Guidelines on

Structural Assessment of Ships carrying Asphalt in Independent Cargo Tanks

2020

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Guidelines

Structural Assessment of Ships carrying Asphalt in Independent Cargo Tanks 2020

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Section 1

Introduction

1.1 General

1.1.1 The present guidelines indicate requirements for structural assessment of the hull and the independent cargo tanks of ships carrying Asphalt/ Bitumen cargoes at temperatures θ^{o} C in accordance with the additional Class Notation, ASPHALT CARRIER (INDEPENDENT TANKS, MAX. CARGO TEMP ≤ XXX℃), Construction requirements for such vessels are specified in Part 5, Chapter 2 of the *Rules and Regulations for the Construction and Classification of Steel Ships*, hereinafter referred to as the Rules.

1.1.2 IRS will specially consider structural assessment of the hull and the independent cargo tanks where designed using other rules or standards, provided it is established that these are no less strict than the requirements in the present guidelines.

1.1.3 Carriage of asphalt cargoes at temperatures exceeding 300^{o}C is not permitted. Carriage of cargoes at such temperatures will be specially considered by IRS.

1.2 Principles of Assessment

1.2.1 The effects of elevated temperature on the material properties in terms of reduction of yield strength, elastic modulus should be considered. The present guidelines contain requirements on the method to quantify this reduction. However, IRS will consider specially any alternative techniques in form of performed material test data or established literature for this purpose.

1.2.2 The effects of thermal stresses on the hull and the independent cargo tank due to the elevated temperatures of the asphalt cargo are to be considered during the scantlings assessment and direct calculations.

1.2.3 Linear elastic behavior of the material of the independent cargo tank can be assumed, unless the material test data for the material at the cargo temperature indicate otherwise.

1.2.4 Environmental conditions in the present rules correspond to the North Atlantic, however route specific conditions may be applied, if the vessel is envisaged to ply only on certain routes which have environment less severe as compared to North Atlantic. Such conditions would be listed as service restrictions.

1.2.5 If environmental conditions encountered by the ship are expected to be more severe than the North Atlantic, then these are to be applied.

1.2.6 The loading procedures and loading rates of cargo are to be selected appropriately so as not to impose thermal shock on the hull and independent cargo tank structures.

Section 2

Hull and Independent Cargo Tank Structure

2.1 Thermal Analysis

2.1.1 Thermal analysis is to be performed to determine the temperature of the hull including the independent cargo tank support structure. The purpose of the analysis is to determine the hull temperatures so as to evaluate the reduction of the yield strength and the elastic modulus as well as the thermal stresses.

2.1.2 The maximum operating cargo temperature is to be considered for the thermal analysis. It is to be assumed that this temperature is uniform throughout the tank and the tank is considered to be completely filled.

2.1.3 Conduction, Convection and Radiation modes of heat transfer are to be considered as applicable for all elements participating in the heat transfer. When considering radiation mode, the temperature is to be used in Kelvin scale.

2.1.4 For the purpose of calculation, the following conditions are to be considered:

- ambient air temperature is to be taken as 45^o C and the ambient water temperature is to be taken as 32^o C.
- the ambient air temperature is to be taken as 5^o C and the ambient water temperature is to be taken as 0^o
- More onerous conditions are to be used for ships which trade in more severe environments than those as specified above.

2.2 Material Properties at Elevated Temperatures

2.2.1 The reduction in material properties of the hull and independent cargo tank structural steel at elevated temperatures (θ^oC) is to be considered for $\theta \geq 80^o$C. For $\theta<80^o$C, the properties of structural steel, as specified in Part 3 of the Rules can be used.

2.2.2 The reduced yield strength of steel ${f_y}^\theta$ is to be estimated using the equation below in absence of any other data for $\theta < 300^o$C.

$$ {f_y}^\theta = f_y\left(1.04 - 0.75\frac{\theta}{1000}\right) $$

2.2.3 The elastic modulus of steel is to be estimated using the equation below in absence of any other data $\theta < 300^o$C.

$$ E^\theta = 205000\left(1.00 - 0.66\frac{\theta}{1000}\right) $$

Note : The reduction in the yield strength and elastic modulus is based upon the data in [1]. Use of actual test data is encouraged to compute the reduction with a higher degree of confidence.

2.3 Hull Scantlings Evaluation

2.3.1 The evaluation of hull scantlings is to be in accordance with Part 3 of the Rules, for the different hull structural members, considering the appropriate ‘k’ factor by utilizing the yield strength of steel at the applicable hull temperature as described in Section 2.2.

