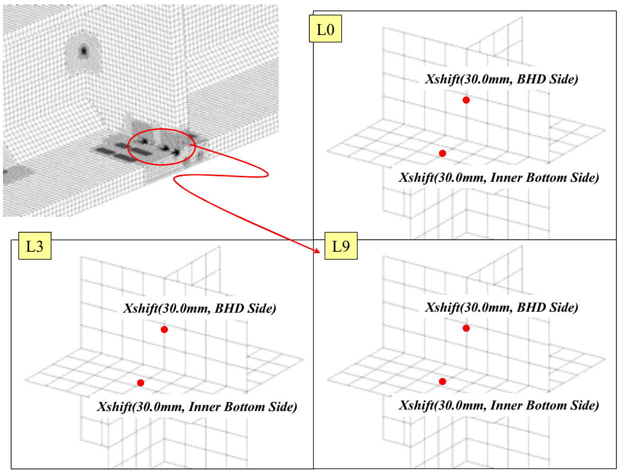

Fig. 10 Spectral fatigue analysis(Double bottom girder connection)

5. SLOSHING

A comparative sloshing strength assessment has been carried out for determination of No96 Box type and of hull scantling of sloshing prone areas. The assessment (Hovem, 2007) has been performed according to the procedure specified in DNV Classification Note No.30.9. The hull scantling check against sloshing pressure involves the following items:

- Strength assessment of the inner hull longitudinal stiffeners
- Hull-containment system interaction analyses to ensure that the stress in the containment system caused by the interaction with the hull structure remains within the limits defined by a reference vessel.

The analyses have been carried out on the following parts of the inner hull structure of the vessel based on an evaluation of the sloshing loads in the tank and the structural dimensions:

1. Stiffener strength and hull-containment system interaction analyses for the inner deck structure towards the transverse bulkhead.
2. Stiffener strength and hull-containment system interaction analyses for the chamfer area towards the transverse bulkhead.
3. Hull-containment system interaction analyses for the insulation boxes adjacent to the upper and lower chamfer knuckle.

The adequacy of the remaining inner hull structures in the tank has been assessed based on an evaluation of the sloshing load levels and the structural dimensions, combined with the results from the mentioned analyses.

The section modulus of the inner deck longitudinals and the longitudinals adjacent to the upper knuckle at the frame space adjacent to the cofferdam bulkhead has been increased according to the analysis to satisfy the acceptance criterion defined in CN30.9.

The inner deck plating has been increased, in the hull interaction analyses, at the frame span adjacent to the cofferdam bulkhead. For the lower part of the chamfer area, the plate thickness has been increased along the whole tank length in order for the containment system to fulfill the criteria specified in the procedure.

6. SLAMMING

Slamming calculations (Adnegard,2007) are performed for the ballast arrival condition with a forward speed of 5 knots. WASIM linear simulations generate time series of ship motion responses in waves of all headings. Based on the results, the ship motion transfer functions can be generated by signal processing.

The most probable largest slamming pressures spanning one plate field, at given positions in the aft and fore ship, for twenty year return period sea state including cosine squared wave spreading, are calculated. The largest predicted pressures at 5knots were used in the local scantling of the fore ship and aft ship areas.

7. STRUCTURAL RISK ANALYSIS AGAINST ICE HAZARDS

(Han, 2007)

The target LNG carrier is designed for the operation from the Baltic Sea to Quebec, Canada, where a number of ice hazards are expected. The structural safety should be guaranteed to a significant extent considering LNG cargo, which will be the source of disaster if any leak occurs. The study of possibility of leak involves safety criteria of cargo containment system. The target vessel is designed using GTT NO 96 containment system for LNG cargo.

Capacity of the double hull structure has been assessed considering inner hull deflection as the critical factor of the safety of the containment system. This Capacity is compared with accidental ice load, as ‘Demand’ to the LNG carrier, from ice hazards that can take place in the Baltic Sea operation or in the East Canadian Coast.

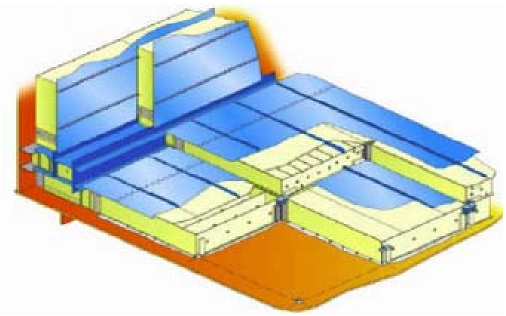

Fig. 11 NO96 cargo containment system (CCS) (Double Barrier)

