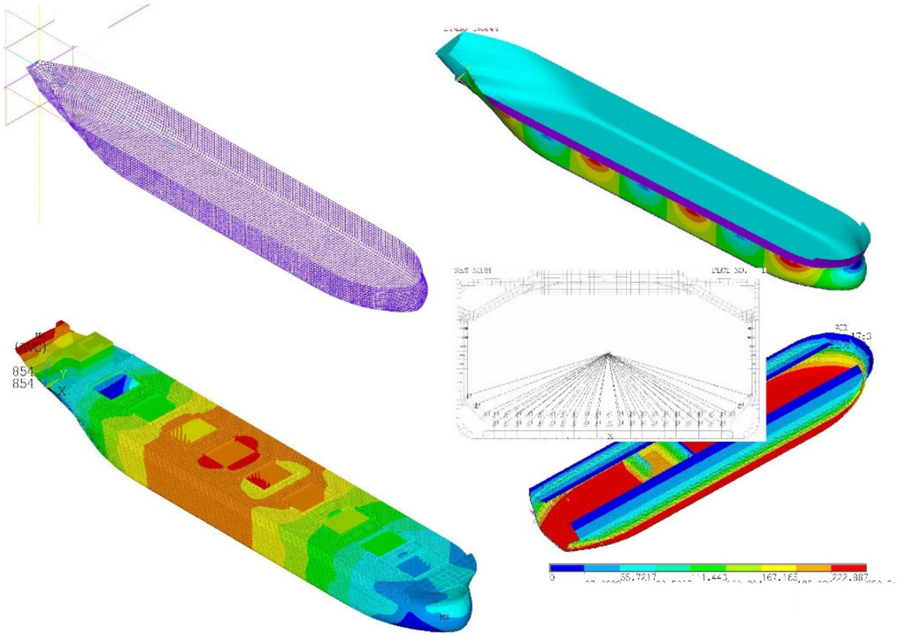
Guidelines on
Application of Direct Seakeeping Loads in Structural Analysis of Ships

2020



IRCLASS

Indian Register of Shipping

CONTENTS

Abbreviation

AP : Aft perpendicular
BL : Base line
CG : Centre of gravity
CL : Centre line
EDW : Equivalent design wave
FE : Finite element
FP : Forward perpendicular
LCB : Longitudinal centre of buoyancy
LCF : Longitudinal centre of flotation
LCG : Longitudinal centre of gravity
RAO : Response amplitude operator
TCG : Transverse centre of gravity
VCG : Vertical centre of gravity

Coordinate System

The coordinate system is defined as follows:

Origin **:** AP, CL, BL
+ve X axis **:** Along the ship’s length from Aft to Fore
+ve Y axis **:** Along the Ship’s beam from CL to Port
+ve Z axis **:** Along the Ship’s depth from Baseline

1. GENERAL

1.1 This document is intended to provide guidelines for the application of direct seakeeping loads in structural analysis of ships. The important aspects and requirements related to application of loads on FE model are discussed in detail.

2. SCOPE

2.1 Present guideline is to be used in conjunction with the guidelines IRS-G-DES-04 and IRS-G-DES-05.

2.2 This application of guideline is as follows in case of:

- Full ship strength analysis with reference to IRS-G-DES-05 Section 2, [2.1].
  - An overview of structural strength analysis of full ship is shown in the Figure 2.2.1.
- The load is to be calculated as per the guideline IRS-G-DES-05. Computed loads are to be transferred to FE model in accordance with the present guideline (IRS-G-DES-06) Spectral fatigue analysis is to be carried out in accordance with guideline IRS-G-DES-04.
  - An overview of spectral fatigue analysis is shown in the Figure 2.2.2. More details are given in Appendix – A.
  - The load is to be calculated as per the guideline IRS-G-DES-05. Computed loads are to be transferred to FE model in accordance with the present guideline (IRS-G-DES-06)