2.3.2 Direct calculations are to be performed to verify the scantlings. The requirements and procedure for the analysis is described in Section 3.

2.3.3 Fatigue analysis of the hull is to be performed for the cargo hold region for ships with rule length > 90 m. The procedure for the fatigue analysis is described in Section 4.

2.3.4 Local fine mesh analysis is to be performed for the hull structure in way of the independent cargo tank supports to verify its integrity against the reactions of the independent cargo tank supports. For this finite element analysis is recommended. The procedure for the analysis is described in Section 3.4.

2.4 Independent Cargo Tank Arrangement and Scantlings Evaluation

2.4.1 The following are to be provided for the Independent Cargo Tanks for carriage of asphalt:

- Supports for the vertical loads imposed by the Independent Cargo Tanks
- Anti-floatation supports
- Anti-rolling supports
- Anti-pitching supports

2.4.2 The number and arrangement of the independent cargo tank supports should ideally be selected such that the effects of the hull deformations on the stresses are not significant.

2.4.3 The reaction forces from the independent cargo tank supports should be appropriately transferred to the primary structural members of the hull.

2.4.4 Independent cargo tanks are to be designed considering them as deep tank bulkheads (please refer Part 3, Chapter 10 of the Rules). For this, the yield strength of the steel is to be considered as provided in Section 2.2. The ‘k’ factor is to be suitably modified. The contribution of the hull girder stresses may be disregarded for the evaluation of the scantlings of the independent cargo tanks.

2.4.5 The dynamic cargo pressures are to be evaluated considering the procedure provided in Part 5, Chapter 4, Section 4.28 of the Rules.

2.4.6 The reaction forces on the independent cargo tank supports obtained from the direct strength analyses in Section 3 are to be used for verification of the strength of the chock supports provided within the various arrangements (as described in 2.4.1) in terms of the permissible bearing pressures and transverse loads (see also 3.3.7.3).

Section 3

Direct Strength Analysis

3.1 Aim and Objective

3.1.1 The objective of the direct strength analysis is to verify the adequacy of the primary structural members of the hull and the independent cargo tanks.

3.1.2 The following items are assessed by the direct strength analysis:

- Cargo Hold Analysis – Structural integrity of the hull girder within the cargo hold region considering combined effects of global and local loads for the yield and ultimate strength/buckling failure modes (assessed using a coarse mesh finite element analysis)
- Independent Cargo tank analysis – Structural integrity of the independent cargo tanks including the support structures considering the dynamic cargo pressures, thermal loads, hull girder deflection as applicable.
- Local Fine Mesh Analysis – Structural integrity of the critical locations within Hull and Independent Cargo tank primary structure (assessed using fine mesh finite element analysis)

3.1.3 Cargo hold analysis is mandatory for ships having rule length exceeding 90m. Independent cargo tank and Local Fine Mesh analysis are required irrespective of the ship size.

3.1.4 The results from the Direct Strength Analysis are not to be used to reduce the scantlings obtained from the applicable prescriptive calculations specified in Part 3 of the Rules.

3.1.5 The present section elaborates requirements for cargo holds within 0.4L amidships. For cargo holds outside this region, principles of this procedure can be applied to verify the scantlings.

3.2 Cargo Hold Analysis

3.2.1 Scope and Extent of the Model

3.2.1.1 A finite element model of the cargo hold within 0.4L mid-ships is to be developed. This typically, would be covering three cargo holds. The central cargo hold is applicable to evaluation of the acceptance criteria (specified in the following sub-sections).

3.2.1.2 All primary structural members with their associated stiffening and faceplates are to be modeled. Primary Structural members are generally listed below for the information of the user but not limited to:

- Outer-hull and Inner-Hull
- Decks, Girders and Stringers
- Longitudinal Bulkheads
- Transverse Bulkheads and Cross deck structures
- Trunk deck structures
- Web-frames
- Large brackets

Independent cargo tanks may also be modeled along with the hull structural model. If modeled, then separate analysis as per Section 3.3 is not required.

3.2.2 Scantlings

3.2.2.1 Gross scantlings are to be considered for the finite element model.

3.2.3 Finite Element Modeling

3.2.3.1 The objective of the finite element model is to accurately capture the structural rigidity of the hull girder in the cargo hold region by modeling the primary and secondary structural members using the appropriate elements with the appropriate options. Any deviations from the provisions of this section are to be agreed with IRS at an early stage.

3.2.3.2 All primary structural members are to be modeled using 4 node plate/shell elements. Commercial finite element packages popularly provide these elements using reduced integration options as default. It is recommended to switch on the full integration options in the software package or ensure a mesh size adequate enough to eliminate the possibility of development of spurious deformation modes.

