Additional Design and Construction Procedures

Guidelines for Requirements of Thermal Analysis for the Hull Structure of Ships Carrying Liquefied Gases in Bulk

April 2016
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Guidelines for Requirements of Thermal Analysis for the Hull Structure of Ships Carrying Liquefied Gases in Bulk

Section 1
Introduction

1.1 Application

1.1.1 This document is based on the requirements of thermal analysis for the hull and tank structure of ships carrying liquefied gases in bulk in accordance with the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)\(^1\), and the relevant Lloyd’s Register Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk (commonly referred to as the Rules for Liquefied Gases)\(^2\). It is intended to provide a guidance to support designers, Operators and LR Surveyors to carry out thermal analysis based on the requirements for the hull structure of liquefied gas ships.

1.1.2 This document presents general methods of temperature distribution calculation of the hull structure and thermal stress analysis of the tank structure of liquefied gas ships.

1.1.3 This document is, in general, applicable to liquefied gas ships with the following tank configurations:

- Membrane tank
- Type B spherical tank
- Type B prismatic tank
- Type A tank
- Type C tank

Those aspects which are not covered in this document shall be implemented according to the IGC Code and relevant LR's Rules and Regulations.

Section 2
General theory and background

2.1 General theory and assumptions

2.1.1 The general theory used for the heat transfer analysis is the first law of thermodynamics. It is the law of conservation of energy. When the temperature distribution is calculated, the following assumptions are acceptable to Lloyd’s Register (hereinafter referred to as LR).

(a) The temperature calculation can be carried out based on the steady state heat transfer.

(b) Temperature is uniform in a space.

(c) If temperature varies significantly in a tank, the tank can be separated into two or more spaces if necessary. The number of spaces used in the idealisation is to be sufficient to represent the temperature distribution in the tank.

(d) Material is isotropic.

2.2 Thermal analysis model

2.2.1 2-D or 3-D models can be used for thermal analysis of the hull structure of liquefied gas carriers. 2-D models can be constructed based on transverse sections. For the forward structure and the structure between engine room and cargo tank, 2-D models can be constructed based on longitudinal sections at the centre line. 3-D models representing a symmetric quarter of the hull structure or the full hull structure in way of the cargo region can be used.

2.3 Thermal properties of material

2.3.1 The thermal properties of materials used for thermal analysis shall be based on the requirements in the IGC Code\(^1\) and LR’s Rules and Regulations\(^2\). These properties shall be proposed by the designer and these shall be subject to LR’s approval.

Section 3
Minimum requirements of thermal analysis for hull structures

3.1 Membrane tank liquefied gas tankers

3.1.1 The temperatures of members between the inner and outer hulls for liquefied gas ships are to be obtained from the thermal analysis calculation. The steel grades for hull structure shall be selected based on the temperature distribution calculated from the thermal analysis.

3.1.2 A membrane cargo tank is in general composed of a primary membrane with primary insulation, and a secondary membrane with secondary insulation. A typical midship section of a membrane tank liquefied gas tanker is shown in Figure 1.3.1 Midship section of membrane tank liquefied gas tanker. The following conditions can be used for the temperature distribution calculation.
3.1.3 **Boundary conditions for temperature distribution calculation**
- Cargo temperature is minus 163°C for LNG.
- Engine room temperature is assumed to be at 5°C. A higher temperature may be assumed subject to agreement with LR.
- Ambient conditions for temperature distribution calculation are those required in the IGC Code\(^1\), LR’s Rules and Regulations\(^2\) and USCG\(^3\), as listed in Table 1.3.1 Ambient conditions for temperature distribution calculation for the hull structure.

3.1.4 **Loading conditions**
The temperature distribution should be calculated for a static fully loaded condition with a cargo leakage for steel grade selection. This implies that LNG is in contact with the secondary barrier and the secondary barrier is assumed to be at cargo temperature.