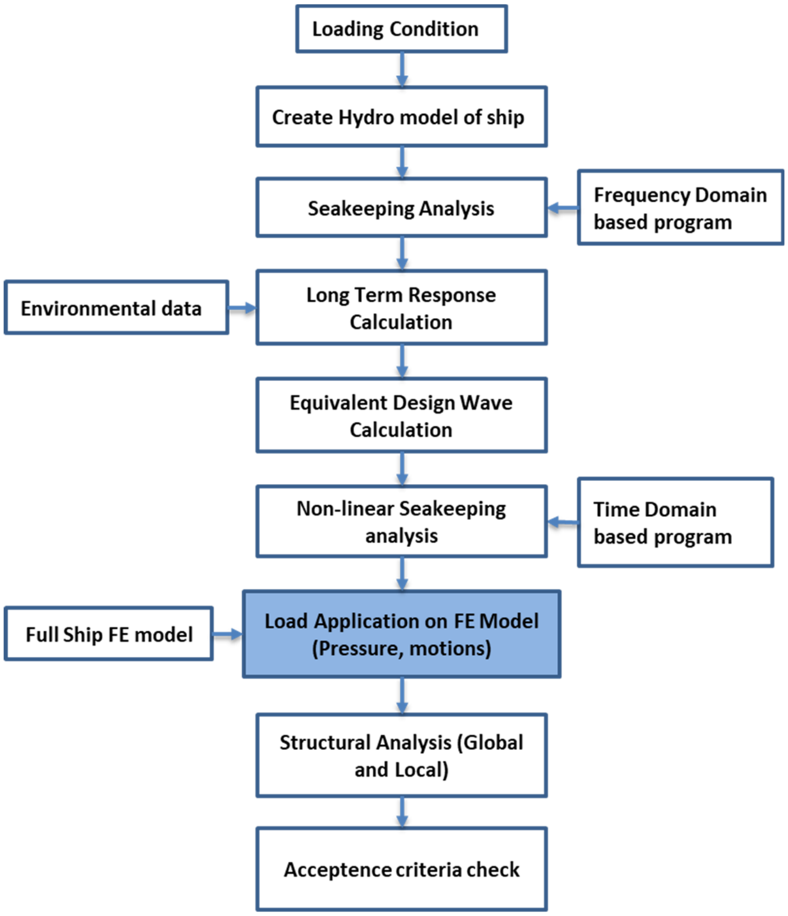


Figure 2.2.1: Schematic representation of full ship Strength Analysis

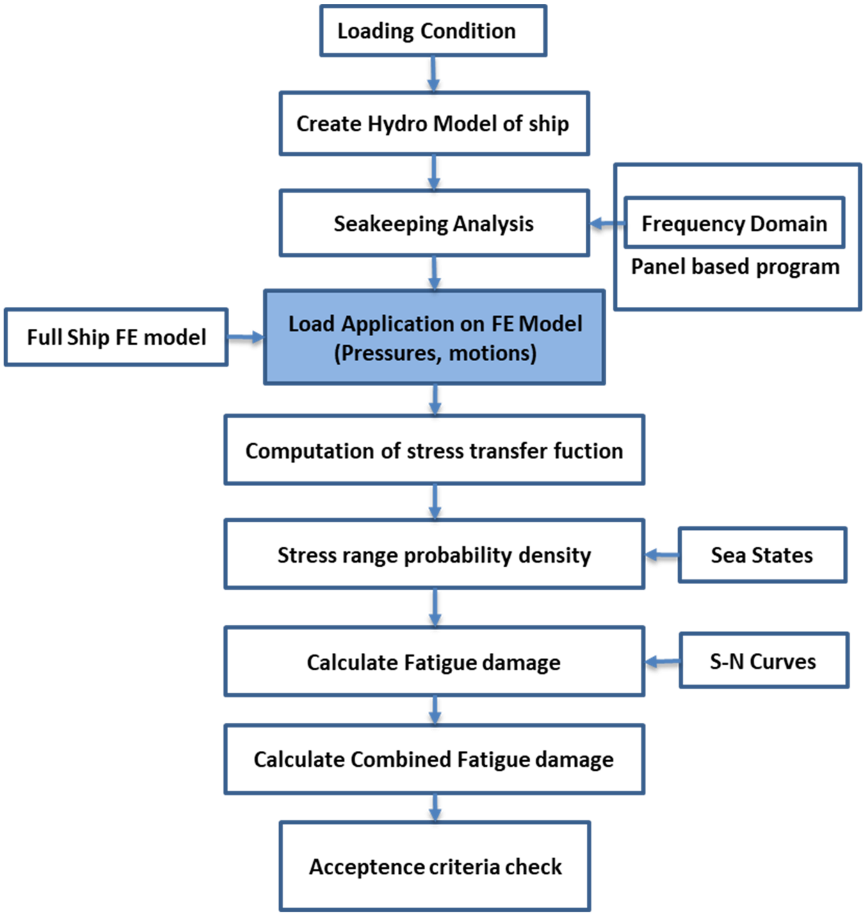


Figure 2.2.2: Schematic representation of Spectral based Fatigue Strength Analysis

3. GLOBAL CORDINATE SYSTEM

3.1 General

3.1.1. The following co-ordinate system is recommended; right hand co-ordinate system, with the x-axis positive forward, y-axis positive to port and z-axis positive vertically from baseline to deck. The origin should be located at the intersection between aft perpendicular (AP), baseline and centreline. The co-ordinate system is illustrated in Figure 3.1 along with the definition of positive motion.

3.1.2 The sign conventions (Refer Figure 3.2) for hull girder loads are as follows:

- The vertical bending moments M_{sw} and M_{wv} are positive when they induce tensile stresses in the strength deck (hogging bending moment) and negative when they induce tensile stresses in the bottom (sagging bending moment).
- The vertical shear forces Q_{sw}, Q_{wv} are positive in the case of downward resulting forces acting aft of the transverse section and upward resulting forces acting forward of the transverse section under consideration.
- The horizontal bending moment M_{wh} is positive when it induces tensile stresses in the starboard side and negative when it induces tensile stresses in the port side.

- The torsional moment M_{wt} is positive in the case of resulting moment acting aft of the transverse section following negative rotation around the X-axis, and of resulting moment acting forward of the transverse section following positive rotation around the X-axis.

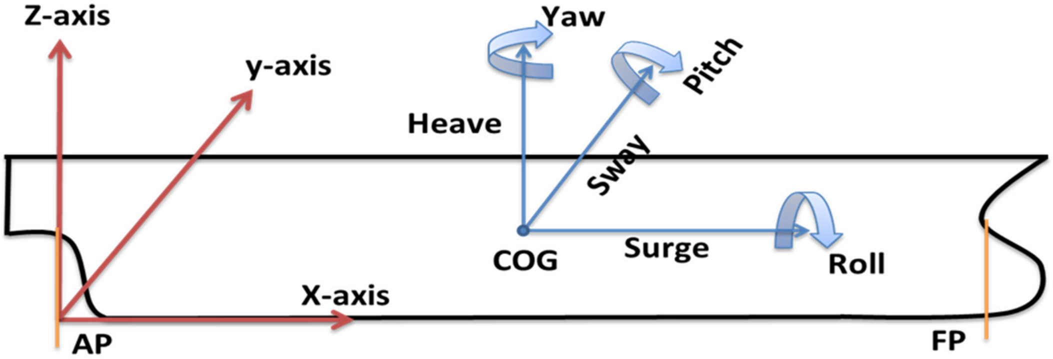


Figure 3.1: Reference coordinate system and definition of positive motions

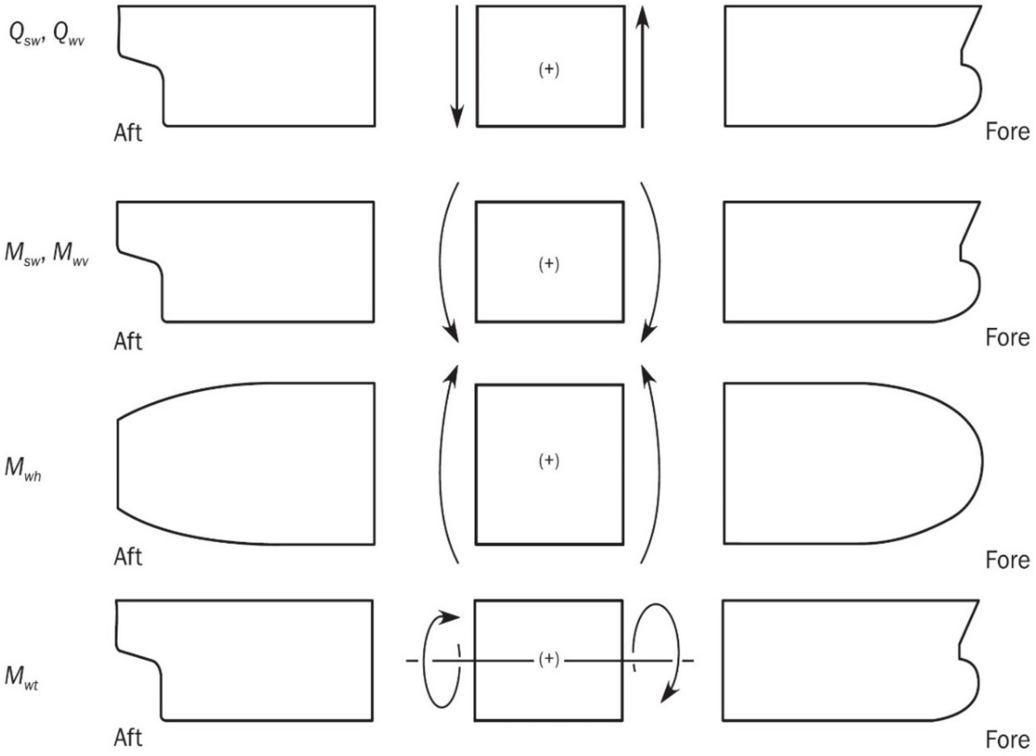


Figure 3.2: Sign convention for hull girder loads

4. SEAKEEPING ANALYSIS

4.1 General

4.1.1 Seakeeping analysis should be performed using an appropriate proven method. The present guidelines are formulated based on the understanding that the seakeeping analysis will be conducted using a three dimensional panel method. All references to a seakeeping model in this guideline are given with respect to a three dimensional panel model.