3.2.3.3 All stiffening members for the primary structural members including faceplates can be modeled using beam elements. The appropriate offsets should be specified while modeling such members so as to ensure the correct representation of the offset of their centroids from the main plating.

3.2.3.4 Small openings need not be modeled. The criteria for definition of a 'small opening' can be referred from the *IRS Rules for Bulk Carriers and Oil Tankers,* Vol.2, Chapter 7. Large openings and manholes are to be modeled.

3.2.3.5 The mass of the hull structure can be modeled by specifying the steel density (preferable) or by applying vertical forces distributed appropriately at the nodes.

3.2.3.6 The material properties of steel can be assumed to be linear elastic. The elastic modulus to be used for the finite element should be evaluated based upon the applicable hull member temperature using the equations in Section 2.

3.2.3.7 Thermal expansion co-efficient of steel can be taken as 1.2×10^{-5} /^{o}C in absence of actual data.

3.2.4 Mesh size

3.2.4.1 The mesh size is to be such that there is one finite element between two adjacent stiffeners and atleast three elements between two adjacent frames.

3.2.4.2 The aspect ratio of the elements should be kept as close to 1 as practicable. It should however not exceed 2.

3.2.5 Modeling Report

3.2.5.1 A report illustrating the finite element modeling is to be submitted to IRS. The report is to include the following but not be limited to:

- Cargo holds modeled
- Software package used for analysis
- Drawings/Plans used for the modeling (the revision number of the plan is to be clearly mentioned)
- Number of elements in the model and the maximum aspect ratio achieved.
- Any assumptions considered while modeling the primary structural members
- Mesh size used.
- Details of modeling of the mass of the hull structure within the cargo hold and other masses as described in 3.2.3.5.
- Thickness plots to demonstrate the modeling according to the latest approved/revised drawing
- Stiffener section details and plots to demonstrate the modeling according to the latest approved/revised drawing
- If deemed necessary, IRS may request the finite element model to be submitted.

3.2.6 Loads

3.2.6.1 Loading Conditions

3.2.6.1.1 The loading conditions to be considered for the analysis are as follows:

- Homogenous loading at scantling draft
- All tanks empty at ballast draught
- Non-homogenous loading conditions (one or more independent cargo tanks empty within the cargo hold(s)) at the applicable drafts as provided in the loading manual.
- One cargo hold flooded with independent cargo tank completely loaded

3.2.6.2 Global Loads

3.2.6.2.1 The Still water and the wave bending moments to be used in the analysis are to be in accordance with the those provided in Part 3 of the Rules.

3.2.6.2.2 The Still water and the Wave shear forces to be used in the analysis are to be in accordance with those provided in Part 3 of the Rules.

3.2.6.3 Local Loads

3.2.6.3.1 External Sea Pressure

.1 External Sea Pressure is composed of the sum of the static and the dynamic pressures as provided in Part 3, Chapter 7 of the Rules. The external sea pressures considering crest and trough conditions are to be used as described below:

A) Wave Crest

a. Below Waterline

$$p = 0.01(T - h) + 10^{-3}\left(3.5 - \frac{1.5(T - h)}{T}\right)C_w R_s$$

b. Above Waterline

$$p = 10^{-3} R_s k_s\left(C_w - 0.8(t - h)\right)$$

B) Wave Trough

a. Below Waterline

$$p = 0.01(T - h) - 10^{-3}\left(3.5 - \frac{1.5(T - h)}{T}\right)C_w R_s$$

b. Above Waterline

$$p = 0$$

.2 The crest and trough can be taken constant throughout the model length for the purpose of the analysis (i.e. the actual shape of the crest or trough need not be modeled).

.3 The crest or trough is to be applied depending upon the type of loading condition (e.g. hogging or sagging) so as to create the most onerous loading on the cargo holds for the particular loading condition.

.4 For the cargo hold in flooded condition, only static loads are to be applied.

3.2.6.3.2 Reactions from the Independent Cargo Tanks

.1 Reactions from the Independent Cargo Tanks should be applied to the finite element model (see Section 3.3). This is not required for cases where the Independent Cargo tanks are explicitly modeled with the hull structure in the cargo hold.

3.2.6.3.3 Ballast Pressure

.1 Ballast Pressure is to be taken in accordance with the equations as below

$$p = max(\, 0.024 + 0.01 A_c (T_{tank} - h), 0)$$

Here, T_{tank} indicates the height of the topmost point of the tank above baseline. *h* is the height above baseline of the point where the pressure is to be evaluated. A_c is the most onerous acceleration in the vertical direction (i.e. $1+a_v$ or $1-a_v$, to be chosen to provide the most onerous combination with the global loads. Part 3 should be referred for calculation of a_v).