3.1.5 **Temperature distribution calculation for hull structures**
2-D models may be used for the temperature distribution calculation for the hull structure of membrane tank liquefied gas tankers. The temperature distribution shall be calculated at least at the following locations:

(a) **Midship** - A 2-D temperature distribution calculation model based on the midship section can be used for steel grade selection for the hull structure over the length of cargo tanks of the same geometry, typically all tanks aft of the foremost tank.

(b) **Foremost cargo tank** - 2-D temperature distribution calculation models based on foremost cargo tank sections can be used for steel grade selection for the hull structure over the length of the foremost tank. Due to the tapered tank, more than one section may be selected. The steel temperature shall be calculated based on the lowest temperature of the tank.

(c) **Cofferdams** - 2-D models can be used for the temperature distribution calculation in cofferdams. The steel grades of transverse bulkheads are to be selected to comply with the requirements of the IGC Code\(^1\), LR’s Rules and Regulations\(^2\) and USCG\(^3\).

The temperature of a stiffener may be taken to be equal to that of the plate to which it is attached. For hopper tank ring webs, top side tank ring webs and trunk deck ring webs the temperature should be taken as the colder of the attached plate or the surrounding fluid. The temperature of the ring web face plate may be taken to be the same as that of the surrounding fluid.

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**Figure 1.3.1 Midship section of membrane tank liquefied gas tanker**

**Table 1.3.1 Ambient conditions for temperature distribution calculation for the hull structure**

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Air Temperature (°C)</th>
<th>Wind Speed (knot)</th>
<th>Sea-water Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGC Code</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>USCG, excluding Alaska</td>
<td>-18</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>USCG, including Alaska</td>
<td>-29</td>
<td>5</td>
<td>-2</td>
</tr>
</tbody>
</table>

**Note 1.** If the ship is designed for operation including in Alaskan waters, Regulation ‘USCG, including Alaska’ is required.

**Note 2.** If the ship is designed for operation in U.S. waters not including Alaskan waters, Regulation ‘USCG, excluding Alaska’ is required.

**Note 3.** Different values of the ambient temperature may be used in accordance with the requirement of the National Authority/Administration for the ship’s registration or operation.
3.1.6 Thermal stress analysis
Thermal stress combined with mechanical stress shall be carried out for the liquid dome pipe penetrations and pump tower base support referring to LR’s ShipRight Procedure Analysis of Pump Tower and Pump Tower Base. Thermal stress calculation shall be carried out at least under the ambient conditions given in Table 1.3.2 Ambient conditions for thermal stress calculation for liquid dome pipe penetrations and pump tower base support of membrane tank LNG tankers.

Table 1.3.2 Ambient conditions for thermal stress calculation for liquid dome pipe penetrations and pump tower base support of membrane tank LNG tankers

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Air Temperature (°C)</th>
<th>Wind Speed (knot)</th>
<th>Sea-water Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IGC Code</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>IGC Code warm condition</td>
<td>45</td>
<td>0</td>
<td>32</td>
</tr>
<tr>
<td>USCG, excluding Alaska</td>
<td>-18</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>USCG, including Alaska</td>
<td>-29</td>
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Note 3. Different values of the ambient temperature may be used in accordance with the requirement of the National Authority/Administration for the ship’s registration or operation.

3.2 Type B Moss tank liquefied gas carriers
3.2.1 Type B Moss cargo tank is spherical in shape with a cylindrical support (skirt). As an example, a midship section of Moss tank liquefied gas carrier is shown in Figure 1.3.2 Midship section of Type B Moss tank liquefied gas carrier. The following conditions are used for the temperature distribution calculation for the hull structure of Type B Moss tank liquefied gas carriers.

![Figure 1.3.2 Midship section of Type B Moss tank liquefied gas carrier](image)

3.2.2 Boundary conditions
- Cargo temperature is minus 163°C for LNG.
- Engine room temperature is assumed to be 5°C. A higher temperature may be assumed subject to agreement with LR.
- Ambient conditions for temperature distribution calculation are those required in the IGC Code, LR’s Rules and Regulations and USCG, as listed in Table 1.3.1 Ambient conditions for temperature distribution calculation for the hull structure.