4.1.2 The validated program should be capable of analyzing ship motions and pressure distribution over ship's hull at given forward-speed. It is to account for rigid body motions in all six-degrees of freedom.

4.1.3 The size of the panels are to be defined such that at least 6 to 10 panel points over minimal wave length should be present. Insufficient number of panels may produce abrupt variations in hydrodynamic response of vessel and therefore, should be appropriately reviewed by the user.

4.2 Objective

4.2.1 The seakeeping analysis is performed to evaluate the following:

- Ship motions
- Hydrodynamic loads (pressure and wave-induced shear forces, bending moments and torsional moment)

4.2.2 The responses of a ship, as defined in 3.2.1 are to be evaluated based on the scope of analysis defined in [2].

4.3 Loading conditions

4.3.1 Prior to seakeeping load computation, appropriate loading conditions are to be taken in accordance with the *Rules and Regulations for the Construction and Classification of Steel Ships* (hereinafter referred to as the Rules). Loading condition typically refers to arrangement of ballast and cargo condition typically found in loading manual. The following information are to be considered for selected loading conditions:

- Contribution of the loading condition in service life of the vessel
- Hold loading, ballast arrangements, draft and trim

4.3.2 Loading conditions for the strength analysis of ships are to be taken as per IRS Rules and IRS-G-DES-05.

4.3.3 In case of fatigue strength analysis, loading conditions are to be taken as per IRS-G-DES-04.

4.4 Coordinate system

4.4.1 The general convention used in seakeeping analysis is to be as shown in the schematic in Figure 4.4.

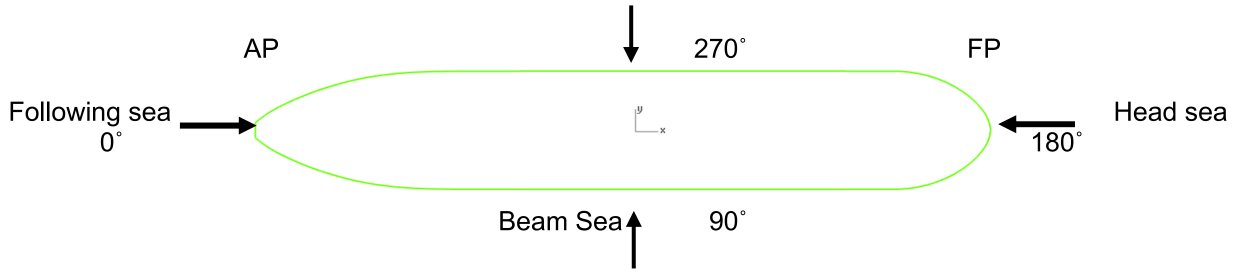


Figure 4.4: Direction of wave headings considered for seakeeping analysis

4.5 Hydrodynamic model

4.5.1 The hydrodynamic model should represent the actual geometry of the vessel. Weight distribution in hydrodynamic model is to reflect the actual weight distribution of the hull, cargo, ballast, bunkering appendages and necessary masses/components of the ship for the considered loading conditions. Any inaccuracy in the mass distribution may result in an unbalanced hydro model and thus leading to incorrect end shear forces and bending moments.

4.5.2 Both the hydrodynamic and structural models are to be identical in term of geometry. The weight distribution in both models is to be the same.

4.6 Balance check

4.6.1 Initial static balance check for hydrodynamic model is to be performed. The convergence of displacement, longitudinal centre of gravity, and still water bending moment (SWBM) are to be checked with respect to values given in loading manual and is to be within the tolerance limits given below.

- Displacement = ± 1%
- LCB = 0.1% of LBP
- SWBM = ± 5%
- Trim = ± 0.5 degrees

4.7 Ship motions and loads

4.7.1 Quasi-static and inertial loads are induced by the rigid body motion. Relevant rotational and translational motions evaluated from seakeeping analysis are to be considered for structural analysis in accordance with [5.4].

4.7.2 Wetted hull surface pressure from seakeeping analysis is to be applied on the structural model in accordance with [5.5].

5. LOAD APPLICATION AND STRUCTURAL ANALYSIS

5.1 General

5.1.1 This section describes the application of direct hydrodynamic loads on the FE model.

5.1.2 It is assumed that the structural model is created by following typical FE modelling procedure as described in IRS Guidelines IRS-G-DES-05. Structural geometry, material properties and stiffness properties are to be simulated appropriately in the model.

5.1.3 Impact loads due to bottom slamming, bow flare and other loads like green see load, tank fluid sloshing loads, vibration and thermal loads are not covered in the scope of present guidelines.

5.2 Finite element modelling

5.2.1 Coordinate system

5.2.1.1 The coordinate systems of structural analysis and seakeeping analysis are recommended to be kept the same in order to avoid discrepancies during load transference. In case of any difference, appropriate transformations/ remedial measures are to be taken by the user.

5.2.2 Global model

5.2.2.1 A model representing the entire hull structure is to be created for the FE analysis. All primary and most secondary structural members are to be modelled in order to simulate the stiffness of the hull girder. All types of weights are to be incorporated in the FE model as discussed in [5.3].

5.2.3 Local model

5.2.3.1 Localised fine mesh structural model is to be prepared to get the hot-spot stress at selected locations for the spectral fatigue analysis. The variation of mesh from coarse to fine should be gradual in order to capture the stress transfer function with higher accuracy. The procedure for stress extraction is to be taken in accordance to type of analysis. IRS guidelines IRS-G-DES-04 and IRS-G--DES-05 are to be referred for the same.

5.3 Weight representation

5.3.1 Lightship weight

5.3.1.2 The lightship weights are to be simulated by providing the density of material or using nodal mass elements. Minor differences in the lightship weight of FE model from actual can be adjusted by providing lumped masses or by changing the density of material, wherever required. However, this procedure is to be performed in such a manner that the CG of the structural model remains intact and same as that given in the loading manual/ stability booklet.