GTT-provided operational and survival limits of the containment system are reviewed to find their applicability to determine ‘Capacity’ of the membrane type LNG carriers. The survival limit suggested by GTT is based on the safety assessment of the invar membrane subjected to elongation or membrane stress. The invar membrane is found to accommodate a very large deflection due to its flexible mechanical property. A possible limit state can be determined considering the strength of the welded connections of the membrane with adjacent membrane sheets or tank boundary wall. The investigation of the elongation of the membrane itself and its welded connection says that the invar membrane system is flexible enough to accommodate a significantly large elongation caused by accidental ice loads. Therefore, the safety of the hull as tank boundary is adopted as alternative criterion to define a survival condition of the membrane LNG carriers with GTT NO 96 containment system.

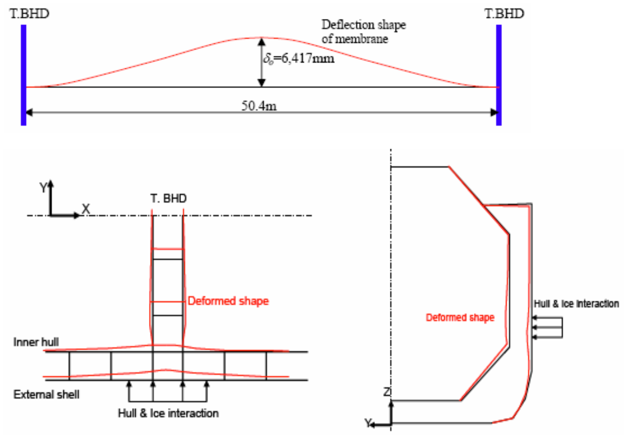

Fig. 12 Theoretical model of deflection

Tank No.1 has been the main target area in the present development, since the fore area is estimated to have a relatively large probability of interactions with ice features while the vessel navigates through a narrow and sharply changing ice channel. Collision with ice floe is estimated to have interactions with side, bilge and bottom along the cargo area while ice bergy bit collision is thought to have interactions only at Tank No.1. In addition, the area of cofferdam bulkhead No.2 has been investigated against ice features to check the integrity of bulkhead structure. A large area from No.1 to No.3 tanks is considered to be stuck by level ice.

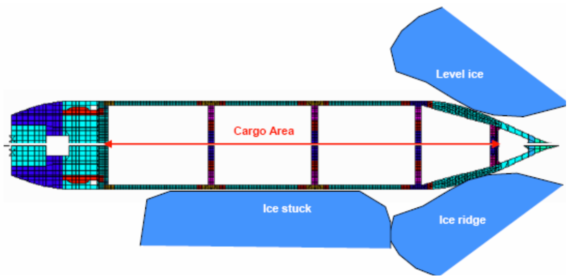

Fig. 13 Example of ice hazards

Loads exerted by ice hazards to the hull structure are quantified in strain energy form that the hull structure will absorb. The strain energy caused by ice hazards is termed ‘Demand’ and compared with ‘Capacity’ of the subject vessel in the present study. Two approaches have been used to calculate ‘Demand’: one is limit stress mechanism; the other is limit energy mechanism.

’Demand’ and ‘Capacity’ are quantified in energy form for direct comparison. The calculated ‘Demand’ is compared with ‘Capacity’ corresponding to considered hull-ice interactions. The target vessel is to be strong enough to withstand ice loads, which covers from common ice interactions in working level to accidental ice loads. The Demand level has been found to be very small compared to the Capacity level. It is concluded from this risk analysis that the target vessel can operate in the proposed areas with a low risk and a sufficient capability of reliable performance without meaningful damages to inner hull structure and the containment system.

8. VIBRATION AND NOISE ANALYSIS

Systematic approach has been taken to understand the effect of ice-caused vibration on the soundness of the hull and other areas including as pump tower structure. Ice features can have various interactions with hull from the foremost area to the aft part involving propeller. The foremost area is thought to have direct contact with ice floes in ice channel operation and with level ice in an accidental case.

Dynamic impact load caused by ice destruction is idealized using model developed by Krylov Shipbuilding Research Institute. (Appolonov, 2007).

The impact effect was evaluated with acceptable limits of vibration level.

Transfer function of ice loading at ship side to vibration responses of pump tower structure has been calculated. The pump tower structure is found not to be influenced seriously by ice impacts at side structure, since the load transfer route is a long way from double side to deck areas, where the pump tower structure is hung.

Dynamic ice forces occurring during ice milling by propeller were quantified and the effect on hull vibration was evaluated. This analysis helped to improve the aft structure design to minimize noise and vibration level in accommodation area.