3.2.3 Loading conditions
At least two loading conditions should be considered for the temperature distribution calculation for steel grade selection for the hull structure.
(a) Static fully loaded condition.
(b) Static fully loaded condition with cargo leakage. The leaked cargo is assumed to be evaporated from the drip tray beneath the cargo tank into the hold space.

3.2.4 Temperature distribution calculation for hull structure
A 3-D symmetric quarter model of the hull, including the cargo tank and cover, may be used for the temperature distribution calculation for the hull structure. The surrounding hull structure should be divided into separate spaces based on the assumption of temperature being uniform in a space.
The temperature distribution shall be calculated at least at the following locations:

(a) Typical cargo hold - the steel temperatures of the hull structure over the cargo hold length may be obtained based on a 3-D quarter model of a typical cargo hold and tank.
(b) Foremost cargo hold - the steel temperature of the hull structure of the foremost cargo hold may be calculated based on a 3-D quarter model of the foremost cargo hold and tank.
(c) Structure between engine room and the aftmost cargo hold - the steel temperatures of the hull structure between engine room and the aftmost cargo hold may be calculated based on a 3-D quarter model of the aftmost cargo hold and tank.
(d) Fore end structure - the temperatures for the fore end structure may be calculated under the ambient condition presented in Table 1.3.1 Ambient conditions for temperature distribution calculation for the hull structure.

All models should be analysed for the two loading conditions specified in 3.2.3. The temperature of a stiffener is taken to be equal to that of the plate to which it is attached. For hopper tank ring webs and second deck passage way frame webs the temperature should be taken as the colder of the attached plate or the surrounding fluid. The temperature of the ring web face plate may be taken to be the same as that of the surrounding fluid.

3.2.5 Temperature distribution calculation for cargo tank and skirt structure

- The temperature distribution calculation for cargo tank and skirt structure shall be carried out for the cargo tank cool-down process and loading process in time steps.
- Initial cargo tank temperature is assumed to be 30°C.
- Temperature of the space outside of the skirt is assumed to be 30°C.

3.2.6 Thermal stress analysis for cargo tank and skirt structure

- The thermal stress shall be combined with mechanical stress for the cargo tank and skirt structure.
- The temperature distributions obtained from 3.2.5 are used as thermal loads for thermal stress analysis of the cargo tank and skirt structure.
- The time steps for the thermal stress analysis are to include those conditions which have the biggest temperature difference between the cargo tank and skirt in the cool-down process and loading process, and stationary fully loaded condition.

3.3 SPB tank liquefied gas carriers

3.3.1 A Type B independent tank primarily constructed of plane surfaces, commonly referred as SPB (Self-supporting Prismatic Type B) tank is similar in configuration to an independent-prismatic Type A tank with the exception of a partial secondary barrier being provided instead of a full secondary barrier in the case of Type A tanks. As an example, a midship section of SPB tank liquefied gas carrier is shown in Figure 1.3.3 Midship section of SPB tank liquefied gas carrier.

3.3.2 Boundary conditions

- Cargo temperature is minus 163°C for LNG.
- Engine room temperature is assumed to be 5°C. A higher temperature may be assumed subject to agreement with LR.
- Ambient conditions for temperature distribution calculation are those required in the IGC Code\(^1\), LR's Rules and Regulations\(^2\) and USCG\(^3\), as listed in Table 1.3.1 Ambient conditions for temperature distribution calculation for the hull structure.

3.3.3 Loading conditions

For the hull structure temperature distribution calculation, a fully loaded condition is to be used with LNG cargo in contact with the secondary barrier. For the cargo tank, the temperature distribution calculation should be carried out in time steps for the cool-down process and loading process. At least the following loading steps, in addition to the time step at which the largest difference in temperature occurs, are to be considered:

(a) Cool-down. The time steps at which the largest differences in temperature occur should be included;
(b) Starting loading;
(c) Loading level at No.1 horizontal girder;
(d) Loading level at No.2 horizontal girder;
(e) Loading level at No.3 horizontal girder if fitted;
(f) Loading level at the mid depth of the cargo tank;
(g) Fully loaded.