5.3.2 Ballast and bunkering

5.3.2.1 Ballast and bunker weights may be represented as tank pressures. The appropriate tank boundaries are to be selected for pressure application. The appropriate pressures acting on internal surfaces of liquid tanks are to be calculated and to be applied to selected entities in FE model. Figure 5.3.2 shows the distribution of ballast pressure in representative tanks.

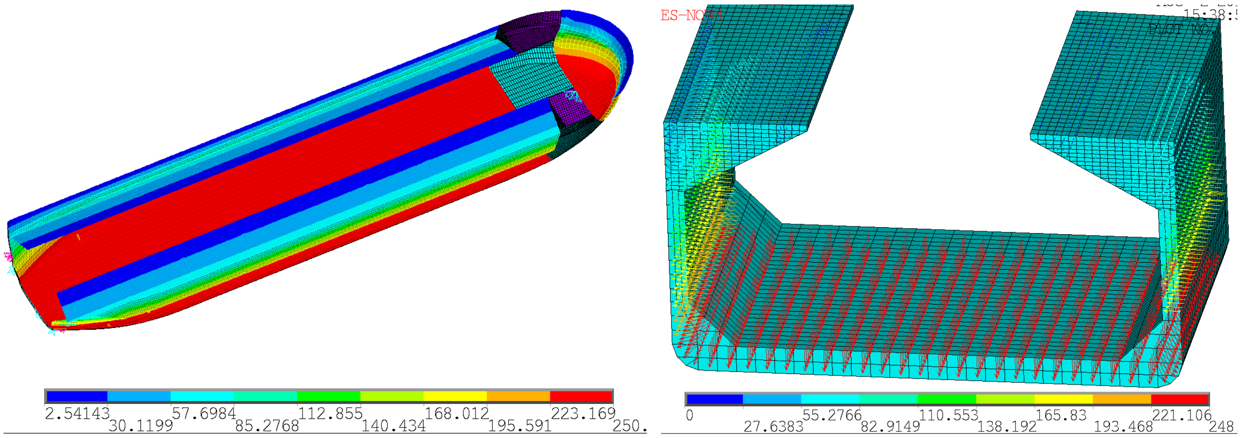


Figure 5.3.2 : Distribution of ballast pressure in normal ballast conditions of a bulk carrier

5.3.3 Cargo pressure

5.3.3.1 General

The cargo weights are modelled considering the loading condition as provided in the loading manual.

5.3.3.2 Liquid

Liquid pressure can be simulated as tank pressure as discussed in 5.3.2.

5.3.3.3 Grain/ore

The bulk cargo mass are to be simulated using point/ lumped mass element at the CG of respective cargo holds. The rigid body elements (RBE) or equivalent suitable element are to be used to connect the mass element to relevant hold surfaces. Connection of rigid body elements is to be made with the bottom of the cargo hold, bulkhead stool plating and hopper sloping tank plating. A representative case using RBE is shown in Figure 5.3.3 (a). The user is to cross-verify the CG of each tank with the loading manual after distribution of cargo loads.

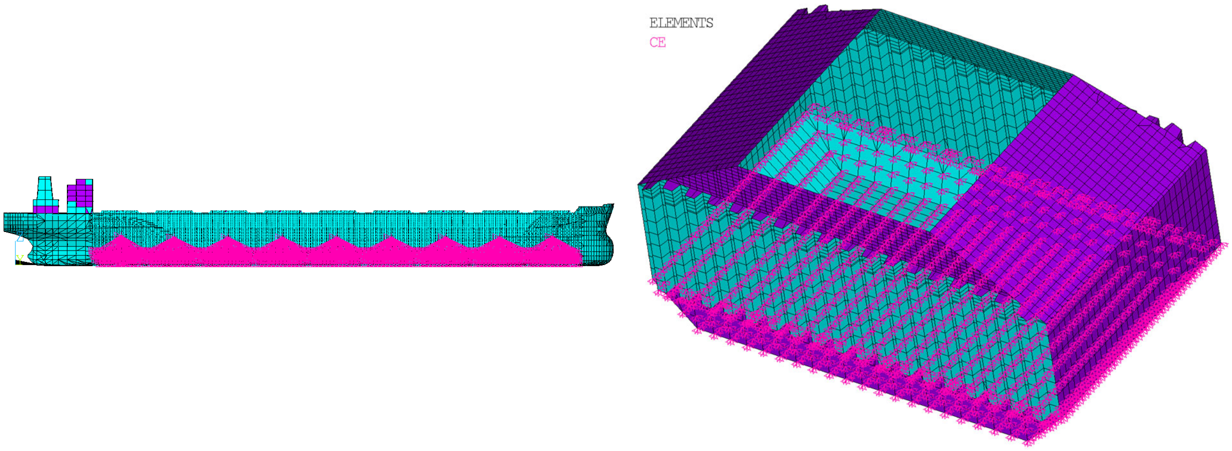


Figure 5.3.3 (a) : Distribution of cargo loads in homogeneous condition

5.3.3.4 Containers

Containers may be distributed as point/ lumped masses with no moment of inertia (at the center of gravities of the containers) connected using rigid body elements. The rigid body element links the mass element to the corresponding nodes on the hold's bottom or on hatch-cover. The user needs to ensure the connectivity of elements and also to cross-verify the CG of the system after weight distribution. Container distribution on deck and in hold using RBE is shown in Figure 5.3.3 (b) for illustration purpose.