9. WINTERIZATION

A number of winterization measures have been implemented to comply with Notation DEICE for ships operating in cold climate areas. The following is the related rule requirements:

- Maintenance of the main functions of the ship
- Maneuverability
- Stability related to icing
- Crew safety (rafts, life boats, gangways etc.)

There is no geographical limitation of trading for ships with this notation. Typical cold climate areas considered in the present development are as follows.

- North Norwegian Coast (Norwegian Sea and Barents Sea)
- East Canadian Coast (Newfoundland and Labrador Coast)
- Alaskan Coast (Bering Sea and Gulf of Alaska)
- North and East Russia

Regarding the icing related problems, icing may occur from freezing of sea spray or atmospheric water (snow, rain and fog). Sea spray on deck is normally the main problem. The centre of gravity of the ship with ice will usually be lifted, affecting the ship stability. Equipment will become inoperable and walking on deck is dangerous.

Icing influences safe navigation of the ship. Even moderate icing may put radio antennas out of operation and will reduce the effect of radar antennas. Ice on wheelhouse windows reduces substantially the visibility through these.

Rescue equipment such as rafts and life boats with davits are vulnerable to accretion of ice. Icing may render the use of such equipment difficult and even impossible. Scuppers in bulwarks may be reduced in size and even closed by build up of ice. Shipped water on deck may then accumulate and place the vessel in a difficult position.

The moderate ice accumulation given in the Rules of ‘ 6 cm/24 hrs’ on the various equipment and areas has unequal effect on the vessel safety. The various equipments have therefore been divided into two categories. Category I equipment/areas shall have measures to keep them completely ice free with relatively severe weather conditions. Category II equipment/areas shall have deicing measures. The arrangement is to be such that accreted ice may be removed within a reasonable period of time (normally 4-6 hours).

Various measures have been taken for deicing and anti-icing depending on type of ship, equipment etc.

Category I equipment/areas are defined as equipment/areas needed for:

- Navigation (e.g. radar)
- Steering (e.g. wheelhouse windows)
- Propulsion (e.g. cooling water sea chests)
- Anchoring
- Fire extinction
- Lifesaving
- Special equipment necessary for safety, depending on type of vessel

Category II equipment/areas to have deicing measures, with ice removal being possible normally within4-6 hours:

- Open decks except cargo area.
- Gang ways and stairways incl. safe access to bow.
- Superstructure.
- Railings.
- Out door piping (unless self-draining)
- Mooring winches
- Deck lightning

Rule defined ice loads were taken into account to determine specification of outfitting facilities. For vessels not required to comply with damage stability requirements, ice loads need not be taken into account in damage stability calculations, only in intact stability calculations. Membrane type LNG carriers, including the present developed vessel, are found to be excellent in stability and visibility even with deck ices.

The material design temperature should reflect the lowest mean daily average air temperature in the area of operation. The extreme design temperature may be set to about 20° C below the lowest mean daily average air temperature, or the material design temperature, if information for the relevant trade area is not available.

10. CONCLUSIONS

The shipping market requires LNG carriers to be designed with higher safety margin compared to other type vessels such as oil tankers or bulk carriers. This demanding market standard is justified from the fact that the LNG cargo might cause a serious disaster to human safety let alone environments. The arctic areas are also considered to be more vulnerable to any contamination and the effects will last for a long time.

Much effort has been put to provide the designed vessel with sufficient strength against harsh waves in terms of general strength, fatigue, sloshing and slamming. Direct wave loads for postulated critical design loading conditions were obtained and applied to the whole ship FE model in ULS and FLS analyses. Sloshing impact pressures were obtained from test and the resultant impact pressures were compared with reference sloshing pressure of 138K m3 LNG carrier. This comparison made possible the determination of No96 CCS box type. These high requirements in structural design are considered to be inevitable from the design requirement that the targeted will trade from Northern Europe to North America, which involve the harshest areas – typical North Atlantic.

In addition, structural risk analysis has been performed to guarantee no disaster from ice hazards such as various ice features in ice channel operation and ice berg collision. ‘Demand’ in energy form was calculated for the various ice features and compared with ‘Capacity’ in energy that the hull can absorb before reaching any critical condition. The determination of critical condition involved comprehensive studies on GTT No96 CCS system. Hull-ice interaction was assessed from the vibration and noise points as well. Direct transient analysis against collision with level ice was performed to understand the resultant vibration level. The effect of ice impact at ship side on pump tower structure hanging at the deck was also investigated by the calculation of transfer function.

Regulations on winterization have been reviewed to develop design basis for various outfitting facilities, which specifies required material grade, necessary measures to be taken to comply with DEICE notation, and required ice loads on top of considered facility.

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