Figure 1.3.3 Midship section of SPB tank liquefied gas carrier
3.3.4 Temperature distribution calculation for hull structure

2-D models may be used for the temperature distribution calculation for the hull structure of SPB tank liquefied gas carriers. The temperature distribution is to be calculated at least at the following locations:

(a) Midship - A 2-D temperature distribution calculation model based on the midship section can be used for steel grade selection for the hull structure in region fitted with common cargo tanks, generally aft of the foremost tank and may include the aftmost tank.

(b) Foremost cargo tank - 2-D temperature distribution calculation models based on the foremost cargo tank sections can be used for steel grade selection for the hull structure over the length of the foremost tank. Due to the tapered tank, more than one section may be selected. The steel temperature shall be calculated based on the lowest temperature of the tank.

(c) Fore end hull structure - the temperature of the fore end structure can be calculated under the ambient conditions presented in Table 1.3.1 Ambient conditions for temperature distribution calculation for the hull structure.

(d) Hull structure between engine room and aftmost cargo tank can be calculated based on the assumptions presented in 3.3.2. The temperature of a stiffener may be taken to be equal to that of the plate to which it is attached. For hopper tank ring webs the temperature should be taken as the colder of the attached plate or the surrounding fluid. The temperature of the ring web face plate may be taken to be the same as that of the surrounding fluid.

3.3.5 Temperature distribution calculation for cargo tank

• Similar models used for the hull structure temperature distribution calculation can be used for the cargo tank temperature distribution calculation based on the loading steps described in 3.3.3.

• Initial cargo tank temperature for thermal stress analysis is assumed to be 30°C.

3.3.6 Thermal stress analysis for cargo tank

• Thermal stress shall be combined with mechanical stress for the cargo tank.

• The temperature distributions obtained from 3.3.5 are used as thermal loads for thermal stress analysis of the cargo tank structure.

3.4 Type A tank liquefied gas carriers

3.4.1 For liquefied gas carriers with independent prismatic cargo tanks, the tank is independent from the hull structure and is supported at the bottom and restrained against movement at anchor points. Insulation is applied on the outside of the tank. A complete secondary barrier is required where the hull structure acts as the secondary barrier. As an example, the midship section of Type A tank liquefied gas carrier is shown in Figure 1.3.4 Midship section of Type A tank liquefied gas carrier. To determine the steel grades of the hull structure, a temperature distribution analysis should be carried out based on the following conditions.

3.4.2 Boundary conditions

• Cargo temperature is the minimum design cargo temperature.

• Engine room temperature is assumed to be 5°C. A higher temperature may be assumed subject to agreement with LR.

• Ambient conditions for temperature distribution calculation are those required in the IGC Code, LR’s Rules and Regulations and USCG as listed in Table 1.3.1 Ambient conditions for temperature distribution calculation for the hull structure.

3.4.3 Loading conditions

The following loading conditions are to be considered:

(a) Static fully loaded condition with the complete secondary barrier assumed to be at the minimum design temperature.

(b) Static fully loaded condition at a heeling angle of 30° with the complete secondary barrier assumed to be at the minimum design temperature.

3.4.4 Temperature distribution calculation for hull structure

2-D models may be used for the temperature distribution calculation for the hull structure of Type A tank liquefied gas carriers. The temperature distribution shall be calculated at least at the following locations:

(a) Midship - A 2-D temperature distribution calculation model can be constructed based on the midship section for steel grade selection of the secondary barrier and the hull structure over the length of the cargo hold with cargo tanks of same geometry, typically all tanks aft of the foremost tank excluding the aftmost tank.
(b) Foremost cargo hold - 2-D temperature distribution calculation models based on the foremost cargo hold sections can be used for steel grade selection for the hull structure over the length of the foremost cargo hold. Due to the tapered hold, more than one section may be selected. The steel temperature shall be calculated based on the lowest temperature of the space.