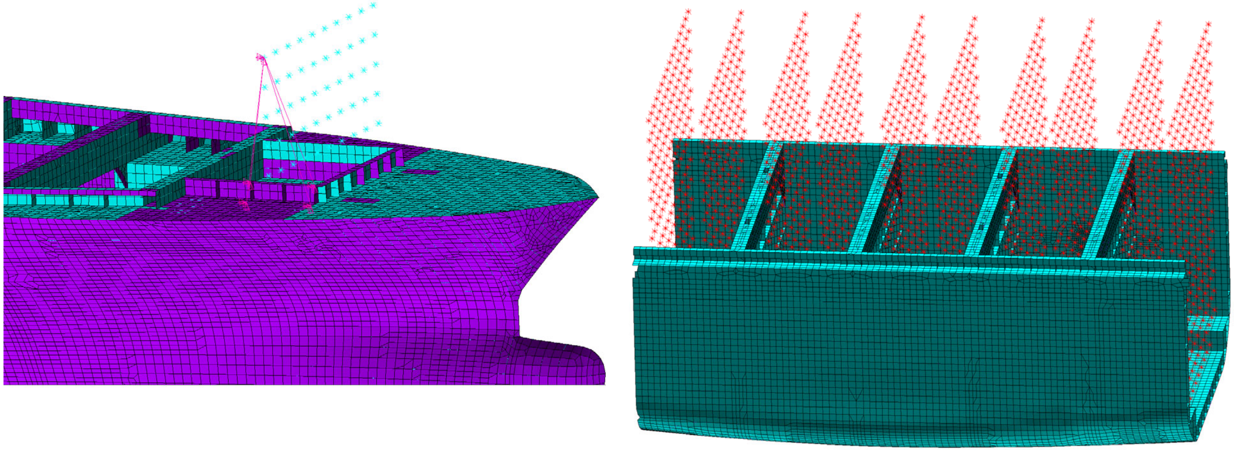


Figure 5.3.3 (b) : Distribution of containers on deck and in hold respectively

5.4 Quasi-static and inertial loads

5.4.1 General

5.4.4.1 Each type of load discussed above (5.3.1 to 5.3.3) consists of static and dynamic load components. The gravity is responsible for static load components whereas the dynamic loads are induced due by the ship motions. The dynamic loads can be further sub-divided into quasi-static and inertial loads. The quasi-static components are part of gravity loads induced due to ship's roll and pitch inclination. The directions of resultant gravity loads in ship's fixed coordinate system are to be evaluated as shown in Figure 5.4.1 with the variation of roll and pitch motion respectively. The inertial loads in FE model are to be simulated by using the Equation (1). All the relevant inputs e.g. ship motions and accelerations from a seakeeping analysis are to be used as shown in Equation (1).

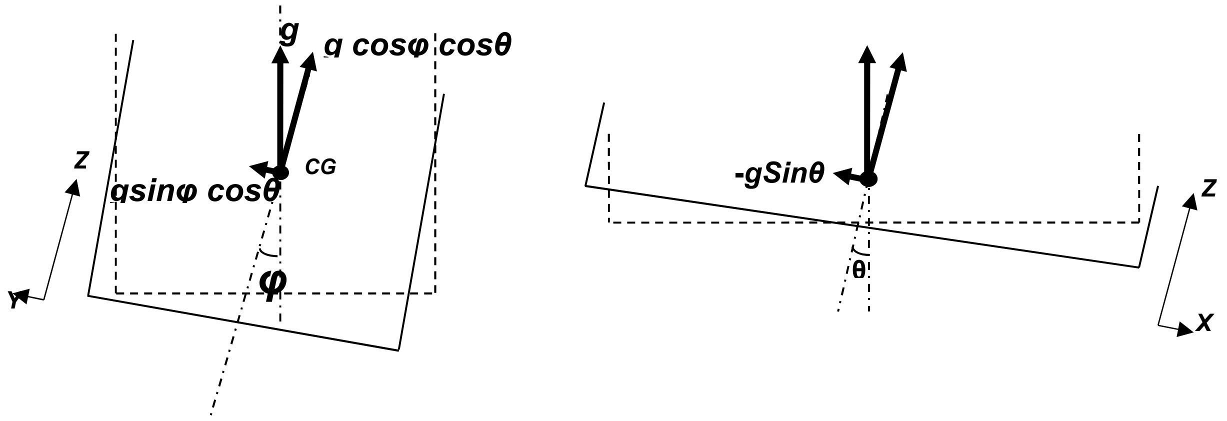


Figure 5.4.1: Inertial load computation

$$\overrightarrow{\mathbf{A_e}} = \vec{\mathbf{A}} + \vec{\mathbf{\Theta}} \times \vec{\mathbf{R}} \qquad (1)$$

where:

$\vec{A}$: Acceleration vector at ship's CG can be estimated as follows in respective directions using Equations (2), (3), (4) as follows

$$\mathbf{A_x} = -\mathbf{g}\sin\boldsymbol{\theta} + \mathbf{a_x} \qquad (2)$$

$$\mathbf{A_y} = \mathbf{g}\sin\boldsymbol{\phi}\cos\boldsymbol{\theta} + \mathbf{a_y} \qquad (3)$$

$$\mathbf{A_z} = \mathbf{g}\cos\boldsymbol{\phi}\cos\boldsymbol{\theta} + \mathbf{a_z} \qquad (4)$$

$\vec{\Theta}$: Roll, pitch and yaw acceleration vector

$\vec{R}$: Distance vector from ship's CG to the calculation point

a_x, a_y, a_z : Accelerations (surge, sway, heave) due to ship motions

θ and ϕ : Pitch and roll angle respectively given by sea keeping program

$-g\sin\theta$, $g\sin\phi\cos\theta$, $g\cos\phi\cos\theta$ are the quasi-static components in x, y and z direction respectively with reference to ship's fixed coordination system due to combined motions of roll and pitch.

5.4.2 Liquid Tank Pressure

5.4.2.1 Static and dynamic pressures on the completely and partially filled tanks are to be taken into account. Appropriate boundaries of tanks are to be considered as discussed in 5.3.2.

5.4.2.2 The static and dynamic liquid tank pressure can be estimated using Equation (5). However, in case of fatigue analysis, the dynamic loads are considered therefore), the static pressure components need to be excluded appropriately from Equation (5):

$$\mathbf{P} = \mathbf{P_0} + \boldsymbol{\rho}_\mathbf{l}\mathbf{h_i}\mathbf{g_{eff}} \qquad (5)$$

where,

$$\mathbf{g_{eff}} = \sqrt{\left(\mathbf{A_{el}}^{2} + \mathbf{A_{et}}^{2} + \mathbf{A_{ev}}^{2}\right)} \qquad (6)$$

P_0 : Vapour pressure or the pressure setting on the pressure/vacuum relief valve

ρ_l : Density of liquid

h_i : Internal pressure head at CG of element measured from the top of tank to the load point

A_{el}, A_{et}, A_{ev} : Accelerations in longitudinal, transverse and vertical direction respectively are to be calculated using Equation (1).

5.4.3 Solid Cargo (Grain/Ore/Containers)

5.4.3.1 General

Bulk cargo is to be provided in the form of mass elements or bulk cargo pressure. The procedure can be followed as discussed below.

5.4.3.2 Mass elements

The procedure for use of mass elements is given in 5.3.3. It should be noted that while simulating the cargo as constrained mass element, ship motions (in term of accelerations) are to be provided appropriately at the CG of the ship to simulate the dynamic loads (quasi-static and inertial).

5.4.3.3 Bulk cargo pressure:

Based on the type of cargo loaded, relevant internal surface of cargo holds are to be selected for the cargo pressure application. Assuming that there is no relative motion between cargo hold and filled cargo, appropriate bulk cargo pressure is to be applied to the surface of cargo tanks using Equation (7) and (8).