3.2.6.3.4 Thermal Loads

.1 The temperature distribution on the hull structure in the cargo hold as evaluated using Section 2 is to be applied on the finite element model. The reference (installation) temperature can be assumed as 20^{o}C for the purpose of evaluating the thermal strains and stresses in absence of actual data.

3.2.7 Boundary Conditions

3.2.7.1 Independent Points are to be created at the aft and the fore ends of the finite element model, which act as the master node of all the nodes (only those attached to the longitudinal strength members; hereafter referred to as slave nodes) at the aft and fore ends. All degrees of freedom of the aft and the fore slave nodes are to be coupled with the master node at the corresponding independent point.

3.2.7.2 At the aft independent point, U_X=U_Y=U_Z=0. At the fore independent point, U_Z=U_Y=ROT_X=0. The co-ordinate system of the ship remains identical to that depicted in Part 3 of the Rules.

3.2.8 Model Balancing

3.2.8.1 The model balancing is performed to ensure correct achievement of the target bending moment in the mid-cargo hold. The target bending moment is given in the equation below:

$$M_{target} = M_{sw} + M_w$$

3.2.8.2 The bending moment is maximized at the centre of the mid-cargo hold. This leads to the target shear force being zero at the same location. The end reaction forces (excluding the reaction force in the X direction) at the aft and the fore master nodes are to be zero (practically less than 0.1% of the net vertical force).

3.2.8.3 The balancing is achieved by applying forces and moments (F_A, M_A, F_F, M_F) at the master nodes attached to the aft and fore independent points. The procedure for balancing is described through Fig.3.2.8.3 and the following equations. While developing the equations, the target shear at the considered location (X_{target}) is taken as zero, since the bending moment (M_{target}) is to be maximized at the same location. The solution of the four equations yield the four end forces. These forces are to be finally applied to the model and the model is to be solved to obtain the deformations and stresses; which are to be assessed using the acceptance criteria.

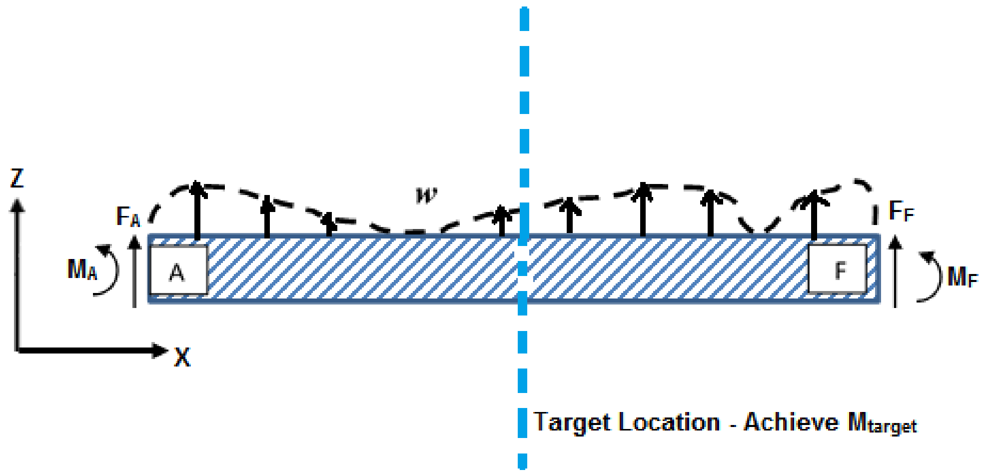

Fig.3.2.8.3 : Model Balancing scheme

$$F_A + F_F + \int_{X_A}^{X_F} w(x)dx = 0$$

$$F_A + \int_{X_A}^{X_{target}} w(x)dx = 0$$

$$M_A + M_{target} + \int_{X_A}^{X_{target}} w(x)xdx = 0$$

$$M_A + M_F + \int_{X_A}^{X_F} w(x)xdx = 0$$

3.2.9 Acceptance Criteria

3.2.9.1 Yield Failure Mode

3.2.9.1.1 Plate/Shell Elements

.1 The stresses in the Plate element (σ_x, σ_y and τ_{xy}) are to be extracted from the model. The von-mises equivalent stress is to be computed as given below:

$$\sigma_e = \sqrt{\sigma_x{}^2 + \sigma_y{}^2 - \sigma_x\sigma_y + 3\tau^2}$$

.2 The von-mises equivalent stress in the plate/shell elements is not to exceed $0.85 f_y{}^\theta$. where $f_y{}^\theta$ is to be evaluated in accordance with Section 2.