(c) Fore end hull structure - The temperature distribution for the hull structure in the fore end region is to be calculated.

(d) Hull structure between engine room and aftmost cargo hold - The temperature distribution should be calculated for the structure between the engine room and aftmost cargo tank. The temperature of a stiffener is taken to be equal to that of the plate to which it is attached. For transverse frame webs, hopper tank ring webs and top side tank ring webs the temperature is taken as the colder of the attached plate or the surrounding fluid. The temperature of the attached face plate is taken to be the same as that of the surrounding fluid.

3.4.5 Thermal stress analysis
Since the minimum cargo temperature that is feasible to be carried in Type A LPG tanks is typically down to minus 55°C, and the tanks are designed to allow contraction over the supports, a thermal stress analysis is not generally required by the IGC. Should this not be the case, then a similar approach explained in SPB tanks should be adopted.

3.5 Type C tank liquefied gas carriers

3.5.1 A secondary barrier is not required for a Type C independent tank. As an example, a midship section of Type C tank liquefied gas carrier is shown in Figure 1.3.5 Midship section of Type C tank liquefied gas carrier.

3.5.2 Boundary conditions
- Cargo temperature is the minimum design cargo temperature in cargo tanks.
- Engine room temperature is assumed to be 5°C. A higher temperature may be assumed subject to agreement with LR.
- Ambient conditions for temperature distribution calculation for the hull structure are those required in the IGC Code¹, LR’s Rules and Regulations² and USCG³.

3.5.3 Loading conditions
Static fully loaded condition is to be used for the temperature distribution calculation for the hull structure.

3.5.4 Temperature distribution calculation for hull structure
2-D models may be used for the temperature distribution calculation for the hull structure of Type C tank liquefied gas carriers. The heat transfer due to conduction through the cradle support shall be included. The temperature distribution shall be calculated at least at the following locations:

(a) Midship - A 2-D temperature distribution calculation model can be constructed based on the midship section for steel grade selection for the hull structure over the length of common cargo tanks.

(b) Foremost cargo hold - A 2-D temperature distribution calculation model can be constructed based on the foremost cargo hold section for steel grade selection for the hull structure over the length of the foremost cargo hold.

(c) Fore end hull structure - The temperature distribution should be calculated for the hull structure in the fore end region.

(d) Hull structure between engine room and aftmost cargo hold - The temperature distribution should be calculated for the structure between the engine room and aftmost cargo tank. The temperature of a stiffener is taken to be equal to that of the plate to which it is attached. For transverse frame webs the temperature is taken as the colder of the attached plate or the surrounding fluid. The temperature of the attached face plate is taken to be the same as that of the surrounding fluid.

3.5.5 Thermal stress analysis
- For traditional Type C tank liquefied gas carriers, the thermal stress analysis generally is not performed.
- If the minimum design cargo temperature is below minus 55°C, the thermal loads during the cooling down period shall be considered. If significant temperature gradients are present in the tank and hull structure, the thermal stress analysis shall be carried out. The analysis method presented in 3.1 Membrane tank liquefied gas tankers to 3.4 Type A tank liquefied gas carriers can be used as references.
Section 4
Steel Grades Selection

4.1 General
4.1.1 According to the temperature distributions calculated, the steel grades of the hull structure are to comply with the requirements of the IGC Code\(^1\), LR’s Rules and Regulations\(^2\) and USCG\(^3\) for service in U.S. waters.

Footnotes

\(^1\) International Maritime Organization (IMO), *International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk*.

\(^2\) Lloyd’s Register’s *Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk*.

\(^3\) US Coast Guard (USCG), CFR 46, Ch I, Pt 154 – *Safety Standards for Self-Propelled Vessels Carrying Bulk Liquefied Gases*.

\(^4\) Lloyd Register’s *ShipRight Procedure Analysis of Pump Tower and Pump Tower Base*. 