The Equation (7) and (8) are to be utilized for calculation of static and dynamic loads:

$$\begin{aligned} &\mathbf{p_{bn}} = \boldsymbol{\rho}_{\mathbf{c}}\mathbf{h_T}\mathbf{A_e}\left(\cos^2\alpha + (1 - \sin\alpha_0)\sin^2\alpha\right) && 0^{\circ} \le \alpha \le 90^{\circ} \\ &\mathbf{p_{bn}} = \mathbf{0} && \text{else} \end{aligned} \qquad (7)$$

$$\begin{aligned} &\mathbf{p_{bt}} = \boldsymbol{\rho}_{\mathbf{c}}\mathbf{h_T}\mathbf{A_e}\left(\sin\alpha_0 \sin\alpha \cos\alpha\right) && 0^{\circ} \le \alpha \le 90^{\circ} \\ &\mathbf{p_{bt}} = \mathbf{0} && \text{else} \end{aligned} \qquad (8)$$

where:

α_0 : Angle of repose for considered bulk cargo

ρ_c : Density of cargo

p_{bn} : Normal component of pressure to the cargo tank surface

p_{bt} : Tangential component of pressure to the cargo tank surface

h_T : Distance from the top of cargo surface to the load point α : Angle between the surface unit normal vector $\vec{n}$ and the acceleration vector $\overrightarrow{A_e}$ can be evaluate as follows (see Figure 5.4.3)

$$= \cos^{-1}\left(\frac{\overrightarrow{A_e}.\vec{n}}{|\overrightarrow{A_e}||\vec{n}|}\right)$$

$\vec{n}$: Unit normal vector of surface in ship’s co-ordinate system, towards inside of cargo tank

$$= n_x\vec{i} + n_y j + n_z\vec{k}$$

A_e : Accelerations (A_{el}, A_{et}, A_{ev}) at CG of ship to be evaluated using the Equation (1) and can be shown in vector form

$$= A_{ex}\vec{i} + A_{ey} j + A_{ez}\vec{k}$$

Both static and dynamic bulk cargo pressures can be decomposed into normal and tangential components relative to the surface of cargo hold. The positive normal component is defined in the opposite direction of $\vec{n}$, and the positive tangential component is defined in the direction of $\vec{n} \times (\vec{n} \times \vec{a})$.

The above Equation (7) and (8) provides the dynamic components, if motions are considered in case of fatigue analysis. The total pressure components P_{bn} and P_{bt} in the Equation (7) and (8) become the static pressure components as A_{ex}, A_{ey}, becomes zero and A_{ez} have only gravity.

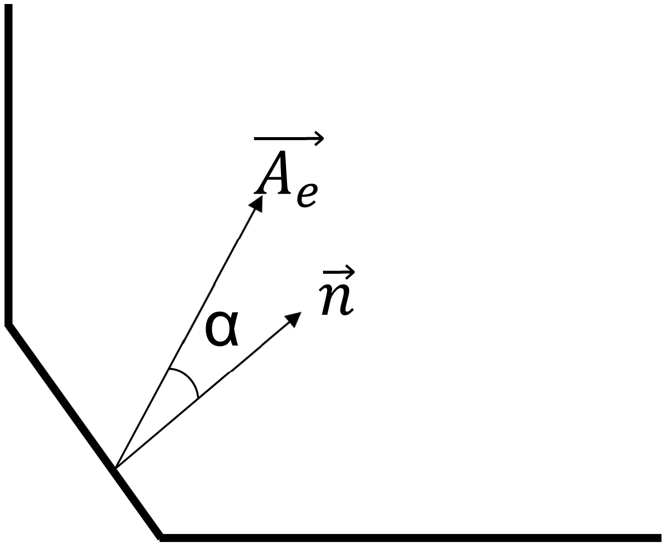


Figure 5.4.3 : Illustration of normal vector and acceleration vector at selected surface of tank

5.4.3.4 Containers

Containers masses are to be simulated as discussed in 5.3.3.4 or in terms of forces. In case of mass elements, all relevant accelerations are to be simulated as discussed in 5.4. If masses are simulated as nodal forces then appropriate dynamic forces are to be estimated using the acceleration calculated from Equation (1).

5.4.3.5 Lightship weight and equipment

Appropriate static and dynamic loads (as discussed in 5.4) are to be evaluated for the lightship structure and equipment.

5.5 Pressure Mapping

5.5.1 The fluid pressure has to be mapped onto the FE model of the ship. An appropriate component is to be created in the FE model for application of fluid pressure as shown in Figure 5.5 (a). The fluid pressures are to be applied on the selected component of FE model. .

5.5.2 The mapping of panel pressure is usually performed using the three dimensional linear interpolation scheme. Due to difference in the size of mesh (see Figure 5.5 (a) and Figure 5.5 (b)), mapping of pressure induces inherent error which may result in unbalanced forces in the FE model. Inertia relief method can be employed to balance the FE model. Inertia relief is a technique in which applied forces and moments are balanced by counter forces induced by accelerating the body. The application of acceleration is performed in such a manner that it precisely cancels or balances the additional forces. However, one should be cautious, since the application of inertia relief may alter the response profile of the structure. Application of inertia relief method in ship structures should be done only when the unbalanced forces are within engineering limits (±1% of total weight of ship in case of fatigue and ±5% in case of strength analysis). Unbalanced forces can be estimated as fraction of total weight of ship. Inertia relief method can be utilized only while performing static analysis.

5.5.3 Figure 5.5 (c)-(d) shows the sample case of pressure distribution evaluated using frequency domain method and applied on the FE model for spectral fatigue analysis. In case of spectral fatigue analysis the real and imaginary components of pressure are to be applied separately. In a physical sense, the real and imaginary parts correspond to two wave systems that are 90 degrees out of phase. Figure 5.5 (e) shows the pressure distribution at a time instance (time domain method) considered for full ship strength analysis.