3.2.9.1.2 Beam Elements

.1 The maximum stresses in the beam elements are to be computed as the combination of axial and bending stress. Maximum shear stress is also to be obtained.

.2 The maximum axial stresses in the beam elements are not to exceed $0.7 f_y{}^\theta$. The maximum shear stresses in the beam elements are not to exceed $f_y{}^\theta$ /√3. $f_y{}^\theta$ is to be evaluated in accordance with Section 2.

3.2.9.2 Buckling/Ultimate Strength Failure Mode

.1 Buckling/Ultimate Strength of Plate Panels, Stiffened Panels and Stiffeners are to be evaluated as provided in the *IRS Rules for Bulk Carriers and Oil Tankers*, Vol.2, Chapter 8. The analysis is to consider the reduced yield stress f_y^{θ} due to the elevated temperature as specified in Section 2.

.2 IRS will specially consider buckling/ultimate strength evaluation using non-linear finite element techniques in lieu of the provisions on 3.2.9.2.1. For this purpose, it has to be demonstrated to the satisfaction of the IRS that the program using non-linear finite element techniques gives satisfactory results. The program is to be able to consider the effects of initial imperfections in the plating according to IACS Recommendation. 47 and residual stresses.

3.3 Independent Cargo Tank Strength Analysis

3.3.1 General

3.3.1.1 Direct calculations are required to verify the scantlings of the independent cargo tank considering the incumbent loads and the support arrangements.

3.3.1.2 Direct calculations are not separately required when the independent cargo tank is modeled along with the hull structure for the cargo hold analysis.

3.3.2 Scope

3.3.2.1 The scope of the analysis is the independent cargo tank primary structure including the supporting structures (including the hull strengthening i.w.o of the cargo tank supports).

3.3.2.2 The reactions on the supports obtained from the analysis are to be used to verify the structural integrity of the adjoining hull structure strengthening i.w.o of the supports. The strengthened hull structure i.w.o of the independent cargo tank supports may be separately modeled or modeled along with the independent cargo tank for this purpose.

3.3.3 Modeling

3.3.3.1 The following independent cargo tank structural members are to be modeled using finite elements

- Tank plating
- Stringers and girders
- Internal bulkheads
- Stiffeners and large brackets
- Large openings
- Primary members i.w.o of the tank supports, anti-floatation, anti-pitching and anti-rolling supports.

3.3.3.2 Shell/Plate elements should be used to model the tank plating as well as the bulkheads, girders and stringers. Stiffeners may be modeled using beam elements.

3.3.3.3 Large openings should be modeled as detailed on the structural drawings

3.3.3.4 Gross scantlings should be used for the finite element model.

3.3.3.5 The finite element model should be discretized such that there is atleast one element between every two adjacent stiffeners and atleast four elements between two adjacent frames. It is recommended to have atleast three elements across the girders and stringer webs. The final aim is to correctly simulate the structural rigidity of the tank structure and the support arrangements.

3.3.4 Material Properties

3.3.4.1 The material properties of independent cargo tank structural steel can be assumed to be linear elastic. The elastic modulus to be used for the finite element should be evaluated based upon the applicable elevated temperature using the equations in Section 2.

3.3.4.2 Thermal expansion co-efficient of steel can be taken as 1.2×10^{-5} /°C in absence of any other data.

3.3.4.3 If the cargo tank structure is fabricated from a material/alloy which is different from structural steel, then the material properties will be specially considered by IRS.

3.3.5 Loads

3.3.5.1 Structural and Outfitting Mass

.1 Structural mass of the independent cargo tank is to be modeled as accurately as possible. Mass of the attached insulation, piping and other outfitting may be modeled as actual structural mass element or assigning equivalent density to the cargo tank structural elements.

3.3.5.2 Cargo Pressures and Support Reactions

.1 Cargo Tank accelerations should be evaluated for different scenarios and loading patterns (see 3.3.5.5) and these should be considered for determining the dynamic cargo pressures as well as the reaction forces to be applied on the cargo hold model. The following conditions are mandatorily recommended:

- Total Maximum vertical force on the supports
- Total Maximum vertical force on the anti-floating arrangement
- Total Maximum reaction on the anti-rolling arrangement
- Total Maximum reaction on the anti-pitching arrangement

.2 Asymmetrical nature of the independent cargo tank and arrangement of the supports should be considered if applicable.

3.3.5.3 Thermal Loads

.1 The temperature distribution on the cargo tank structural members and supports is to be modeled as evaluated in Section 2.