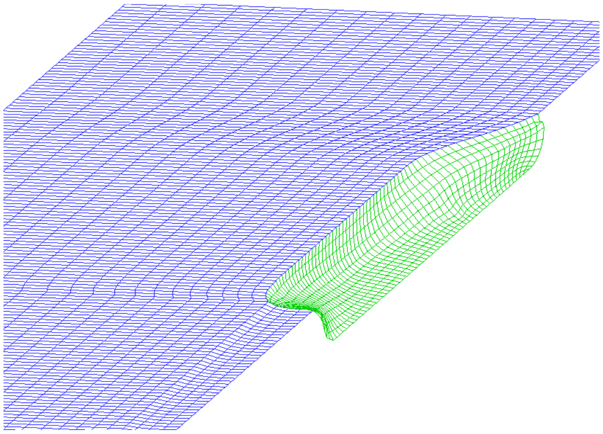


Figure 5.5 (a) : Panel distribution on ship (half breadth) geometry and wave domain

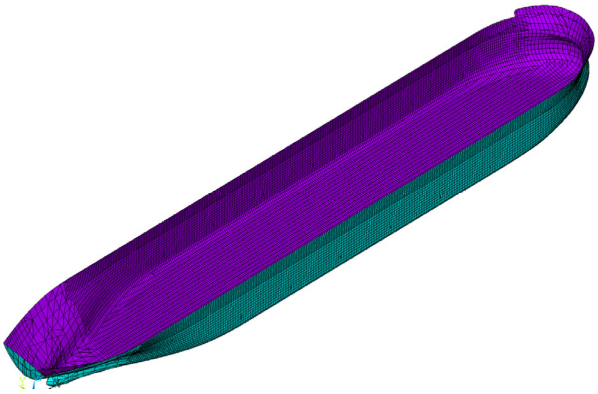


Figure 5.5 (b): Outer hull component

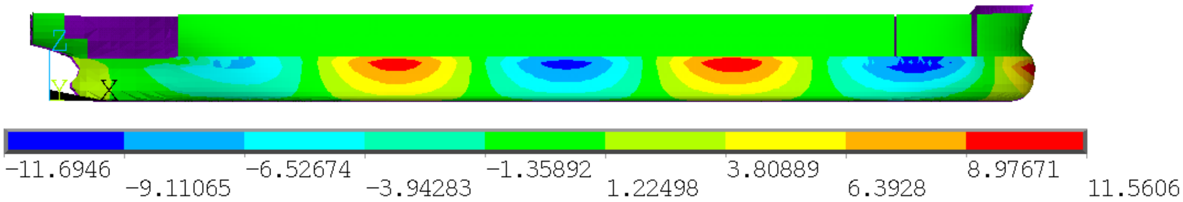


Figure 5.5 (c) : Distribution of real component of complex pressure in frequency domain (Heavy ballast condition, freq. = 0.80)

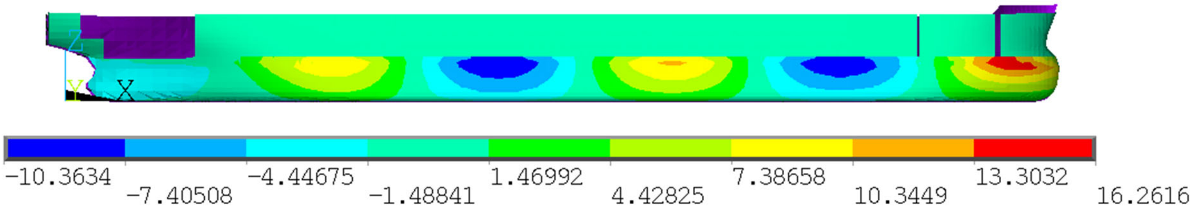


Figure 5.5 (d) : Distribution of imaginary component of complex pressure in frequency domain (Heavy ballast condition, freq. = 0.80)

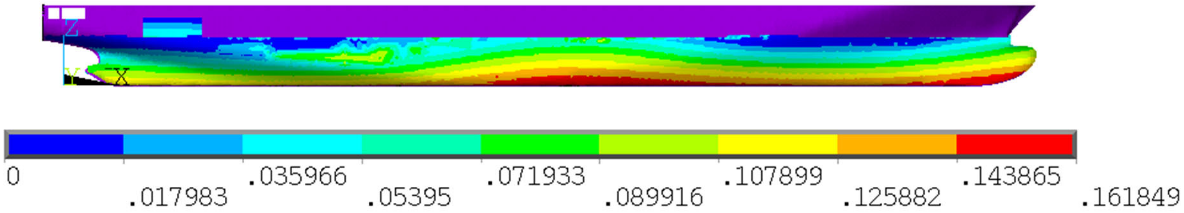


Figure 5.5 (e) : Distribution of pressure in time domain at given time instant (Full load condition, T=10s)

5.6 Boundary Conditions

5.6.1 To simulate the buoyant condition of ship in static structural analysis of ship, some artificial support is required to be added to the FE model. The effect of these support reaction should be minimal in order to capture the actual response of structure. The following boundary conditions can be provided as indicated in Table 5.6 and Figure 5.6.

Table 5.6 : Boundary conditions for global model

	Location	**Direction**
Engine Room Front Bulkhead	SB & PS	Z
	CL	Y
Collision Bulkhead	CL	X, Y, Z

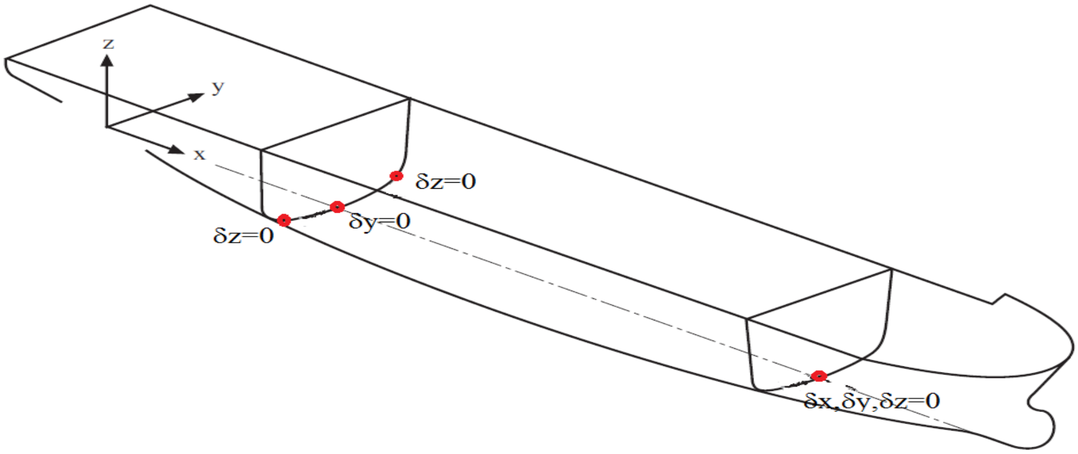


Figure 5.6 : Boundary conditions

5.7 Structural Modelling

5.7.1 A three dimensional (3D) global FE model representing the entire hull needs to be created to simulate the structural response using direct hydrodynamic loads. The FE model's geometry, configuration and stiffness are to be closely approximated as that of the actual structure. IRS guideline IRS-G-DES-05 is to be referred regarding the structural modelling aspects.

5.7.2 A local structure may be assessed using a refined mesh distribution in the said particular area. Local structure is to be provided with all relevant geometric details and suitable mesh density. A separate analysis of local structure can be performed using sub-modelling technique. Care should be taken to apply the extracted displacements as the boundary conditions and appropriate loads on local sub-model. More details on structural modelling using fine mesh and very fine mesh may be referred in the IRS-G-DES-05 and IRS-G-DES-07 guidelines respectively.

5.8 Structural analysis

5.8.1 General

5.8.1.1 Static structural analyses are to be performed for the given number of load cases corresponding to each loading condition.

5.8.2 FE Simulations

5.8.2.1 The number of FE simulation may vary depending on the type of analysis (or fatigue); e.g. in case of structural strength verification, the EDW based simulation may contain a few load cases to induce the maximum loads. But in case of spectral fatigue analysis the number of FE simulations may rise to more than 500 cases for a given loading condition and speed. In such scenario, the time and computational resources increases drastically.

5.8.3 Equilibrium check

5.8.3.1 Equilibrium check for each load case is mandatory. The applied hydrodynamic panel pressure is to be in equilibrium with applied loads on the full length structural model of ship. To estimate the unbalanced forces, all the forces and moments are to be summed up in the global direction. In case of presence of unbalanced forces, a suitable method to balance the FE model is to be employed before performing the structural analysis.

5.9 Verification of Model

5.9.1 Before proceeding with the structural response evaluation, the following values from FE model are to be verified with values given in the loading manual or stability booklet for each loading condition:

- All the representative weights as discussed in 5.3 and CG (LCG, VCG and TCG) of each tank/hold
- Total weight and LCG,VCG and TCG considering total weight distribution
- Shear force distribution along the length of ship
- Moment distribution along the length of ship

5.10 Structural Assessment

5.10.1 General

The permissible criteria for structural response are to be taken in accordance with the IRS rules and guidelines (IRS-G-DES-05 and IRS-G-DES-07). Structural response evaluation can be done using induced quantities from FE model discussed in 5.10.2 to 5.10.4.

5.10.2 Deflection

Appropriate deflection acceptance criteria are to be checked in accordance with the IRS rules and guidelines (IRS-G-DES-05 and IRS-G-DES-07).

5.10.3 Stress

The appropriate stresses should be extracted from the FE model and are to be checked with the acceptance criteria. The following stress can be used for same:

- Von-Mises stresses can be utilized to check the permissible stress criteria (IRS-G-DES-05)
- Axial stresses can be used to check the permissible stress criteria or to get the hot-spot stress for fatigue analysis. The procedure for the same are detailed in Guidelines IRS-G-DES-07.

5.10.4 Shear force/ bending moment

5.10.4.1 Shear forces can be utilized to get the distribution of forces over the entire ship and the critical structural location/details can be selected as per the applicable criteria check.

5.10.4.2 Bending moments can be utilized to get the distribution of vertical and horizontal bending moment and thereby to identify the critical regions and check the applicable criteria.

APPENDIX – A

A.1 General

This section elaborate the processes used for strength analysis of full ship as given in Section 2, IRS-G-DES-05 (see Figure 2.2.1).

A.2 Loading conditions

The arrangement of the cargo and ballast conditions are normally referred as the loading condition. Most representative loading conditions typically found in the loading manual are to be considered for the full ship analysis. Other cargo loading conditions that may be deemed critical can also be considered in the full ship analysis. The need to consider other loading conditions or additional loading conditions is to be determined in consultation with IRS.

A.3 Speed of Vessel

Speed of the vessel is to be considered appropriately. The consideration of the speed reduction in heavy weather conditions can be taken into account.

A.4 Load cases

The development of load cases are to be performed considering the loading conditions, speed of vessel and the maximum load situations. For each Load Case, the applied loads to be developed for structural FE analysis are to include both the static and dynamic parts of each load component. The dynamic loads represent the combined effects of a maximum load situation and other accompanying loads acting simultaneously on the hull structure, if any. It contains the loads e.g. external wave pressures, internal tank pressures, bulk cargo loads, container loads and inertial loads on the structural components and equipment. The load application is to be considered in accordance to [A.11].

A.5 Maximum Load Situations

As per Section 2, IRS-G-DES-05.

A.6 Seakeeping Analysis based on frequency domain method

Linear seakeeping analysis is to be performed to calculate the ship motions and wave loads for a number of wave headings and frequencies. The response of vessel in term of RAOs are used to calculate the long-term extreme values for considered maximum load situations. Also, these RAOs will be used to determine the equivalent design wave system.

A.7 Environmental Data

The environmental data is to be considered as specified for vessel. In case of unrestricted services, the North Atlantic Ocean is to be assumed (IACS Recommendation 34, as may be amended).

A.8 Long Term Response Calculation

The long-term response of each maximum load situation described in A.4 is to be calculated for various loading conditions based on the Response Amplitude Operators (refer A.5) and the wave scatter diagram (refer A.6). The long-term response refers to the long-term most probable extreme value of the response at a specific probability level of exceedance. The exceedance probability level of 10^{-8} are considered for the design of life of 25 year.

A.9 Equivalent Design Wave

An equivalent design wave is a regular wave that simulates the long-term extreme value for the considered maximum load situation. The equivalent design wave can be characterized by wave amplitude, wave length, wave heading, and wave crest position referenced to the amidships. For each of the maximum load situation (refer A.4), an equivalent design wave is to be determined. Simultaneous load components acting on the hull structure are to be considered for that design wave at the specific time instant when the load reaches its maximum for a given situation as defined in A.4.

A.10 Non-linear Seakeeping Analysis

The ship motion and wave loads are to be calculated for the calculated equivalent design wave. Linear seakeeping analysis considers only the hull geometry below the mean waterline as a linear approximation. Non-linear seakeeping analysis is recommended to perform to effectively account for instantaneous nonlinear effects during the time simulation. The following type of loads can be captured using the Non-linear seakeeping analysis

i) Nonlinear hydrostatic restoring force, and

ii) Nonlinear Froude-Krylov force

These loads are acting on the instantaneous wetted hull surface below the exact wave surface at every time step during the time simulation.

A.11 Load Application

The structural loadings are to include both static and dynamic load components. The applicable motions and loads are to be applied as per IRS-G-DES-06

A.12 Finite Element Modelling and Structural Analysis

The finite element modelling, structural analysis and acceptance criteria check are to be performed as per IRS-G-DES-05.

References:

IRS (2016) *Review Report – Strength assessment of ships and offshore structures by direct application of wave induced loads*. Project No. RIC-16004-RR. Mumbai

IRS (2016) *ISSC 2018 – Fatigue and Fracture Committee Benchmark Study.* Project No. RIC-16028-SR. Mumbai

Parihar Y., Dan S., Doshi K., Thirunaavukarasu S.G. (2017) *Application of direct hydrodynamic loads in spectral fatigue analysis*. Proceedings of the ASME 2017 36th International Conference on Ocean, Offshore and Arctic Engineering OMAE 2017, Trondheim

*****End of Guidelines*****