3.3.5.4 Hull girder deflections

.1 Hull girder deflections underneath the cargo tank supports should be considered for the analysis. These can be applied as translations (3 DOF) at the tank supports.

3.3.5.5 Loading patterns

.1 The independent cargo tank is to be considered completely filled for the analysis. For independent tank subdivision with internal bulkheads which permit segregation, the most onerous conditions are to be considered (e.g. alternate loading, checkerboard loading pattern). However, if the cargo will not be loaded in such patterns through the life of the ship, then these conditions may be disregarded with addition of a note to this effect to the classification certificate.

.2 The loading patterns described in 3.3.5.5.1 should also be considered for the thermal analysis subject to their applicability.

.3 Partial filling conditions of the cargo tanks (if applicable) will be specially considered by IRS.

3.3.6 Boundary Conditions

3.3.6.1 Vertical restraints at the tank supports (including anti-floatation supports) should be modeled as pinned supports. See also 3.3.5.4.

3.3.6.2 Horizontal restraints in form of anti-pitching and anti-rolling chocks may be modeled similar to the vertical restraints (these restraints should be activated as relevant. e.g. all anti-pitching or anti-rolling chocks would not be typically active depending upon the direction of rolling and pitching motions).

3.3.7 Acceptance Criteria

3.3.7.1 Yield failure

.1 The von-Mises stress should not exceed 0.9 ${f_y}^{\theta}$ for the shell/plate elements for the independent cargo tank. For the strengthened hull structural elements supporting the independent cargo tank, the combined von-mises stress (global and local) should not exceed the allowable stress as specified in 3.2.9.

.2 The axial stress in the beam elements should not exceed $0.75{f_y}^{\theta}$. The shear stresses in the beam elements should not exceed ${f_y}^{\theta}/\sqrt{3}$.

3.3.7.2 Buckling/Ultimate Strength Failure Mode

.1 Buckling/Ultimate Strength of Plate Panels, Stiffened Panels and Stiffeners are to be evaluated as provided in *the IRS Rules for Bulk Carriers and Oil Tankers*, Vol.2, Chapter 8. The analysis is to consider the reduced yield stress ${f_y}^{\theta}$ due to the elevated temperature as specified in Section 2.

.2 IRS will specially consider buckling/ultimate strength evaluation using non-linear finite element techniques in lieu of the provisions on 3.3.7.2.1. For this purpose, it has to be demonstrated to the satisfaction of the IRS that the program using non-linear finite element techniques gives satisfactory results. The program is to be able to consider the effects of initial imperfections in the plating according to IACS Recommendation 47 and residual stresses.

3.3.7.3 Strength of the Chock Supports

.1 The reaction forces at the various types of chock supports are to be utilized to verify their adequacy. This may be carried out by comparison with the allowable forces specified by the manufacturer.

3.4 Local Fine Mesh Analysis

3.4.1 General

3.4.1.1 The present section provides the requirements to be fulfilled by the local structural details using a fine mesh analysis. The analysis of such details is necessary because the stresses obtained using the coarse mesh model may not be accurate due to idealization of the structural detail.

3.4.1.2 It is acceptable to IRS if the coarse mesh and the local fine mesh analysis are performed together using the finite element model where the fine mesh areas are modeled in accordance with the requirements provided within the present sub-section.

3.4.2 Mandatory list of details to be evaluated

3.4.2.1 The following structural details in the cargo hold and the independent cargo tanks are to be subjected to the local fine mesh analysis

- Independent Cargo Tank and Hull Structural details i.w.o of tank supports (atleast one for each support type) including the anti-pitching, anti-rolling and anti-floatation supports.
- Side frames connection with the bottom and the deck plating
- Transverse bulkhead connection with the bottom plating

- Transverse frame connections with the bottom within the independent Cargo tank
- Swash bulkhead and tank bulkhead connections with the bottom within the independent cargo tank
- Other details as identified from the cargo hold and independent cargo tank analysis

3.4.3 Structural Modeling

3.4.3.1 Plate/Shell elements are to be used for modeling.

3.4.3.2 The detail as depicted in the approved drawing is to be modeled.

3.4.3.3 The hotspot(s) are to be flanked by atleast 10 elements in each direction. The aspect ratio of the elements is not to exceed 1.2. The element size is not to exceed 50 mm in any direction.

3.4.3.4 If a local model is used, the extent of the model is to be such that the boundary conditions at the model ends are distant enough to not affect the stress magnitude at the hotspot(s).

3.4.4 Loads

3.4.4.1 The loads and the loading conditions to be considered are the same as provided Section 3.2 and 3.3.

3.4.5 Boundary Conditions

3.4.5.1 If the coarse mesh cargo hold model is being used in conjunction with the local modeling of the fine mesh areas, then the boundary conditions in Section 3.2.7 are to be used.

3.4.5.2 If a local sub-model is used, then the boundary conditions have to be provided based upon the magnitudes of the displacements and the rotations at the respective nodes in the global model; which are then imposed upon the corresponding nodes in the local model.

3.4.6 Model Balancing

3.4.6.1 If the coarse mesh cargo hold model is being used in conjunction with the local modeling of the fine mesh areas, then the balancing procedure in Section 3.2.8 is to be used.

3.4.6.2 If a local sub-model is used, then the model balancing is not to be performed, as the resultant boundary conditions applied at the modeled ends depict the displacement fields of the balanced model.

3.4.7 Acceptance Criteria

3.4.7.1 The utilization factor in yield failure mode is to be determined as below

$$\lambda \le \lambda_{perm}$$
$$\lambda = \frac{\sigma_e}{{f_y}^{\theta}}$$

Where:
σ_e is the maximum von-Mises equivalent stress in the elements immediately adjacent to the hotspot

λ_{perm} = 1.7 (for elements not adjacent to weld)
= 1.5 (for elements adjacent to weld)

Section 4

Fatigue Assessment

4.1 Aim and Objective

4.1.1 Fatigue Assessment is necessary to ensure that the design of the cargo hold and the independent cargo tank primary structure is robust against the deterioration caused due to cyclic loads through the service life of the Ship. The fatigue damage of the structure is evaluated due to the global and local cyclic loads.

4.1.2 Fatigue assessment is mandatory for ships with rule length exceeding 90m.

4.1.3 Spectral Fatigue Analysis would also be acceptable in lieu of the requirements in the present section. Such an analysis is to be in accordance with the *IRS Guidelines for Spectral Fatigue Analysis of Ship Structures*.

4.2 Fatigue Assessment Principles

4.2.1 Fatigue evaluation performed considering the nominal stress or the hotspot stress approach would be acceptable to IRS.

4.2.2 SN curve-based damage evaluation approach is recommended. SN curves considered for evaluation are to be suitable for 97.7% probability of survival.

4.2.3 The nominal stress approach is considered to be adequate for standard fatigue details (e.g. longitudinal stiffener – web frame connection), however hotspot stress evaluation is necessary for certain details especially where a multiaxial state of stress is anticipated.

4.2.4 IRS may consider to omit fatigue assessment for those details which have been designed in accordance with well-established practices and have demonstrated a satisfactory service history (e.g. IRS Rules for Bulk Carriers and Oil Tankers, Vol.2, Part 1, Chapter 9, Section 6).

4.2.5 IRS will specially consider those fatigue details for which weld improvement techniques are utilized. Please refer 4.7.

4.2.6 The long-term stress range is to be determined using the Weibull distribution.

4.2.7 The loads considered for fatigue life evaluation are to consider operations of the ship solely in the North Atlantic environment. For ships engaged on world-wide trade or specific routes, IRS will consider the load evaluation considering the actual wave data on those routes subject to submission of the necessary documentation.

4.2.8 The accumulation of fatigue damage is to be evaluated using the Palmgren-Miner Rule.

4.2.9 The present section prescribes evaluation of the fatigue life considering predominantly high cycle fatigue. Based on its review of the documentation, IRS may request and additional evaluation of the fatigue life, considering low cycle fatigue.

4.2.10 It is recommended to follow procedure and methodology for fatigue assessment as described in [2].

4.3 Structural details for Fatigue Assessment

4.3.1 The following structural details are to be mandatorily assessed:

- All Longitudinal stiffeners – web frame connections within 0.4L of Midships
- Connection of primary structural members with the transverse bulkheads of the Cargo Hold
- Structures in the hull and independent cargo tanks i.w.o of the independent cargo tank supports
- Stiffener-frame connections within the independent cargo tanks
- Primary members- transverse bulkhead connections within the independent cargo tanks

4.4 Loads for Fatigue Assessment

4.4.1 The stress ranges for each structural detail in 4.3 are to be evaluated. These should consider the global loads (bending moments, shear forces), applicable local loads (external sea pressures, cargo pressure, ballast pressures etc.) and any other fluctuating loads. In the absence of any service or site restrictions, the North Atlantic wave environment is to be considered for the evaluation of fatigue loads. It is recommended that the stress ranges be evaluated considering a probability of exceedance which may range from 10^{-3} – 10^{-5} [3]. Consideration of alternate probability of exceedance would need to be suitably justified.

4.4.2 The mean stress effect should be taken into account while evaluating the stress range.

4.4.3 The evaluated stress range should be representative of the stress fluctuations expected over the service life of the ship or 20 years, whichever is higher. The stress cycles considered for the fatigue assessment are not to be less than $1x10^8$.

4.4.4 Local stress concentrations as well as the correlation between the global stress range and the local stress ranges should also be considered (e.g. the maxima of the global stresses and the local stresses may not necessarily occur at the same time).

4.4.6 Finite element methods can also be used to evaluate the stresses for which stress concentration factors are not readily available.

4.5 SN Curves

4.5.1 SN Curves (adapted from the data contained within UK HSE report [4]) as shown in Table 4.5.1 should be used for the fatigue evaluation. It may be noted that these curves are two standard deviations below the median (i.e. 97.7% probability of survival, indicated by the equation $NS^m = K_2$, where N corresponds to the number of fatigue load cycles to failure at stress range S (N/mm^2), K_2 is indicated in the table 4.5.1 for each fatigue class). The SN curves have a change of slope from m to m+2 at N=10^7 cycles, which corresponds to the stress range S_q (N/mm^2). These SN curves are valid for details in air environment or details exposed to sea-water but sufficiently protected from corrosion. For unprotected joints exposed to sea-water, the fatigue life obtained from these curves is to be reduced by a factor of 2. For details which have their life distributed between protective and non-protective environment, this should be considered during the fatigue life evaluation.

Table 4.5.1 : SN Curves

Class	K_1			m	Standard Deviation		K_2	S_q
		Log_{10}	Log_e		Log_{10}	Log_e		
B	2.34E+15	15.3697	35.39	4	0.1821	0.4194	1.01E+15	100.2
C	1.08E+14	14.0342	32.3153	3.5	0.2041	0.47	4.23E+13	78.2
D	3.99E+12	12.6007	29.0144	3	0.2095	0.4824	1.52E+12	53.4
E	3.29E+12	12.5169	28.8216	3	0.2509	0.5777	1.04E+12	47
F	1.73E+12	12.237	28.177	3	0.2183	0.5027	6.30E+11	39.8
F2	1.23E+12	12.09	27.8387	3	0.2279	0.5248	4.30E+11	35
G	5.66E+11	11.7525	27.0614	3	0.1793	0.4129	2.50E+11	29.2
W	3.68E+11	11.5662	26.6324	3	0.1846	0.4251	1.60E+11	25.2

4.5.2 Based upon the class of the detail and type of stress utilized (whether nominal or hotspot), appropriate SN curve should be selected. The SN curves are applicable for plate thicknesses which do not exceed the reference thickness of 22 mm. For plate thickness exceeding 22 mm, the stress range is to be multiplied by a factor $(t/22)^{0.25}$, where t is the thickness of the member whose fatigue life is being evaluated.

4.5.3 The SN curves in Table 4.5.1 are generally utilized for hull structural members with temperatures at ambient environment conditions. For hull and independent cargo tank structural members which are subject to higher temperature loading through their life, pertinent data is to be used for the fatigue evaluation (typically more rapid rate of structural deterioration due to fatigue is expected). This data is to be submitted to IRS (see also 4.6.3).

4.6 Fatigue Life Evaluation

4.6.1 Fatigue life evaluation is based upon the Palmgren-Miner damage summation. The damage index D=1 is to be considered to be the limit state for fatigue failure.

4.6.2 The fatigue life of all the mandatory details should not be less than the service life of the ship or 20 years, whichever is higher.

4.6.3 For fatigue locations at high temperatures for which SN data is not available (see 4.5.3), IRS may accept a fatigue life evaluated using fatigue design factor of 2.

4.7 Fatigue Life Improvement

4.7.1 The use of weld improvement techniques such as burr grinding, hammer peening etc. may be considered for enhancing the fatigue life of the structural details. These should be clearly indicated on the drawings for those structural details where they are to be used along with other accompanying information as may be necessary.

4.7.2 The fatigue life improvement using the techniques in 4.7.1 is to be documented in the report with suitable justification for the expected increase in fatigue life using the above techniques.

References

1. Steel Construction Institute (1990). Fire Resistant Design of Steel Structures – A handbook to BS 5950: Part 8. SCI Publication 080. ISBN 1870004485.

2. Espen Cramer, Robert Loseth, Kjell Olaison (1995). Fatigue Assessment of Ship Structures. Journal of Marine Structures. Vol.8, pp. 359-383.